FEHMARNBELT MARINE BIOLOGY

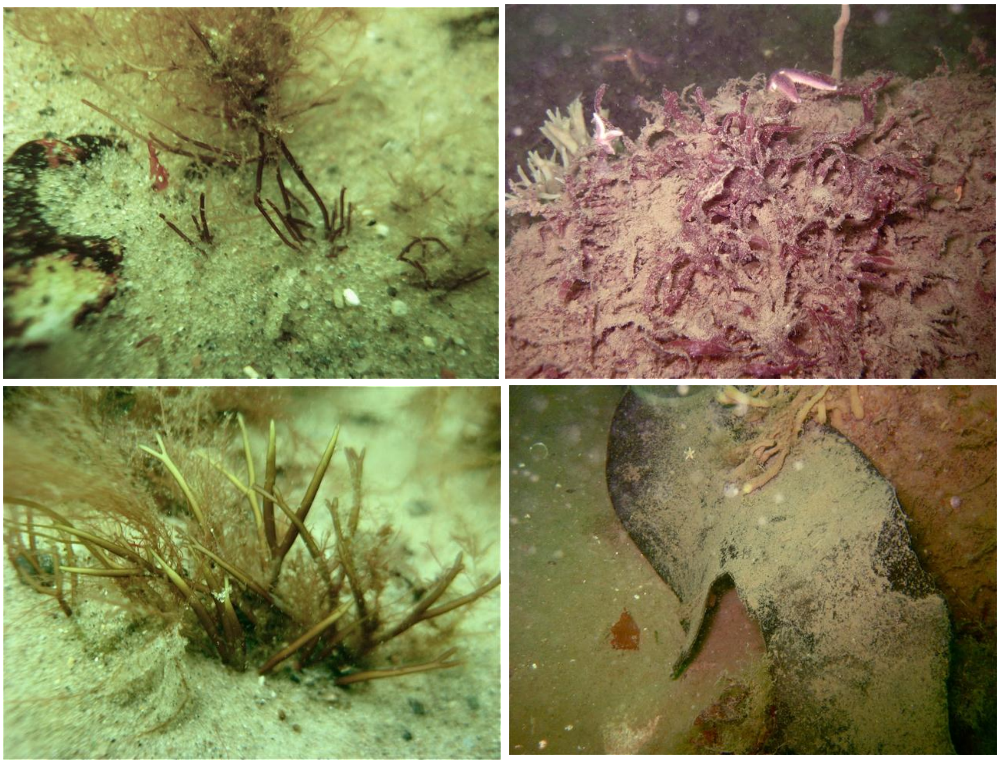
Final Report

FEHMARNBELT FIXED LINK MARINE BIOLOGY SERVICES (FEMA)

Marine Fauna and Flora - Impact Assessment

Benthic Flora of the Fehmarnbelt Area

E2TR0021 Volume I



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ACRONYMS AND ABBREVIATIONS

EQS	Environmental Quality Standards are levels used to assess the risk of chemical pollutant effects on water quality to the health of aquatic plants and animals.
IUCN	International Union for Conservation of Nature
POP	Persistent organic pollutants
PAH	Polycyclic aromatic hydrocarbons

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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).

0 EXECUTIVE SUMMARY

Present report

Denmark and Germany have agreed to establish a Fixed Link between Denmark and Germany across the Fehmarnbelt. In order to get approval of the Project an Environmental Impact Assessment (in Denmark VVM and in Germany UVS) has been conducted. This report is one of a number of background reports forming the base of the Environmental Impact Assessment (EIA) for the Fehmarnbelt Fixed Link; contributing to the marine fauna and flora assessment. The focus of the report is assessment of impact on marine benthic flora communities in the Fehmarnbelt area of pressures resulting from the construction, operation and the structures of the Fixed Link. Separate reports are prepared for impact assessments of Natura 2000 sites and this aspect is therefore not included in this report.

The specific objectives of this report are, for each of the two main alternatives, an immersed tunnel and a cable-stayed bridge to:

- Predict the magnitude of pressures and severity of impacts on benthic flora from
    - temporal activities of dredging and reclamation during construction of the Fehmarnbelt Fixed Link
    - permanent placement of new structures in the marine environment
    - permanent activities during operation of the fixed link
- Assess the significance of the predicted impacts for the survival and functioning of the ecosystems in the near zone and on local, national and transboundary scale
- Assess the impact of decommissioning of the tunnel and bridge alternative
- Assess the effect of expected climate changes for the predicted impacts
- Assess if there is any cumulative impacts

And to

- Compare the impacts on benthic flora of the bridge and the tunnel alternatives
- If predicted impacts are significant to suggest mitigations

The basis of the assessment

The benthic flora communities of the Fehmarnbelt are important components of the marine costal ecosystem and they have been thoroughly investigated during the baseline study (FEMA (2013a). Eight flora communities were identified in this study; five hard bottom communities, two soft bottom communities constituting of flowering plants and one mixed algae-flowering plant community. The communities are the basic entities on which the impact assessment is based.

The importance of benthic vegetation is defined by its functional value for the ecosystem (Figure 0-1). Benthic vegetation is a valuable part of the ecosystem due to its function as a three-dimensional habitat as well as nursery, breeding or feeding ground for invertebrates and fish. The habitat function of vegetation communities is dependent on the complexity and longevity of their key species as well as the size and coverage of the habitat itself. The functionally based classification criteria have been adjusted for German waters to fulfil regulatory conditions.

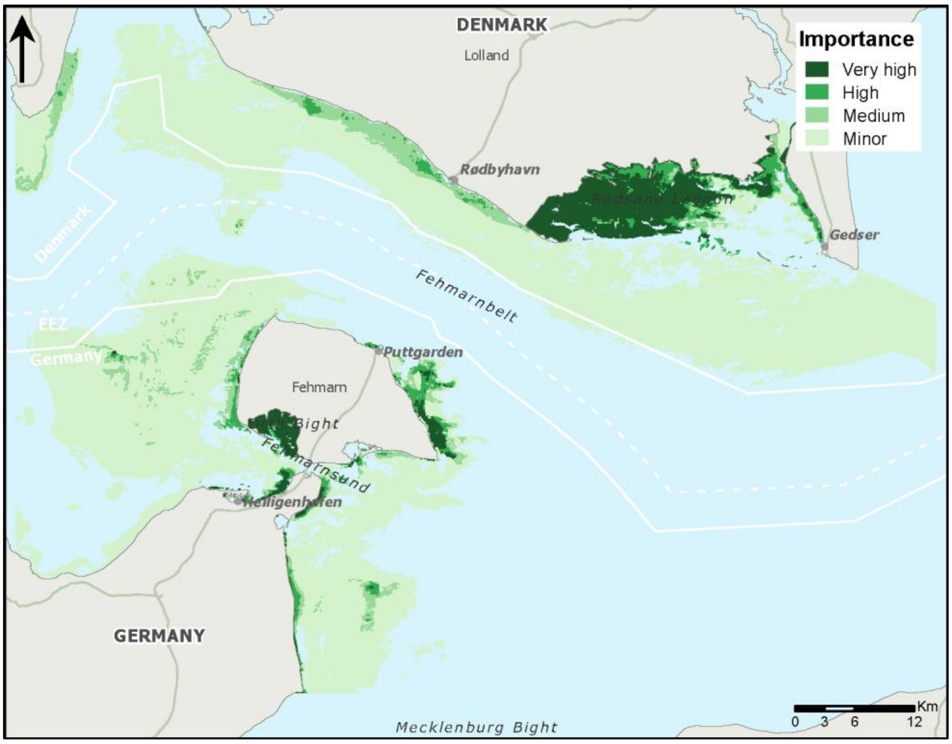


Figure 0-1 Map of importance for benthic vegetation.

Project pressures

Ten pressures have been determined to have a potential impact on benthic flora in the construction phase, due to project structures or in the operation phase (Table 0-1).

Table 0-1 Pressures potentially causing an impact on benthic flora in the construction, structure and operation phases of the project.

Phase	Pressure	Brief description
Construction	Suspended sediment	Spilled sediment increases the light attenuation in the water column and reduces light availability for photosynthesis and growth.
	Sedimentation	Spilled sediment causes deposition of sediment and affects the flora by physically disturbance or reduces primary production.
	Toxic substances	Dredging activities may release toxic substances to the water column and affect growth or reproduction.
	Nutrients	Dredging activities may release nutrients to the water column. High nutrient concentrations may change the presence and dominance of functionally different species.
	Construction vessels and imported material	Increased ship traffic and imported material may increase the risk of introducing non-indigenous species.
Structure	Footprint	Habitats may be lost were structures like reclamation areas and bridge piers cover the seabed.
	Solid substrate	New solid substrate within the photic zone may potentially be colonised by macroalgae and thereby have a positive effect on the flora.
	Seabed and coastal morphology	Changes in the current regime may course changes in natural erosion or sedimentation process and thus loss of benthic flora
	Hydrographical regime and Water quality	Changes in current patterns may alter salinity, temperature, nutrients and light attenuation, potentially affecting distribution and abundance.
Operation	Drainage	Freshwater outlets discharging run offs from project structures may potentially affect composition and abundance.

Assessment methods

The assessment area corresponds to the investigation area of the baseline study (FEMA 2013a). To characterize the spatial range of impacts, specific geographical zones were defined. The different zones are illustrated in Figure 0-2. A distinction is made between national zones (DK, DE), coastal and EEZ zones as well as zones illustrating the impact's extent from the alignment and the project (near and local zone). In this report near zone plus local zone are called the Fehmarnbelt area.

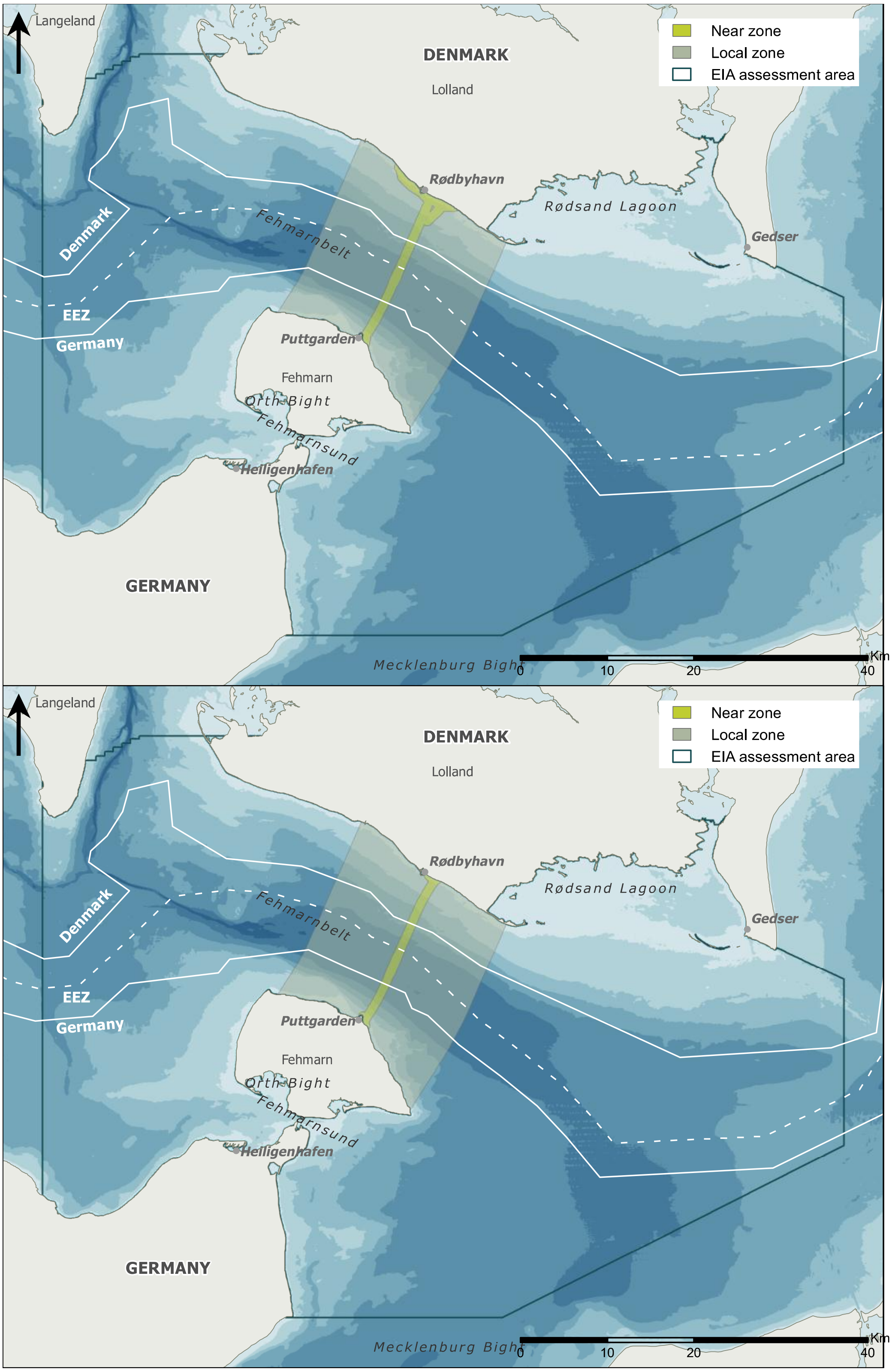


Figure 0-2 Assessment area and defined zones for the tunnel (above) and the bridge alternative (below).

Generally, the impact assessment has been carried out using the following steps for each of the main alternatives (immersed tunnel and cable-stayed bridge) and each pressure of the alternatives:

1. Determination of the *magnitude of pressure*
2. Determination of the *sensitivity* of the flora communities towards the pressure
3. Assessment of the *degree of impairment*
4. Assessment of the *severity of* impairment
5. Assessment of the *severity* of loss
6. Assessment of the *significance of impacts*

Impairment is a change in the function of benthic flora and loss is caused by permanent and provisional loss of area due to the footprint of the Project.

Magnitude of pressure
The magnitudes of the pressures are characterised by their type, intensity, duration and range. The pressures during construction and from provisional structures have varying duration while pressures from staying physical structure (e.g. bridge piers) and from the operation phase are permanent. The effect of a pressure may both be negative and positive.

The magnitude of pressure is analysed for each of the ten pressures. For some of the pressures the magnitude is so limited in intensity, duration and range that the magnitude of pressure is below minor and impacts on the flora can be excluded. This is the case for the following pressures:

- Toxic substances – no changes are predicted for the water column concentrations and the deposited sediment is not containing critical levels.
- Nutrients – the estimated release of nutrients is negligible compared to natural availability of N and P.
- Construction vessels and imported material – no enhanced risk of introduction of non-indigenous species.
- Seabed and coastal morphology – changes in seabed morphology are within natural variability for the tunnel alternative and changes in coastal morphology are within natural variability for the bridge alternative.
- Hydrographic regime and water quality – changes are small and resulting in negligible impacts.
- Drainage – changes are small and resulting in negligible impacts.

Five pressures have magnitudes of pressure that need further analysis and these are assessed in detail. These pressures are: suspended sediments, sedimentation, footprint, additional solid substrate and seabed (bridge) and coastal (tunnel) morphology (Table 0-2).

Table 0-2 Overview of pressure indicators and analytical methods applied for the five pressures that are assessed in details.

Pressure	Pressure indicator	Method
Suspended sediment	Light reduction at the bottom (% reduction)	Light reduction was modelled based on sediment spill data from FEHY (2011a).
Sedimentation	Sedimentation (cm) for a	Post processing of sedimentation

Pressure	Pressure indicator	Method
	duration of 10 days or more	data from the dynamic sediment spill modelling (FEHY 2013c)
Footprint	Structure- and construction-related footprint area (ha)	GIS shapes produced from technical drawings
Solid substrate	Areas (m^2) of new solid substrate in depth intervals	Areas calculated from technical drawings
Seabed (for bridge only) and coastal (for tunnel only) morphology	Changes in erosion and sedimentation areas	GIS shapes produced from seabed and coastal morphology assessment data (FEHY 2013b, d)

The footprint of the project and the changes in seabed and coastal morphology cause loss of areas with flora while the pressures suspended sediment, sedimentation and solid substrate may result in impairment of the flora, i.e. result in weakening of the functions of the flora.

Sensitivity
The sensitivity describes the environmental factors intolerance and ability to recover. Intolerance is the susceptibility of a community or species to a pressure. Recovery is the time it takes for a species or community to return to the state close to the one before the activities started.

Degree of impairment
The degree of impairment is assessed by combining magnitude of pressure and sensitivity. The tools used to combine the magnitude of pressure with sensitivity of the flora are either a dynamical model or a matrix concept/GIS analysis (Table 0-3). The degree of impairment is described by the intensity, the duration and if feasible, the range. The general assessment criteria for the pressures are listed in Table 0-4. The criteria rank the impairments on a four grade scale: minor, medium, high and very high.

Table 0-3 Overview table of methods used to assess the degree of impairment.

Pressure	Assessment methods
Suspended sediment	Modelling of reduction of benthic flora biomass; based on FEHY modelled sediment spill, resulting light reduction and the light response of benthic flora growth
Sedimentation	GIS analysis using matrix combining magnitude of sedimentation and sensitivity of benthic flora to sedimentation
Solid substrate	Calculation of biomass of potential new hard bottom communities; based on area of new substrate estimated from technical drawings

Table 0-4 General impairment criteria for benthic flora.

Pressure	Description of assessment criteria for impact prediction	Impact intensity
Suspended sediment	High to very high reduction in biomass	Very high

Pressure	Description of assessment criteria for impact prediction	Impact intensity
(construction-related)		
	Medium to high reduction in biomass	High
	Minor to medium reduction in biomass	Medium
	Negligible to minor reduction in biomass	Minor
Sedimentation (construction-related)	High to very high reduction in growth Increased mortality in relation to mean plant height and high to very high sedimentation thickness Reduction in recruitment area compared to other criteria negligible	Very high
	Medium to high reduction in growth Increased mortality in relation to mean plant height and medium to high sedimentation thickness Reduction in recruitment area compared to other criteria negligible	High
	Minor to medium reduction in growth Increased mortality in relation to mean plant height and minor to medium sedimentation thickness Reduction in recruitment area compared to other criteria negligible	Medium
	Reduction of recruitment area for macroalgae caused by coverage of hard substrates	Minor
Footprint (structure-related)	Habitat loss. Criteria correspond to the importance levels of the different communities	Very high
Solid substrate (structure-related)	Case-by-case, qualitative criteria on the relation between new artificial substrate and the available hard substrate area	Case-by-case related
Seabed and coastal morphology (structure-related)	Habitat loss. Criteria correspond to the importance levels of the different communities	Very high

Severity and significance
Severity of impairment expresses the consequences of the impairment taking the importance of the flora communities into consideration; i.e. by combining the degree impairment with importance. Severity of loss expresses the consequences of the loss of habitats. It is analysed by combining the footprint with importance of the flora community.

The significance is the concluding evaluation of the impacts on the benthic flora community. It is an expert judgment based on the results of all analyses.

0 - alternative

If there will be no tunnel or bridge construction the ferry operation will continue. No adverse effects on benthic flora are expected from continuing the ferry operation.

Impact of main tunnel alternative

The tunnel alternative impairs all of the vegetation communities. Footprints cause permanent loss of vegetation. Beside footprints, especially the pressures suspended sediment and sedimentation affect the flora, and the impacts exceed the local zone for those two pressures. In the reclamation area the *Furcellaria* community is permanently lost. This loss is considered significant. The communities that are most affected by suspended sediment and sedimentation are the *Furcellaria* community followed by the eelgrass community. The impact is temporary and not considered to be significant.

Suspended sediment
The response of benthic flora to increased concentrations of suspended sediment is expected to be highest in the two first years of the tunnel construction phase. During the following years (2017-2019), the benthic flora is expected to recover to a state close to the for the reference situation with no sediment spill. Figure 0-3 shows the reduction in biomass at the end of the growth season 2015 and the corresponding degree of impairment.

Macroalgal biomass at the end of the growth season 2015 is expected to be reduced with 0 to 60% compared to the baseline conditions (Figure 0-3). Most of the impact is in the *Furcellaria* community along the Lolland coast. The highest reductions (50-60%) occur in small areas close to the alignment and impact decreases with distance to the alignment. In Rødsand Lagoon, eelgrass biomass is predicated to be reduced by between 0 and >50% by the end of the growth season 2015. Along the German coast, the predicted reductions in biomass are 0-10% and occur in limited areas.

The impacts correspond to minor to high severity of impairment. The most severe impacts are expected in the Danish near zone of the construction area. Totally, the high severity area constitutes <1% of the total impacted area.

The impacts on benthic flora biomass of the pressure suspended sediment are temporary and in combination with a relatively fast recovery, impacts will not cause significant long-term effects on the function of the local or regional ecosystem.

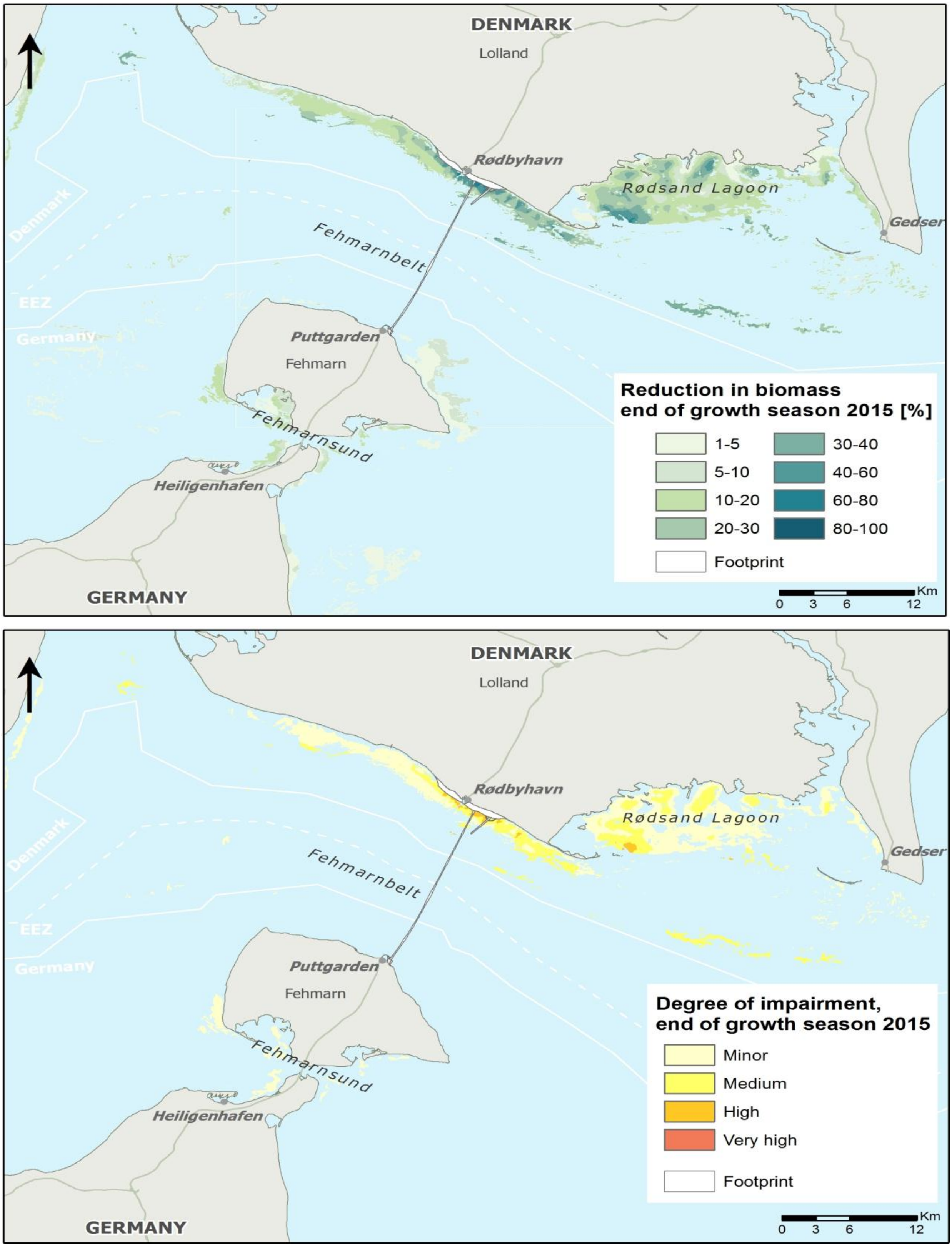


Figure 0-3 Spatial distribution of reduction in benthic flora biomass and degree of impairment at the end of the growth season 2015. Similar figures illustrating the impacts in the years 2017, 2018 and 2019 can be seen in Appendix C.

Sedimentation
764 ha of benthic flora communities are affected by sedimentation (Figure 0-4). Of this area, 65% is impaired to a minor degree in Danish (284 ha) and German national waters (217 ha), while 32% are impaired to a medium degree of impairment and nearly exclusively in Danish waters (244 ha). High degree of impairment appears exclusively in a very small area (10 ha) along the Lolland coast. No very high degree of impairment occurs due to sedimentation. The impact is distributed among most communities but the *Furcellaria* and eelgrass communities are affected the most. The severity of the impacts on these communities is largely minor or medium.

The impact on benthic flora of the pressure sedimentation is temporary and will not cause significant effects on the function of the local or regional ecosystem.

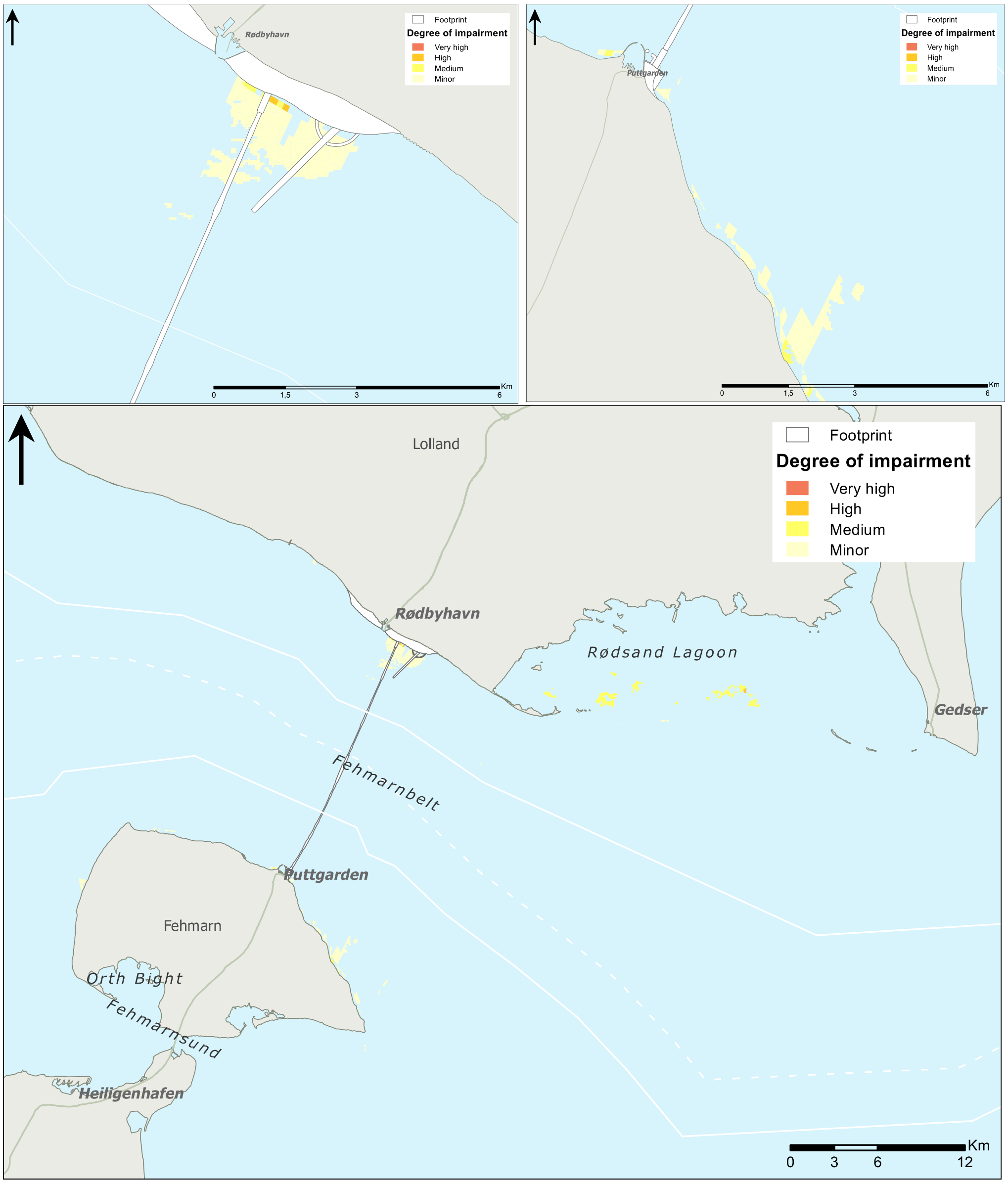


Figure 0-4 Spatial distribution of the degree of impairment caused by sedimentation for the tunnel alternative in detailed zones (above, left: Lolland coast, right: Fehmarn coast) and as overview (below).

Footprint
Overall, the tunnel footprints affect 298 ha of benthic flora. Most of the impact (218 ha) is from the permanent loss due to reclamation areas and only a smaller part (80 ha) is due to the tunnel trench and other temporary structures. The severity of loss is of minor (90 ha), medium (190 ha) and high (18 ha) severity. Nearly all of the lost area occurs along the coast of Lolland. The loss along the Fehmarn coast is estimated at 0.22 ha.

The footprint causes loss of the *Furcellaria* and the filamentous species communities. Within most of the impacted area (208 ha) the *Furcellaria* community occurs. The loss is mainly caused by permanent footprints (188 ha), and therefore not reversible. The 188 ha of lost *Furcellaria* corresponds 8% of the community in Fehmarnbelt and to 5% of the occurrence in the assessment area.

The *Furcellaria* community is a valuable part of benthic flora in the Fehmarnbelt. The area loss will not threaten the existence of the community in the Fehmarnbelt but is assessed to be significant for the functioning of the local ecosystem. This is because perennial macrophytes are important as habitat structuring elements contribution to the coastal primary production, O_2 production and creating habitats for associated flora and fauna.

Solid substrate
80 ha of solid substrate are added in the depth interval 0-20 m due to the structures of the tunnel. If all new solid substrate is colonised by macroalgae, with the same biomasses as found on natural rocks in the baseline study, the new area corresponds to 10% of the area and 7% of the biomass of the existing communities in the near zone. This is a positive impact.

Assuming that the same communities will be established, this will to some degree counterbalance the loss from the footprint. However, it is unlikely that macroalgae will colonise all new surfaces and biomasses on artificial surfaces are likely to be lower than on natural rocks.

On the larger scales (e.g. local), the potential new communities will not significantly change the functioning of the ecosystem as they only make up 1.5% or less of the existing area and biomass.

Coastal morphology
The impact due to changes in coastal morphology covers a total area of 8 ha. The main impact is in the *Furcellaria* community (6 ha) corresponding to < 1 % of the *Furcellaria* community in Fehmarnbelt. The impact due to changes in coastal morphology is insignificant for the benthic flora communities.

Impacts of main bridge solution
The bridge alternative impacts only few benthic vegetation communities and most of the impacts are assessed as being of minor severity. In addition, the impacted areas are small. The spatial range of the impacts only exceeds the local zone for the small impact of suspended sediment on eelgrass. Only the *Furcellaria* community is impacted with higher degree of severity, but all affected areas are small and none of the impacts is significant.

Suspended sediment
Very small reductions in biomass of benthic flora are expected as consequences of increased concentrations of suspended sediment for the bridge alternative. Macroalgae are not impacted to any degree of severity. Eelgrass is not impacted to any degree of severity in the first year of the bridge construction. The reduction in light in the near coast areas is highest in the second and third year of the construction phase. In the second year 12 ha, and the third year 32 ha eelgrass is impacted to minor degree of severity. The impact is only of minor severity and impacting less than 0.5% of eelgrass in the assessment area and is therefore considered to be non-significant.

Sedimentation
83 ha of benthic flora are affected by sedimentation. 86% (71 ha) is affected with a minor degree and 14% (12 ha) with a medium degree of impairment. No very high and no high degree of impairment occurs due to sedimentation. It is mainly the *Furcellaria* community that is affected (58 ha). *Fucus* and *Phycodrys/Delesseria* communities are affected in smaller areas. Eelgrass communities are not affected.

The impact corresponds to minor to medium severity. At the same time the areas are small and the impact temporary, and therefore the impact on the macroalgal communities due to sedimentation for the bridge alternative is insignificant.

Footprint
Overall, the bridge footprint affects 25 ha of benthic flora; 15 ha are affected by bridge piers or other permanent footprints and 10 ha by temporary footprints. Nearly all of the lost area is in Danish waters. Medium severity loss of the *Furcellaria* community is observed in 8 ha, corresponding to 0.38% of *Furcellaria* in Fehmarnbelt. The area is small and impact on the *Furcellaria* community due to footprints is therefore insignificant. The impact due to footprints is also insignificant for the other impacted communities: filamentous algae and single vegetation stands.

Solid substrate
25 ha of solid substrate are added in the depth interval 0-20 m due to the structures of the bridge. If all new solid substrate is colonised by macroalgae, with the same biomasses as found on natural rocks in the baseline study, the new solid substrate contribute with 11% additional area and 16% more biomass in the near zone. However, it is unlikely that macroalgae will colonise all new surfaces and biomasses on artificial surfaces are likely to be lower than on natural rocks.

On the larger scales (e.g. local), the potential new communities will not contribute significantly to the functioning of the ecosystem as they only make up 1% or less of the existing area and biomass. The additional new substrate is not considered to cause any significant changes to the function of the ecosystem in Fehmarnbelt.

Seabed morphology
The loss due to changes in seabed morphology comprises less than 1% of the communities in the Fehmarnbelt and is therefore insignificant.

Comparison of bridge and tunnel main alternatives

The comparison of the two main technical alternatives is based on the assessment results of the relevant pressures in terms of the affected areas and the severity of the impairments/loss, summarized in Table 0-5.

Table 0-5 The lost/impaired areas for both alternatives are listed pressure by pressure and divided into severity grades. Significant impacts are marked with (s). For suspended sediment, the year with the worst impact is shown.

		Tunnel	Bridge
Suspended sediment (2015)			
Severity of loss		No loss occurs	
Severity of impairments	Very high		
	High	115	
	Medium	2689	
	Minor	11751	32
	Total	**14555**	32
Sedimentation			
Severity of loss		No loss occurs	
Severity of impairments	Very high		
	High	1	
	Medium	262	12
	Minor	309	56
	Total	572	68
Footprint			
Severity of loss	Very high		
	High	18	1
	Medium	190 (s)	8
	Minor	90	19
	Total	298	28
Seabed and coastal morphology			
Severity of loss	Very high		
	High	0.15	
	Medium	6	
	Minor	2	3
	Total	8	3

Based on the estimates in Table 0-5 and consideration on the impacts. E.g. on community level, the alternatives have been graded against each in order to identify the alternative with the least environmental impacts (Table 0-6). For benthic flora, the bridge alternative is predicted to have lesser impact than the tunnel alternative.

Table 0-6 Results for the comparison between alternatives (++ environmental advantage preferred, + slightly environmental advantage, 0 no difference).

	Tunnel	**Bridge**
Suspended sediments		+
Sedimentation		+
Footprint		++
Solid substrate	0	0
Seabed and coastal morphology	0	0
Total		++

For the pressure suspended sediment, the reason why the bridge is more advantageous from an environmental point of view is that the intensity and area impacted is much smaller than for the tunnel. The overall impaired area for the tunnel alternative is by a factor of 1000 larger and it is only for the tunnel alternative, high severity of impairment is assessed.

Although the impairments for the tunnel for sedimentation is insignificant, the bridge is the slightly more advantageous from an environmental point of view, because of the much smaller impairment area and the subsequent lower number of affected vegetation communities.

For the pressure footprint the bridge is also more advantageous, because of the much smaller area lost and the insignificance of the impacts. The overall lost area for the tunnel alternative is a factor 10 larger compared to the bridge alternative. Especially the lost area with high severity is much larger for the tunnel and the *Furcellaria* community is significantly impacted.

For new solid substrate there is no difference between the bridge and the tunnel alternative. The area and biomasses of new benthic flora communities predicted for the tunnel and bridge alternatives are not in any of the cases causing a significant contribution to the benthic flora of Fehmarnbelt.

Similarly, there is no difference between bridge and tunnel with regard to seabed and coastal morphology. In both cases the lost area are similar and very low. No significant impact is assessed for any of the alternatives.

Other issues

Protected species
Only the German Nature conservation act (Bundesnaturschutzgesetz, *BNatSchG*) is relevant for marine benthic flora in terms of protected habitats and species. In §30 (the following marine macrophyte biotopes are listed: seagrass beds and other macrophytes stocks. No exact definition for “other macrophytes stocks” is given, but normally this refers to important perennial and dense macrophyte stocks and not to opportunistic annual macroalgae stands.

For both alternatives, no significant loss or impairments of seagrass beds or perennial macrophyte stocks within German waters have been assessed.

WFD and MSFD
Along the Danish coast, impacts are predicted in five different water bodies for the tunnel and in three different water bodies for the bridge alternative. Basis for the WFD classification in Denmark is solely the eelgrass depth limit. As none of the project related pressures for tunnel or bridge show impacts on the eelgrass depth limit, no impacts in terms of WFD ecological status are expected.

Along the German coast, impacts are predicted in three different water bodies for the tunnel and in two different water bodies for the bridge. Mainly the water body Fehmarnbelt is opposed to several pressures, whereas the water bodies Fehmarnsund and Orth Bight are impacted only by suspended sediment and to a minor degree. According to the national WFD monitoring of Germany, the ecological status of Fehmarnbelt is good (0.6) at the good-moderate boundary (Fürhaupter et al. 2008).

Due to suspended sediment and sedimentation, some flora communities are impaired to minor degree of impairment in German waters. Minor impairments are slight growth/biomass reductions and/or reduction in recruitment. Dominance and/or biomass of the key-species in the communities are included in the German WFD indicators. The predicted minor impairments may cause slight changes in dominance or reduction in biomass and thus potentially result in a minor reduction in the ecological value of the Fehmarnbelt water body. The water body is classified at the boundary between good and moderate ecological status. Therefore, minor impairments can result in a downgrade of the water body to a moderate ecological status.

Climate change
Over a long time span, climate change is likely to change the current baseline conditions in the future through a change in the environmental conditions and a subsequent reaction of the benthic vegetation communities. The most likely changes are a decreased salinity, more frequent storm events and an increasing water temperature. The impact of climate change is not foreseen to add to the pressures from the construction of the Fixed Link.

Cumulative
There are no cumulative impacts for the benthic flora for the tunnel and bridge alternatives.

Mitigation and compensation
Mitigation can reduce the magnitude of pressure and subsequent loss and impairment of the environmental factors. Mitigation measures have to be pressure-specific and may differ between sub-components (communities). Only mitigation of significant impacts is included.

The tunnel reclamation area along the Lolland coastline causes a significant loss of the *Furcellaria* community. The project has already included optimisation of the impact of the footprint through the comparison of alignments and along the Fehmarn coastline, the chosen shape and area of footprints exclude the loss of vegetation nearly completely. The present footprints fulfil technical requirements of the project and further mitigation is not possible.

Compensation is a legal requirement, if protected habitats/species are lost or impaired significantly. As none of the pressures will affect protected benthic vegetation by significant loss or impairment, compensation of benthic flora is not necessary for the tunnel or bridge alternative.

Transboundary
No transboundary impacts on benthic flora are predicted for the tunnel and bridge alternatives.

Knowledge gabs
The baseline investigations for benthic flora conducted in 2009–2010 provided the basis for the environmental impact assessment. They delivered a comprehensive documentation of the distribution, composition and abundance (coverage) of benthic flora and communities of the Fehmarnbelt. No gaps in terms of occurrence and status of vegetation are identified for the assessment area.

Starting from those input data the effects of the different pressures on benthic flora and their sub-components are predicted. The knowledge and data basis of the effects varied between pressures.

For suspended sediment, literature supplemented with laboratory experiments in general have provided comprehensive knowledge about the aspects of light attenuation due to sediment spill and the effect on benthic vegetation.

The quantitative effects of sedimentation on benthic flora communities or species are in general not or poorly known.

For the risk of introducing non-indigenous species, it is nearly impossible to foresee, which species could be introduced, and if they will have an invasive potential. There exists only scarce information, which specific features of the life and growth cycles of the introduced species and which ecosystem functions of the newly inhabited area, enables an "invasion".

1 INTRODUCTION

Denmark and Germany are planning to build a Fixed Link between Denmark and Germany across the Fehmarnbelt. An important part of this work is to prepare an Environmental Impact Assessment (in Denmark VVM and in Germany UVS) in order to have the project approved by the authorities in Denmark and Germany.

The task of Fehmarnbelt Fixed Link - Marine Biology Services (FEMA) has been to describe the baseline and assess possible impacts of constructing a tunnel or bridge on marine flora and fauna (phyto- and zooplankton, benthic flora and fauna) as well as describing and assessing the impact of toxic substances and nutrients from the sediment.

This report describes the predicted impacts on benthic flora of constructing and operating a fixed link across Fehmarnbelt. Separate reports are prepared for impact assessments of Natura 2000 sites and this aspect is therefore not included in this report. The report is one of several FEMA publications reporting the results of the impact assessment for marine flora and fauna.

1.1 Environmental theme

Constructions of marine infrastructure projects like fixed links and wind farms may affect the marine benthic flora. The impacts relate to the construction phase, the new structures or the operation phase.

During construction, sediment spill cause reduced light availability for photosynthesis and growth of benthic flora and sedimentation may increase mortality and reduce recruitment. Dredging may also release nutrients and toxic substance to the water in concentrations large enough to affect the flora.

Flora habitats located in the area of new structures like piers and pylons of the bridge or reclamation areas of the tunnel construction will be lost. The new structures may also permanently change the current speed and mixing of water resulting in changes in temperature and salinity.

Impacts on benthic flora of operating the fixed link are limited to the possible effects of drainage water from the new constructions.

Some changes may also be beneficial for the benthic flora. Macroalgae need solid substrate for attachment. Solid substrate in Danish and German coastal waters mainly consists of scattered stones and boulders along the coast and availability of suitable substrate is often limiting the distribution. New structures as bridge piers and pylons or scour protection may serve as new hard bottom areas for colonisation of macroalgae.

The significance of the impacts for the survival and function of the ecosystem depends on the area, intensity and duration of the impact as well as the importance of the impacted communities for the local, regional or larger scale ecosystems.

The overall objective of the Fehmarnbelt Fixed Link - Marine Biology Services (FEMA) benthic flora impact assessment is to carry out detailed analyses of permanent and temporary impacts arising from the construction and operation activities and from the new structures of the Fehmarnbelt Fixed Link.

The purpose of this report is to present the results of the benthic flora impact assessment, with the specific objectives:

- Predict the magnitude of pressures and severity of impacts on benthic flora from temporal activities of dredging and reclamation during construction of the Fehmarnbelt Fixed Link
- Predict the severity of impact on benthic flora from permanent placement of new structures in the marine environment
- Predict the magnitude and severity of impact of permanent activities during operation of the fixed link
- Assess the significance of the predicted impacts for the survival and functioning of the ecosystems in the near zone and at local, national and transboundary scale
- Assess the impact of decommissioning of the tunnel and bridge alternative
- Assess the effect of expected climate changes for the predicted impacts
- Compare the impacts on benthic flora of the bridge and the tunnel alternatives
- If predicted impacts are significant to suggest mitigations

The basis for the impact assessment is the distribution and abundance of benthic flora communities found during the baseline study. The basis for determining the range, duration and intensity of the pressures is the project description, modeled sediment spill, hydrography and marine soil scenarios and available literature data. The impacts are predicted using ecological modeling, GIS analysis and expert knowledge.

1.2 Benthic flora communities

Five hard bottom macroalgal communities, two soft bottom communities constituted of flowering plants and one mixed algae-flowering plant community were identified during the baseline study (2009-2010) in Fehmarnbelt and adjacent areas (FEMA 2013a).

Hard bottom (macroalgae) communities
The five hard bottom (macroalgae) communities were: *Fucus*-community, *Furcellaria*-community, *Phycodrys/Delesseria*-community, *Saccharina*-community and filamentous species-community (Figure 1-1).

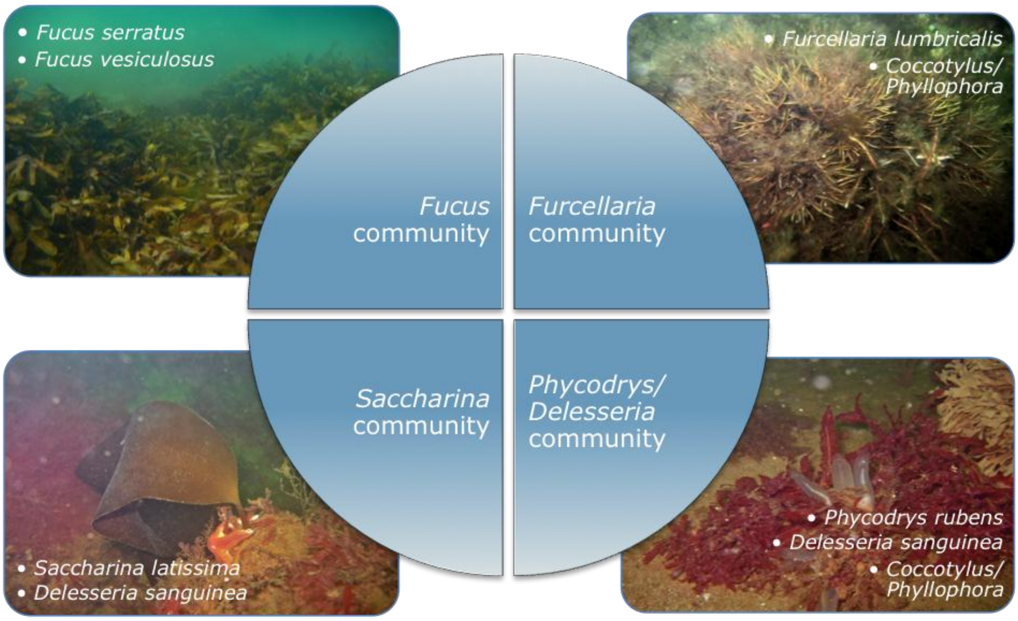


Figure 1-1 Characteristic hard bottom macroalgal communities within the assessment area.

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

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

The *Phycodrys/Delesseria*-community is found at depths between 5–19 m and had a large spatial distribution in the study area. 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*.

The *Saccharina*-community is found at depths between 12–19 m. Key species is the perennial brown algae *Saccharina latissima*. Accompanying species are rare and are mostly annual, filamentous algae (e. g. *Desmarestia aculeata*, *Polysiphonia stricta*) or 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.

Soft bottom (flowering plant) communities
The two soft bottom (angiosperm) communities are an eelgrass- and a tasselweed/dwarf eelgrass-community (Figure 1-2).

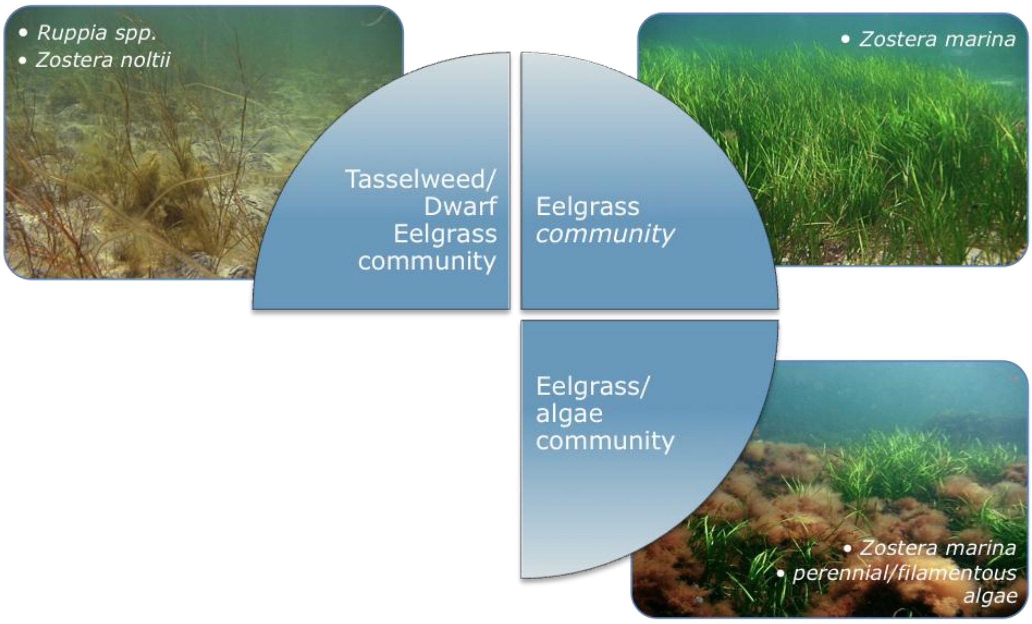


Figure 1-2 Characteristic soft and mixed bottom flowering plant communities within the investigation area in 2009.

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 coast. Contrary to the communities mentioned above, 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.

Figure 1-3 shows the distribution of the benthic flora communities in the area.

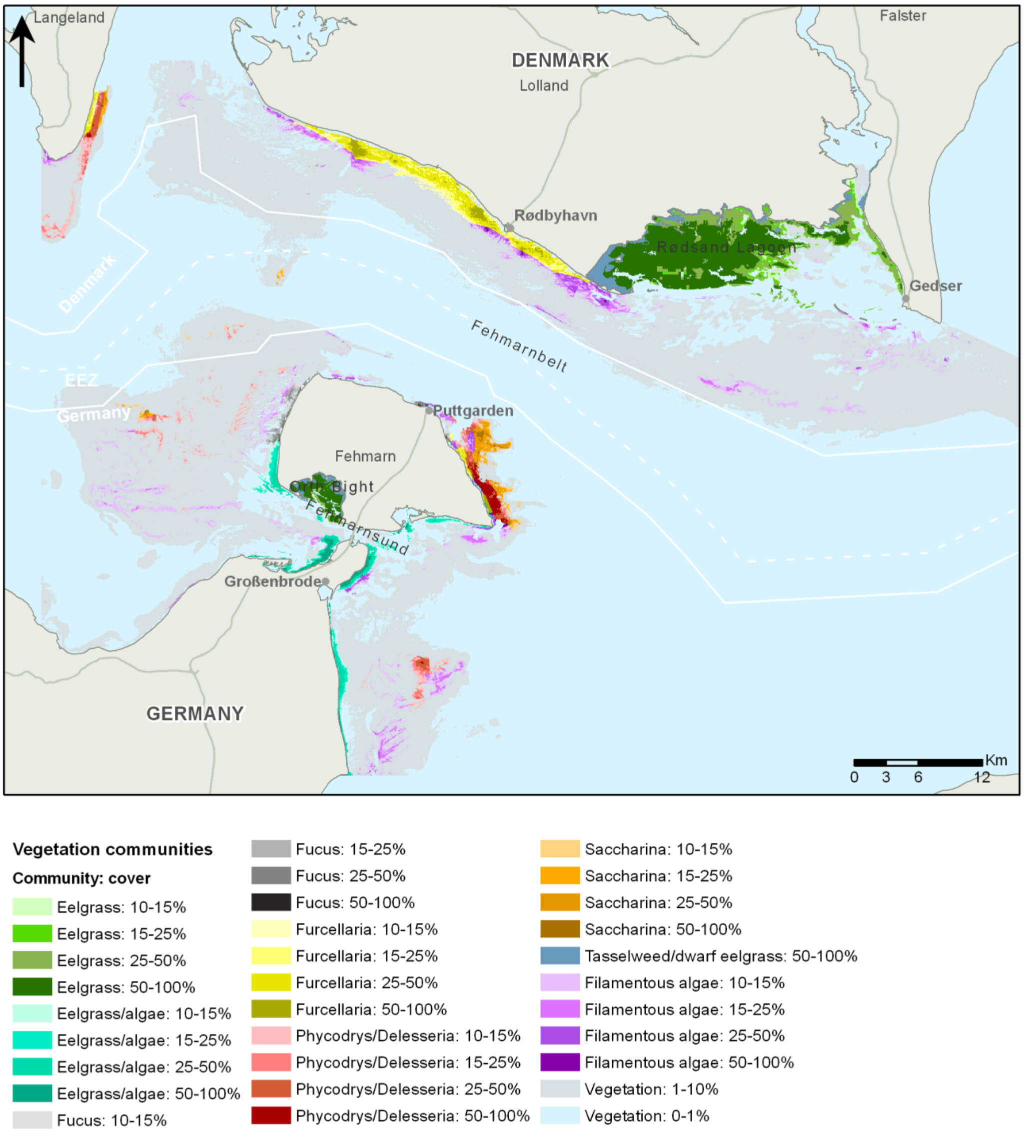


Figure 1-3 Distribution and coverage of the different vegetation communities within the assessment area.

1.3 Importance

The importance of benthic vegetation is defined by its 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 (and to a less 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 communities 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. Consequently, the functionally based classification criteria have been extended for German waters to fulfil the regulatory conditions. The classification of vegetation communities to the different levels of importance is described in detail in the flora baseline report (FEMA 2013a).

The definition of the importance levels is given in Table 1-1 and the outcome of the importance analysis is illustrated in the map in Figure 1-4.

Table 1-1 Importance levels for the characteristic vegetation communities of different area cover within the assessment area. For Germany, classification is adjusted to comprise national legislation. For Denmark, the classification is solely based on ecological values.

Importance level	DE		DK	
	Community	**Coverage**	**Community**	**Coverage**
Very high	All (beside filamentous algae)	≥ 50 %	Eelgrass Eelgrass/ algae Tasselweed/ dwarf eelgrass *Fucus*	≥ 50 %
High	All (beside filamentous algae)	25–50 %	*Furcellaria* *Phycodrys/ Delesseria* *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 %

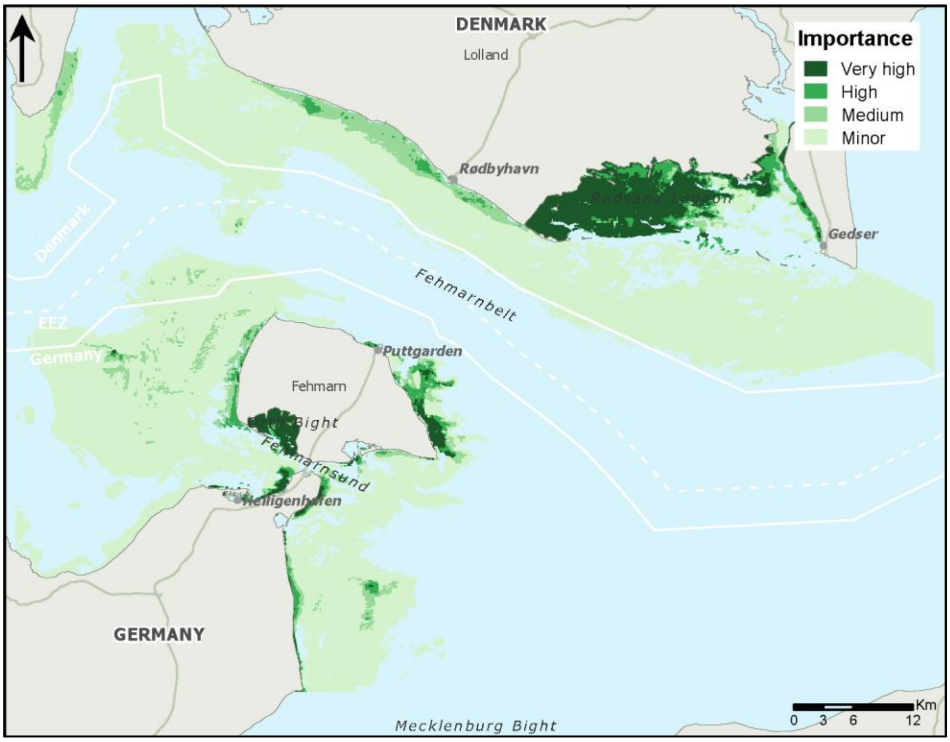


Figure 1-4 Map of importance for benthic vegetation.

1.4 Environmental components assessed

The sub-factor marine benthic flora includes the components flowering plants and macroalgae. The components are divided into sub-components representing the different communities (Table 1-2). The impact assessment has been carried out on the scale of components or sub-components.

Table 1-2 The environmental sub-factors, components and sub-components within the factor flora and fauna, assessed in this report.

Factor	**Sub-factor**	**Components**	**Sub-components**
Fauna and flora (including biodiversity)	Marine benthic flora	Flowering plants	Eelgrass community Eelgrass/ algae community Tasselweed/ dwarf eelgrass community
		Macroalgae	*Fucus* community *Furcellaria* community *Phycodrys/ Delesseria* community *Saccharina* community Filamentous species community

2 THE FEHMARNBELT FIXED LINK PROJECT

The Impact assessment is undertaken for two fixed link solutions:

- Immersed tunnel E-ME (August 2011)
- Cable Stayed Bridge Variant 2 B-EE (October 2010)

2.1.1 *The Immersed Tunnel (E-ME August 2011)*

The alignment for the immersed tunnel passes east of Puttgarden, crosses the Fehmarnbelt in a soft curve and reaches Lolland east of Rødbyhavn as shown in Figure 2-1 along with near-by NATURA2000 sites.

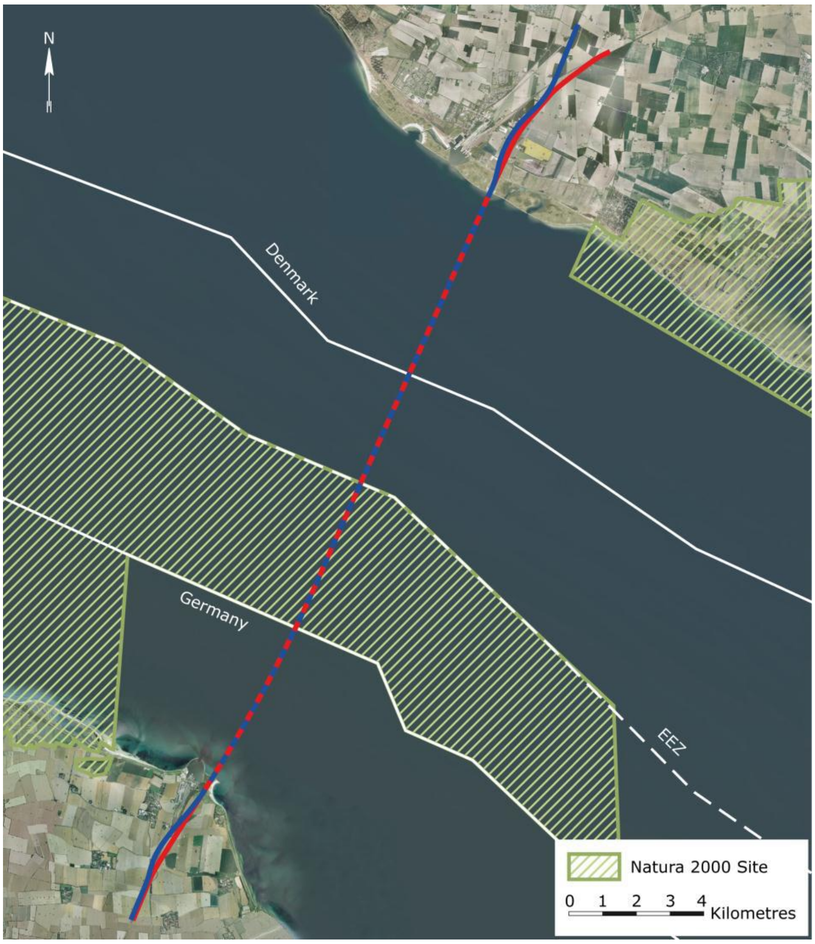


Figure 2-1 Proposed alignment for immersed tunnel E-ME (August 2011)

Tunnel trench

The immersed tunnel is constructed by placing tunnel elements in a trench dredged in the seabed, see Figure 2-2. The proposed methodology for trench dredging comprises mechanical dredging using Backhoe Dredgers (BHD) up to 25m water depth and Grab Dredgers (GD) in deeper waters. A Trailing Suction Hopper Dredger (TSHD) will be used to rip the clay before dredging with GD. The material will be loaded into barges and transported to the near-shore reclamation areas where the soil will be unloaded from the barges by small BHDs. A volume of approx. 14.5 mio. m^3 sediment is handled.

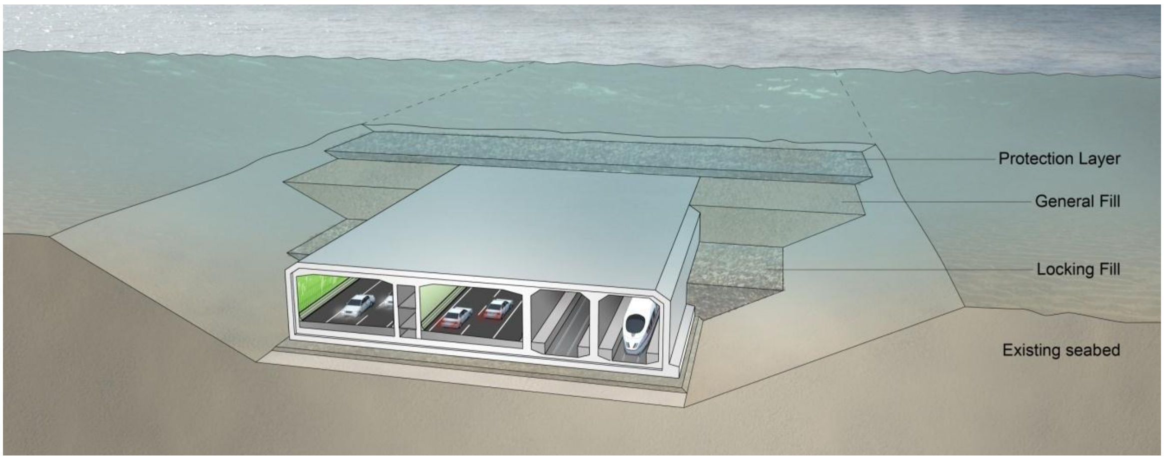


Figure 2-2 Cross section of dredged trench with tunnel element and backfilling

A bedding layer of gravel forms the foundation for the elements. The element is initially kept in place by placing locking fill followed by general fill, while on top there is a stone layer protecting against damage from grounded ships or dragging anchors. The protection layer and the top of the structure are below the existing seabed level except near the shore. At these locations, the seabed is locally raised to incorporate the protection layer over a distance of approximately 500-700m from the proposed coastline. Here the protection layer is thinner and made from concrete and a rock layer.

Tunnel elements

There are two types of tunnel elements: standard elements and special elements. There are 79 standard elements, see Figure 2-3. Each standard element is approximately 217 m long, 42m wide and 9m tall. Special elements are located approximately every 1.8 km providing additional space for technical installations and maintenance access. There are 10 special elements. Each special element is approximately 46m long, 45m wide and 13m tall. After placement of the elements, the tunnel trench will be backfilled with marine material, potentially partly from Kriegers Flak.

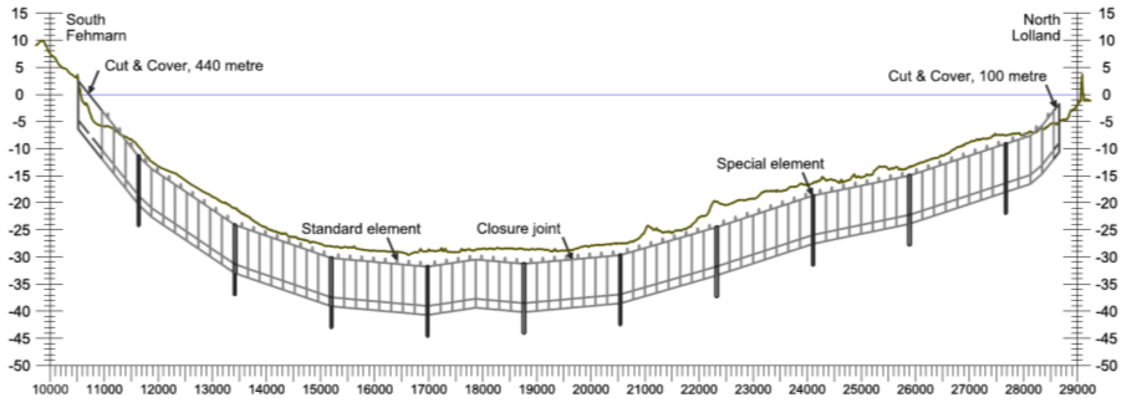


Figure 2-3 Vertical tunnel alignment showing depth below sea level

The cut and cover tunnel section beyond the light screens is approximately 440m long on Lolland and 100m long on Fehmarn. The foundation, walls, and roof are constructed from cast in-situ reinforced concrete.

Tunnel drainage

The tunnel drainage system will remove rainwater and water used for cleaning the tunnel. Rainwater entering the tunnel will be limited by drainage systems on the approach ramps. Fire fighting water can be collected and contained by the system for subsequent handling. A series of pumping stations and sump tanks will transport the water from the tunnel to the portals where it will be treated as required by environmental regulations before being discharged into the Fehmarnbelt.

Reclamation areas

Reclamation areas are planned along both the German and Danish coastlines to accommodate the dredged material from the excavation of the tunnel trench. The size of the reclamation area on the German coastline has been minimized. Two larger reclamations are planned on the Danish coastline. Before the reclamation takes place, containment dikes are to be constructed some 500m out from the coastline.

The landfall of the immersed tunnel passes through the shoreline reclamation areas on both the Danish and German sides

Fehmarn reclamation areas

The proposed reclamation at the Fehmarn coast does not extend towards north beyond the existing ferry harbour outer breakwater at Puttgarden. The extent of the Fehmarn reclamation is shown in Figure 2-4. The reclamation area is designed as an extension of the existing terrain with the natural hill turning into a plateau behind a coastal protection dike 3.5m high. The shape of the dike is designed to accommodate a new beach close to the settlement of Marienleuchte.

Figure 2-4 Proposed reclamation area at Fehmarn

The reclaimed land behind the dike will be landscaped to create an enclosed pasture and grassland habitat. New public paths will be provided through this area leading to a vantage point at the top of the hill, offering views towards the coastline and the sea.

The Fehmarn tunnel portal is located behind the existing coastline. The portal building on Fehmarn houses a limited number of facilities associated with essential equipment for operation and maintenance of the tunnel and is situated below ground level west of the tunnel.

A new dual carriageway is to be constructed on Fehmarn for approximately 3.5km south of the tunnel portal. This new highway rises out of the tunnel and passes onto an embankment next to the existing harbour railway. The remainder of the route of the highway is approximately at level. A new electrified twin track railway is to be constructed on Fehmarn for approximately 3.5km south of the tunnel portal. A lay-by is provided on both sides of the proposed highway for use by German customs officials.

Lolland reclamation area

There are two reclamation areas on Lolland, located either side of the existing harbour. The reclamation areas extend approximately 3.7km east and 3.4km west of the harbour and project approximately 500m beyond the existing coastline into the Fehmarnbelt. The proposed reclamation areas at the Lolland coast do not extend beyond the existing ferry harbour outer breakwaters at Rødbyhavn.

The sea dike along the existing coastline will be retained or reconstructed, if temporarily removed. A new dike to a level of +3m protects the reclamation areas against the sea. To the eastern end of the reclamation, this dike rises as a till cliff to a level of +7m. Two new beaches will be established within the reclamations. There will also be a lagoon with two openings towards Fehmarnbelt, and revetments at the openings. In its final form the reclamation area will appear as three types of landscapes: recreation area, wetland, and grassland - each with different natural features and use.

The Lolland tunnel portal is located within the reclamation area and contained within protective dikes, see Figure 2-5. The main control centre for the operation and maintenance of the Fehmarnbelt Fixed Link tunnel is housed in a building located over the Danish portal. The areas at the top of the perimeter wall, and above the portal building itself, are covered with large stones as part of the landscape design. A path is provided on the seaside of the proposed dike to serve as recreation access within the reclamation area.

Figure 2-5 Proposed design of tunnel portal area at Lolland

A new dual carriageway is to be constructed on Lolland for approximately 4.5km north of the tunnel portal. This new motorway rises out of the tunnel and passes onto an embankment. The remainder of the route of the motorway is approximately at level. A new electrified twin track railway is to be constructed on Lolland for approximately 4.5km north of the tunnel portal. A lay-by is provided in each direction off the landside highway on the approach to the tunnel for use by Danish customs officials. A facility for motorway toll collection will be provided on the Danish landside.

Marine construction works

The temporary works comprises the construction of two temporary work harbours, the dredging of the portal area and the construction of the containment dikes. For the harbour on Lolland an access channel is also provided. These harbours will be integrated into the planned reclamation areas and upon completion of the tunnel construction works, they will be dismantled/removed and backfilled.

Production site

The current design envisages the tunnel element production site to be located in the Lolland east area in Denmark. Figure 2-6 shows one production facility consisting of two production lines. For the construction of the standard tunnel elements for the Fehmarn tunnel four facilities with in total eight production lines are anticipated.

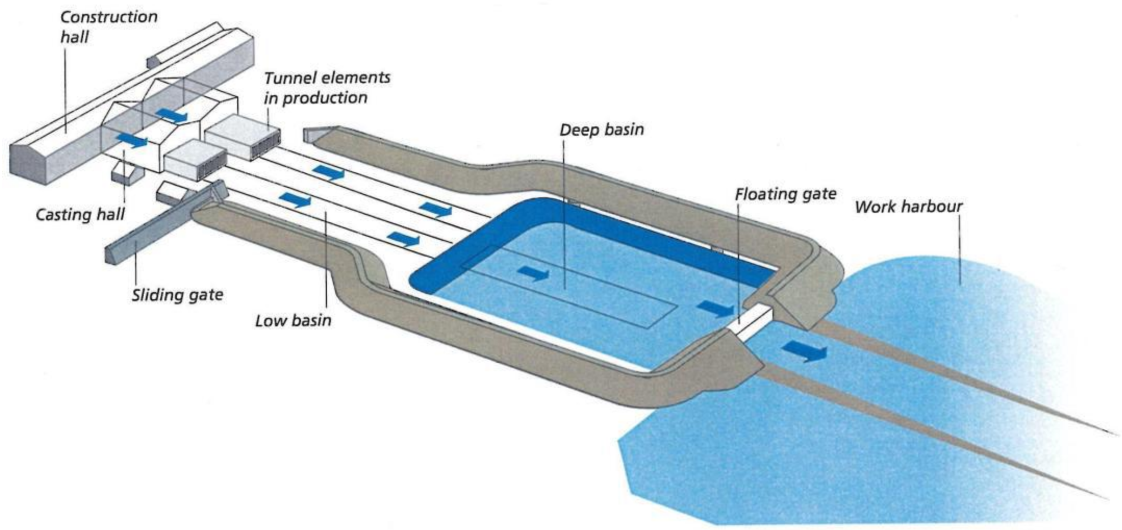


Figure 2-6 Production facility with two production lines

In the construction hall, which is located behind the casting and curing hall, the reinforcement is handled and put together to a complete reinforcement cage for one tunnel segment. The casting of the concrete for the segments is taking place at a fixed location in the casting and curing hall. After the concrete of the segments is cast and hardened enough the formwork is taken down and the segment is pushed forward to make space for the next segment to be cast. This process continues until one complete tunnel element is cast. After that, the tunnel element is pushed into the launching basin. The launching basin consists of an upper basin, which is located at ground level and a deep basin where the tunnel elements can float. In the upper basin the marine outfitting for the subsequent towing and immersion of the element takes place. When the element is outfitted, the sliding gate and floating gate are closed and sea water is pumped into the launching basin until the elements are floating. When the elements are floating they are transferred from the low basin to the deep basin. Finally the water level is lowered to normal sea level, the floating gate opened and the element towed to sea. The proposed lay-out of the production site is shown in Figure 2-7.

Dredging of approx. 4 million m^3 soil is required to create sufficient depth for temporary harbours, access channels and production site basins.

Figure 2-7 Proposed lay-out of the production site east of Rødbyhavn

2.1.2 *The Cable Stayed Bridge (Variant 2 B-EE, October 2010)*

The alignment for the marine section passes east of Puttgarden harbour, crosses the belt in a soft S-curve and reaches Lolland east of Rødbyhavn, see Figure 2-8.

Bridge concept

The main bridge is a twin cable stayed bridge with three pylons and two main spans of 724m each. The superstructure of the cable stayed bridge consists of a double deck girder with the dual carriageway road traffic running on the upper deck and the dual track railway traffic running on the lower deck. The pylons have a height of 272m above sea level and are V-shaped in transverse direction. The main bridge girders are made up of 20m long sections with a weight of 500 to 600t. The standard approach bridge girders are 200m long and their weight is estimated to ~ 8,000t.

Caissons provide the foundation for the pylons and piers of the bridge. Caissons are prefabricated placed 4m below the seabed. If necessary, soils are improved with 15m long bored concrete piles. The caissons in their final positions end 4m above sea level. Prefabricated pier shafts are placed on top of the approach bridge caissons. The pylons are cast in situ on top of the pylon caissons. Protection Works are prefabricated and installed around the pylons and around two piers on both sides of the pylons. These works protrudes above the water surface. The main bridge is connected to the coasts by two approach bridges. The southern approach bridge is 5,748m long and consists of 29 spans and 28 piers. The northern approach bridge is 9,412m long and has 47 spans and 46 piers.

Figure 2-8 Proposed main bridge part of the cable stayed bridge

Land works

A peninsula is constructed both at Fehmarn and at Lolland to use the shallow waters east of the ferry harbours breakwater to shorten the Fixed Link Bridge between its abutments. The peninsulas consist partly of a quarry run bund and partly of dredged material and are protected towards the sea by revetments of armour stones.

Fehmarn

The peninsula on Fehmarn is approximately 580m long, measured from the coastline, see Figure 2-9. The gallery structure on Fehmarn is 320m long and enables a separation of the road and railway alignments. A 400m long ramp viaduct bridge connects the road from the end of the gallery section to the motorway embankment. The embankments for the motorway are 490m long. The motorway passes over the existing railway tracks to Puttgarden Harbour on a bridge. The profile of the railway and motorway then descend to the existing terrain surface.

Lolland

The peninsula on Lolland is approximately 480m long, measured from the coastline. The gallery structure on Lolland is 320m long. The existing railway tracks to Rødbyhavn will be decommissioned, so no overpass will be required. The viaduct bridge for the road is 400m long, the embankments for the motorway are 465m long and for the railway 680m long. The profile of the railway and motorway descends to the natural terrain surface.

Figure 2-9 Proposed peninsula at Fehmarn east of Puttgarden

Drainage on main and approach bridges

On the approach bridges the roadway deck is furnished with gullies leading the drain water down to combined oil separators and sand traps located inside the pier head before discharge into the sea.

On the main bridge the roadway deck is furnished with gullies with sand traps. The drain water passes an oil separator before it is discharged into the sea through the railway deck.

Marine construction work

The marine works comprises soil improvement with bored concrete piles, excavation for and the placing of backfill around caissons, grouting as well as scour protection. The marine works also include the placing of crushed stone filling below and inside the Protection Works at the main bridge.

Soil improvement will be required for the foundations for the main bridge and for most of the foundations for the Fehmarn approach bridge. A steel pile or reinforcement cage could be placed in the bored holes and thereafter filled with concrete.

The dredging works are one of the most important construction operations with respect to the environment, due to the spill of fine sediments. It is recommended that a grab hopper dredger with a hydraulic grab be employed to excavate for the caissons both for practical reasons and because such a dredger minimises the sediment spill. If the dredged soil cannot be back-filled, it must be relocated or disposed of.

Production sites

The temporary works comprises the construction of two temporary work harbours with access channels. A work yard will be established in the immediate vicinity of the harbours, with facilities such as concrete mixing plant, stockpile of materials, storage of equipment, preassembly areas, work shops, offices and labour camps.

The proposed lay-out of the production site is shown in Figure 2-10.

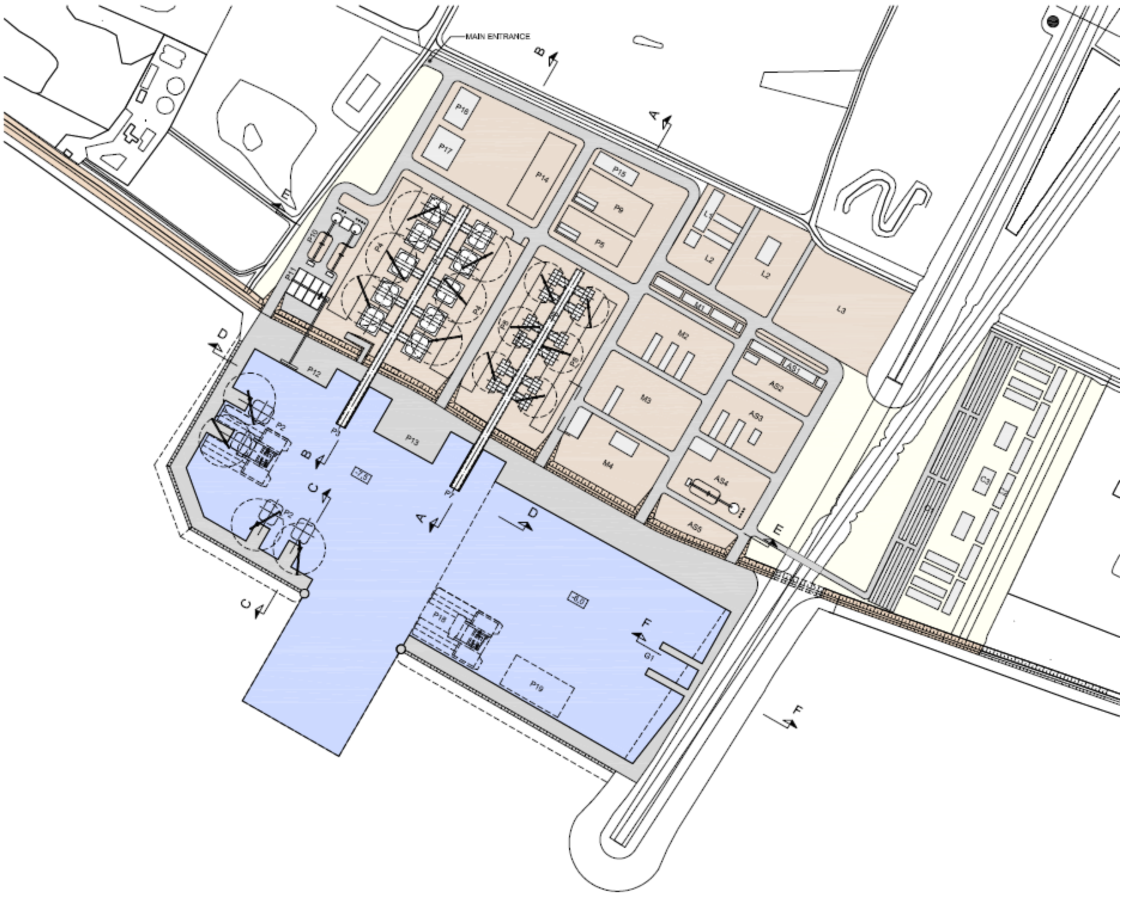


Figure 2-10 Proposed lay-out of the production site at Lolland east of Rødbyhavn

2.2 Relevant project pressures

The pressures identified to potential impact benthic flora due to activities during the construction and operation phases and due to new structures are listed in Table 2-1. The construction-related pressures have a limited duration while structure- and operation-related pressures are permanent. Some pressures are restricted to the near zone in the close vicinity of the constructions (± 500 m of the alignment), while other may extend further in the local zone (± 10 km) or beyond the local zone (> 10 km, Table 3-4 and Figure 3-4.

Table 2-1 Pressures potentially causing an impact on benthic flora in the construction, structure and operation phases of the project.

Phase	Pressure
Construction	Suspended sediment
	Sedimentation Toxic substances Nutrients
	Construction vessels and imported material
Structure	Footprint
	Solid substrate
	Seabed and coastal morphology
	Hydrographical regime (salinity, temperature) and Water quality (nutrients, Secchi-depth)
Operation	Drainage

The pressures relevant to the benthic flora and their expected duration and range of each pressure are briefly described below.

2.2.1 *Suspended sediment*

During the construction phase sediment will be spilled due to dredging and backfilling activities (e.g. dredging of working harbours or tunnel trench and backfilling at bridge pylons or tunnel trench). The sediment spill is dispersed to the surrounding areas by currents and may, after sedimentation, be re-suspended by waves and currents.

The increased concentrations of suspended sediment in the water reduce light availability for photosynthesis and growth of benthic flora. The spatial range of the increased concentrations of suspended sediment and the intensity of the light reduction depends on the amount and characteristics of the sediment spilled during dredging and the hydrographical conditions (e.g. current direction and speed). Small particles have the lowest settling velocity and are therefore transported further away than large particles. As the small particles also have the highest mass-specific effect on light attenuation, the effect of the pressure may extend beyond the local zone.

Reduced light availability may decrease production and thus the biomass of the benthic flora. Benthic flora species differ in their light requirements and ability to sustain growth in periods of low light. Since the light requirement is largest during the growth season, the impact of reduced light should be smallest during the winter months and highest in the growth season of the benthic flora.

In summary: The pressure relates to the construction, the duration is restricted to the construction phase and the suspended sediments may extend outside the local zone.

2.2.2 *Sedimentation*

Dredging and backfilling activities during construction cause sediment spill and subsequent deposition of sediment on the seabed. The spatial range of sedimentation and the intensity of deposition depend on the amount and characteristics (thickness and duration, grain size) of the sediment spilled and the hydrographical conditions (e.g. current direction and speed).

Sedimentation leads to physical stress as sediment on the thallus of the plant reduces the active surface area for photosynthesis and nutrient uptake (Lyngby & Mortensen 1996). A reduction of primary production, growth (Santelices et al. 1984) and, if physical stress is too severe, an increased mortality (Airoldi 2003 and references therein) are the consequences.

Sedimentation also affects recruitment of macroalgae. The exact mechanisms for the settlement of macroalgae propagules are not well known (Vadas et al. 1992), but it is evident that propagules need hard substrates for attachment. Layers of sediment on the hard bottom are known to reduce attachment of spores and survival and growth of juvenile plants (Devinny & Volse 1978, Chapman & Fletcher 2002, Umar et al. 1997, Eriksson & Johansson 2005). However, the recruitment of soft bottom macrophytes (higher plants and charophytes) is rarely negatively impacted by sedimentation, as their life cycles are adapted to those conditions.

In summary: The pressure relates to the construction, the duration is restricted to the construction phase and the sedimentation may extend outside the local zone.

2.2.3 *Toxic substances*

Dredging activities in the construction phase may release toxic substances such as heavy metals and persistent organic pollutants (POPs) to the water column. The magnitude depends on the concentrations of heavy metals and POPs along the fixed link alignment where dredging are expected to take place, the amount of sediment dredged and the character of the sediment.

Environmental Quality Standards (EQS's) are levels that are used to assess the risk of chemical pollutant effects on water quality to the health of aquatic plants and animals. If dredging activities are resulting in concentrations in the water column exceeding environmental quality standards (EQS) for seawater, effects on the benthic flora can be expected. Although some heavy metals are essential to the metabolism of marine plants at very low concentrations, they may become toxic at higher levels (Sunda 1998, Baumann et al 2008). POPs can affect growth and reproduction of marine algae and higher plants (Katagi 2010).

In summary: The pressure relates to the construction, the duration is restricted to the dredging phase and the impact is restricted to the near zone.

2.2.4 *Nutrients*

Dredging activities in the construction phase may also release nutrients to the water column. The spatial range and intensity of increased nutrient loading depends on the concentration of nutrients in the dredged sediments, the amount of the sediment spill and the hydrographical conditions (e.g. current direction and speed) determining the rate of dilution.

Benthic flora responds to increased nutrient loadings by changing the presence and dominance of functionally different species in the communities (Duarte 1995, Borum & Sand-Jensen 1996, Kraufvelin et al. 2006, 2009). These changes include loss of benthic slow-growing, perennial macroalgae and seagrasses and increased dominance of fast growing folious and filamentous macroalgae. Ultimately, phytoplankton will dominate at very high nutrient loadings (Karez 2004, Kautsky et al. 1986, Eriksson et al 1998, Nielsen et al 2002). It should be mentioned that the described possible effects are related to high nutrient loading.

In summary: The pressure is related to the construction, the duration is restricted to the dredging phase and the impact is restricted to the near zone.

2.2.5 *Construction vessels and imported material*

For several activities during the construction phase transportation by vessels and additional imported sediments from specific marine excavation sites or land are necessary. The spatial range and intensity of the pressure depend on the number of additional vessels, the amount of imported material and the distance between the working area and ports of loading and/or excavation sites.

The increase in ship traffic and imported material increases the risk of an introduction of non-indigenous species. Those species can be part of the imported material, the ballast water of the vessels or be attached to the underwater hull.

According to the Ballast Water Convention, the ballast water has to be treated in the future (not later than 2016) on board before being discharged into the marine environment (IMO 2004). This source for species introduction can therefore be excluded in future.

Benthic vegetation may be affected, if the newly introduced species spread widely or quickly and alter the species composition and dominance structure of the benthic flora communities. Non-indigenous species, which negatively impact the economy, human health or ecology of a region, are called invasive species (definition from IUCN).

In summary: The pressure is related to the construction and the duration is restricted to the construction phase. The increased ship traffic will be limited to the shipping route to and from the work harbours. The extent for imported material is restricted to near zone.

2.2.6 *Footprint*

Footprint/sealing occurs due to structures of the proposed fixed link occupying the seabed, like reclamation areas or the base of bridge pylons and piers. Below these permanent structures, the habitat will be lost through the lifetime of the project. Several construction processes may also constitute footprints (e.g. working harbours, access channels). For these provisional structures, a re-establishment of the seabed and the vegetation community is possible after the "footprint" is gone. The spatial range and intensity of the pressure depend on the size of the footprints and the possibility of re-establishment.

The effect of the footprint to benthic flora is a loss of habitat.

The pressure is related to the structures or construction; the duration either can be permanent or lasts until the community is re-established. In both cases the spatial extend is near zone.

2.2.7 *Solid substrate*

Additional solid substrate relates to the structure of the proposed fixed link. New structures like bridge piers and pylons, scour protection and the dikes of the tunnel reclamation areas introduce new areas for colonization of benthic macroalgae. Only the areas that are within the photic zone can potentially be colonised.

Macroalgae depend on hard substrates for settlement whereas flowering plant communities cannot grow on hard substrate.

Additional solid substrate can have an impact on the benthic flora communities in three ways. Firstly, it can introduce hard bottom macroalgal communities to areas previously dominated by soft bottom communities. Secondly, it can increase the risk of introducing new species and lastly, it can increase the area of already existing macroalgal communities.

In summary: The pressure is related to the structure, it is a permanent pressure, restricted to the near zone.

2.2.8 *Seabed and coastal morphology*

Structures like ramps, pylons and new land reclamation areas are barriers in the natural current regime. Barriers at the coastline can cause variations in the longshore drift and barriers or trenches at the sea bottom can cause variations in the near-bottom currents (bed-load transport). Both mechanisms implicate shifts in the natural sedimentation and erosion processes around the new structures. The spatial range and intensity of the pressure depend on the barrier effect of the structures and the implications to the overall hydrographical regime.

Changes in natural sedimentation and erosion processes may cause loss of benthic vegetation. If soft bottoms are eroded, rooted vegetation loose its stability and can easily be torn off by wave action. On the other hand, if soft sediments accumulate on hard substrates, habitat for macroalgae is lost.

Along the coastline marine habitat could get lost, if sediment accretion is high enough to create new land.

In summary: Changes in coastal and seabed morphology are related to the structures of the proposed fixed link, the impact on the dynamics of the sediment is permanent and the changes may extend outside the local zone.

2.2.9 *Hydrographical regime and water quality*

Permanent new structures like reclamation areas, bridge pylons and piers may change the current patterns, including the general flow of water through the Fehmarnbelt and the degree of vertical mixing of the water column. Such changes may alter salinity, temperature, nutrient concentrations and light availability. Since the distribution and abundance of benthic flora are regulated by, amongst others, these factors a change in these conditions may cause changes in the distribution and abundance of species and communities.

In summary: The pressure is related to the structure, it is a permanent pressure that may extend outside the local zone.

2.2.10 *Drainage*

During operation of the fixed link drainage will be necessary. The water comes from: accumulated rainwater, wash water and water needed for combating accidental damages (fire, chemical spills). Timing of outlet events and amount of water is depending on the origin and is partly unpredictable.

Depending on the origin, the water can contain heavy metals, polycyclic aromatic hydrocarbons (PAH), oils, soap, salt from winter salting, or suspended solids. Pure rainwater (without contact to highway or railroad) can be discharged without treatment, whereas wastewater has to be treated according to the national environmental legislation for water discharge. This includes e.g. traps for suspended solids or oil separators.

The spatial range and intensity of the pressure depend on the amount and frequency of drainage, the dilution rate and the hydrographical conditions (e.g. current direction and speed).

The drainage water is mainly freshwater. At the point of the outlet the benthic vegetation will experience a higher variability in salinity compared to natural conditions. Quick or major changes in salinity may affect the vegetation by a change in species/community composition and/or biomass.

In summary: Drainage is related to the operation, the duration is permanent but occurs as momentarily and periodic events. At the outlets the discharged water will be diluted with the surrounding water, so the pressure is restricted to the near zone.

3 DATA AND METHODS

3.1 Basis for the impact assessment

The report draws upon the following data:

- FEHY (2010). Baseline for Suspended Sediment, Sediment Spill, related Surveys and Field experiments. The spreading of spilled sediment. Report No. E1TR0020

- FEHY (2013a). Fehmarnbelt Fixed Link EIA. Marine Water. Impact Assessement. Hydrography of the Fehmarnbelt Area. Report No. E1TR0058 Volume II

- FEHY (2013b). Fehmarnbelt Fixed Link EIA. Marine Soil - Impact Assessment. Seabed Morphology of the Fehmarnbelt Area – Report No. E1TR0059 Volume I

- FEHY (2013c). Fehmarnbelt Fixed Link EIA. Marine Soil. Impact Assesessment Sediment spill during construction of the Fehmarnbelt Fixed Link. Report No. E1TR0059 Volume II

- FEHY (2013d). Fehmarnbelt Fixed Link EIA. Marine Soil – Impact Assessment. Coastal Morphology along Fehmarn and Lolland. Report No. E1TR0059 Volume III, 204 pp.

- FEHY (2013f). Fehmarnbelt Fixed Link EIA. Marine Soil – Baseline. Seabed Chemistry of the Fehmarnbelt Area. Report No. E1TR0056 Volume II. 95 pp.

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

3.2 Tunnel and bridge alternatives assessed

The Impact assessment is carried out for two fixed link solutions:

- Immersed tunnel E-ME (August 2011)

- Cable Stayed Bridge Variant 2 B-EE (October 2010)

For some of the reports and model results in 3.2 the primary assessment is carried out for other designs. This flora assessment uses data and results from the named reports assuming that they are representative of impacts cause by the tunnel E-ME (August 2011) and Cable Stayed Bridge Variant 2 B-EE (October 2010).

The differences are described in FEHY reports but are shortly described here. For the tunnel the version used for the sediment spill modelling had a slightly larger spill than the August 2011 version. The tunnel alignment is also slight different (incl. different position of the access channel), thus the magnitude of pressure data basis was corrected by a minor shift of the results. For the bridge the sediment spill modelling is based on an earlier bridge version (April 2010). The sediment spill is conservative compared to the finals bridge version by a factor of about 2. The differences in alignment between the former and the final bridge are corrected by a minor shift of the results. Hydrography and water quality is based on the April 2010 version of the bridge version.

3.3 The Assessment Methodology

To ensure a uniform and transparent basis for the EIA, a general impact assessment methodology for the assessment of predictable impacts of the Fixed Link Project on the environmental factors (see box 3.1) has been prepared. The methodology is defined by the impact forecast methods described in the scoping report (Femern and LBV-SH-Lübeck 2010, section 6.4.2). In order to give more guidance and thereby support comparability, the forecast method has been further specified.

As the impact assessments cover a wide range of environs (terrestrial and marine) and environmental factors, the general methodology is further specified and in some cases modified for the assessment of the individual environmental factors (e.g. the optimal analyses for migrating birds and relatively stationary marine bottom fauna are not identical). These necessary modifications are explained in Section 3.2.2. The specification of methods and tools used in the present report are given in the following sections of Chapter 3.

3.3.1 Overview of terminology

To assist reading the background report as documentation for the German UVS/LPB and the Danish VVM, the Danish and German terms are given in the columns to the right.

Term	*Explanation*	*Term DK*	*Term DE*
Environmental factors	The environmental factors are defined in the EU EIA Directive (EU 1985) and comprise: Human beings, Fauna and flora, Soil, Water, Air, Climate, Landscape, Material assets and cultural heritage. In the sections below only the term environmental factor is used; covering all levels (factors, sub-factors, etc.; see below). The relevant level depends on the analysis.	Miljøforhold/-faktor	Schutzgut
Sub-factors	As the Fixed Link Project covers both terrestrial and marine sections, each environmental factor has been divided into three sub-factor: Marine areas, Lolland and Fehmarn (e.g. Marine waters, Water on Lolland, and Water on Fehmarn)	Sub-faktor	Teil-Schutzgut
Components	To assess the impacts on the sub-factors, a number of components and sub-components	Component/sub-	Komponente

Term	Explanation	Term DK	Term DE
and sub-components	are identified. Examples of components are e.g. Surface waters on Fehmarn, Groundwater on Fehmarn; both belonging to the sub-factor Water on Fehmarn. The sub-components are the specific indicators selected as best suitable for assessing the impacts of the Project. They may represent different characteristics of the environmental system; from specific species to biological communities or specific themes (e.g. trawl fishery, marine tourism).	komponent	
Construction phase	The period when the Project is constructed; including permanent and provisional structures. The construction is planned for 6½ years.	Anlægsfase	Bauphase
Structures	Constructions that are either a permanent elements of the Project (e.g. bridge pillar for bridge alternative and land reclamation at Lolland for tunnel alternative), or provisional structures such as work harbours and the tunnel trench.	Anlæg	Anlage
Operation phase	The period from end of construction phase until decommissioning.	Driftsfase	Betriebsphase
Permanent	Pressure and impacts lasting for the life time of the Project (until decommissioning).	Permanent	Permanent
Provisional (temporary)	Pressure and impacts predicted to be recovered within the life time of the project. The recovery time is assessed as precise as possible and is in addition related to Project phases.	Midlertidig	Temporär
Pressures	A pressure is understood as all influences deriving from the Fixed Link Project; both influences deriving from Project activities and influences originating from interactions between the environmental factors. The type of the pressure describes its relation to construction, structures or operation.	Belastning	Wirkfaktoren
Magnitude of pressure	The magnitude of pressure is described by the intensity, duration and range of the pressure. Different methods may be used to arrive at the magnitude; dependent on the type of pressure and the environmental factor to be assessed.	Belastnings-størrelse	Wirkintensität
Footprint	The footprint of the Project comprises the areas occupied by structures. It comprises two types of footprint; the permanent footprint deriving from permanent confiscation of areas to structures, land reclamation etc., and provisional footprint, which are areas, recovered after decommissioning of provisional structures. The recovery may be due to natural processes or Project aided re-establishment of the	Areal-inddragelse	Flächeninan-spruchnahme

Term	Explanation	Term DK	Term DE
	area.		
Assessment criteria and Grading	Assessment criteria are applied to grade the components of the assessment schemes. Grading is done according to a four grade scale: very high, high, medium, minor or a two grade scale: special, general. In some cases grading is not doable. Grading of magnitude of pressure and sensitivity is method dependent. Grading of importance and impairment is as far as possible done for all factors.	Vurderingskriterier og graduering	Bewertungskriterien und Einstufung
Importance	The importance is defined as the functional values to the natural environment and the landscape.	Betydning	Bedeutung
Sensitivity	The sensitivity describes the environmental factors capability to resist a pressure. Dependent on the subject assessed, the description of the sensitivity may involve intolerance, recovery and importance.	Følsomhed/ Sårbarhed	Empfindlichkeit
Impacts	The impacts of the Project are the effects on the environmental factors. Impacts are divided into Loss and Impairment.	Virkninger	Auswirkung
Loss	Loss of environmental factors is caused by permanent and provisional loss of area due to the footprint of the Project; meaning that loss may be permanent or provisional. The degree of loss is described by the intensity, the duration and if feasible, the range.	Tab af areal	Flächenverlust
Severity of loss	Severity of loss expresses the consequences of occupation of land (seabed). It is analysed by combining magnitude of the Project's footprint with importance of the environmental factor lost due to the footprint.	Omfang af tab	Schwere der Auswirkungen bei Flächenverlust
Impairment	Impairment is a change in the function of an environmental factor.	Forringelse	Funktionsbeeinträchtigung
Degree of impairment	The degree of impairments is assessed by combining magnitude of pressure and sensitivity. Different methods may be used to arrive at the degree. The degree of impairment is described by the intensity, the duration and if feasible, the range.	Omfang/grad af forringelser	Schwere der Funktionsbeeinträchtigung
Severity of impairment	Severity of impairment expresses the consequences of the Project taking the importance of the environmental factor into consideration; i.e. by combining the degree impairment with importance.	Virkningens væsentlighed	Erheblichkeit
Significance	The significance is the concluding evaluation of the impacts from the Project on the environmental factors and the ecosystem. It is an ex-		

Term	Explanation	Term DK	Term DE
	pert judgment based on the results of all analyses.		

It should be noted that in the sections below only the term environmental factor is used; covering all levels of the receptors of the pressures of the Project (factors, sub-factors, component, sub-components). The relevant level depends on the analysis and will be explained in the following methodology sections (section 3.2.3 and onwards).

3.3.2 *The Impact Assessment Scheme*

The overall goal of the assessment is to arrive at the severity of impact where impact is divided into two parts; loss and impairment (see explanation above). As stated in the scoping report, the path to arrive at the severity is different for loss and impairments. For assessment of the *severity of loss* the footprint of the project (the areas occupied) and the *importance* of the environmental factors are taken into consideration. On the other hand, the assessment of severity of impairment comprises two steps; first the *degree of impairment* considering the magnitude of pressure and the sensitivity. Subsequently the severity is assessed by combining the degree of impairment and the importance of the environmental factor. The assessment schemes are shown in Figure 3-1 - Figure 3-3. More details on the concepts and steps of the schemes are given below. As mentioned above, modification is required for some environmental factors and the exact assessment process and the tools applied vary dependent on both the type of pressure and the environmental factor analysed. As far as possible the impacts are assessed quantitatively; accompanied by a qualitative argumentation.

3.3.3 *Assessment Tools*

For the impact assessment the assessment matrices described in the scoping report have been key tools. Two sets of matrices are defined; one for the assessment of loss and one for assessment of impairment.

The matrices applied for assessments of severity of loss and degree of impairment are given in the scoping report (Table 6.4 and Table 6.5) and are shown below in Table 3-1 and Table 3-2, respectively.

Table 3-1 The matrix used for assessment of the severity of loss. The magnitude of pressure = the footprint of the Project is always considered to be very high.

Magnitude of the predicted pressure (footprint)	**Importance of the environmental factors**			
	Very high	High	Medium	Minor
Very High	**Very High**	**High**	**Medium**	**Minor**

The approach and thus the tools applied for assessment of the degree of impairment varies with the environmental factor and the pressure. For each assessment the most optimal state-of-the-art tools have been applied, involving e.g. deterministic and statistical models as well as GIS based analyses. In cases where direct analysis of causal-relationship is not feasible, the matrix based approach has been applied using one of the matrices in Table 3-2 (Table 6.5 of the scoping report) combining the grades of magnitude of pressure and grades of sensitivity. This method gives a direct grading of the degree of impairment. Using other tools to arrive at the degree of impairment, the results are subsequently graded using the impairment criteria. The specific tools applied are described in the following sections of Chapter 3.

Table 3-2 The matrices used for the matrix based assessment of the degree of impairment with two and four grade scaling, respectively

Magnitude of the predicted pressure	**Sensitivity of the environmental factors**			
	Very high	High	Medium	Minor
Very high	**General loss of function, must be substantiated for specific instances**			
High	**Very High**	**High**	**High**	**Medium**
Medium	**High**	**High**	**Medium**	**Low**
Low	**Medium**	**Medium**	**Low**	**Low**

Magnitude of the predicted pressure	**Sensitivity of the environmental factors**	
	Special	General
Very high	**General loss of function, must be substantiated for specific instances**	
High	**Very High**	**High**
Medium	**High**	**Medium**
Low	**Medium**	**Low**

To reach severity of impairment one additional matrix has been prepared, as this was not included in the scoping report. This matrix is shown in Table 3-3.

Table 3-3 The matrix used for assessment of the severity of impairment

Degree of impairment	**Importance of the environmental factors**			
	Very high	High	Medium	Minor
Very High	**Very High**	**High**	**Medium**	**Minor**
High	**High**	**High**	**Medium**	**Minor**
Medium	**Medium**	**Medium**	**Medium**	**Minor**
Low	**Minor**	**Minor**	**Minor**	**Negligible**

Degree of impairment	**Importance of the environmental factors**	
	Special	General
Very high	**Very High**	**Medium**

High	**High**	**Medium**
Medium	**Medium**	**Medium**
Low	**Minor**	**Minor**

3.3.4 *Assessment Criteria and Grading*

For the environmental assessment two sets of key criteria have been defined: Importance criteria and the Impairment criteria. The importance criteria is applied for grading the importance of an environmental factor, and the impairment criteria form the basis for grading of the impairments caused by the project. The criteria have been discussed with the authorities during the preparation of the EIA.

The impairment criteria integrate pressure, sensitivity and effect. For the impact assessment using the matrix approach, individual criteria are furthermore defined for pressures and sensitivity. The criteria were defined as part of the impact analyses (severity of loss and degree of impairment). Specific assessment criteria are developed for land and marine areas and for each environmental factor. The specific criteria applied in the present impact assessment are described in the following sections of Chapter 3 and as part of the description of the impact assessment.

The purpose of the assessment criteria is to grade according to the defined grading scales. The defined grading scales have four (very; high, Medium; minor) or two (special; general) grades. Grading of magnitude of pressure and sensitivity is method dependent, while grading of importance and impairment is as far as possible done for all factors

3.3.5 *Identifying and quantifying the pressures from the Project*

The pressures deriving from the Project are comprehensively analysed in the scoping report; including determination of the pressures, which are important to the individual environmental sub-factors (Femern and LBV SH Lübeck 2010, chapter 4 and 7). For the assessments the magnitude of the pressures is estimated.

The magnitudes of the pressures are characterised by their type, intensity, duration and range. The *type* distinguishes between pressures induced during construction, pressures from the physical structures (footprints) and pressures during operation. The pressures during construction and from provisional structures have varying duration while pressures from staying physical structure (e.g. bridge piers) and from the operation phase are permanent. Distinctions are also made between direct and indirect pressures where direct pressures are those imposed directly by the Project activities on the environmental factors while the indirect pressures are the consequences of those impacts on other environmental factors and thus express the interactions between the environmental factors.

The *intensity* evaluates the force of the pressure and is as far as possible estimated quantitatively. The *duration* determines the time span of the pressure. It is stated as relevant for the given pressure and environmental factor. Some pressures (like footprint) are permanent and do not have a finite duration. Some pressures occur in events of different duration. The *range* of the pressure defines the spatial extent. Outside of the range, the pressure is regarded as non-existing or negligible.

The magnitude of pressure is described by pressure indicators. The indicators are based on the modes of action on the environmental factor in order to achieve most optimal descriptions of pressure for the individual factors; e.g. mm deposited sediment within a certain period. As far as possible the magnitude is worked out quantitatively. The method of quantification depends on the pressure (spill from dredging, noise, vibration, etc.) and on the environmental factor to be assessed (calling for different aggregations of intensity, duration and range).

3.3.6 *Importance of the Environmental Factors*

The importance of the environmental factor is assessed for each environmental sub-factor. Some sub-factors are assessed as one unity, but in most cases the importance assessment has been broken down into components and/or sub-components to conduct a proper environmental impact assessment. Considerations about standing stocks and spatial distribution are important for some sub-factors such as birds and are in these cases incorporate in the assessment.

The assessment is based on *importance criteria* defined by the functional value of the environmental sub-factor and the legal status given by EU directives, national laws, etc. the criteria applied for the environmental sub-factor(s) treated in the present report are given in a later section.

The importance criteria are grading the importance into two or four grades (see section 3.2.4). The two grade scale is used when the four grade scale is not applicable. In a few cases such as climate, grading does not make sense. As far as possible the spatial distribution of the importance classes is shown on maps

3.3.7 *Sensitivity*

The optimal way to describe the sensitivity to a certain pressure varies between the environmental factors. To assess the sensitivity more issues may be taken into consideration such as the intolerance to the pressure and the capability to recover after impairment or a provisional loss. When deterministic models are used to assess the impairments, the sensitivity is an integrated functionality of the model.

3.3.8 *Severity of loss*

Severity of loss is assessed by combining information on magnitude of footprint, i.e. the areas occupied by the Project with the importance of the environmental factor (Figure 3-1. Loss of area is always considered to be a very high magnitude of pressure and therefore the grading of the severity of loss is determined by the importance (see Table 3-1). The loss is estimated as hectares of lost area. As far as possible the spatial distribution of the importance classes is shown on maps.

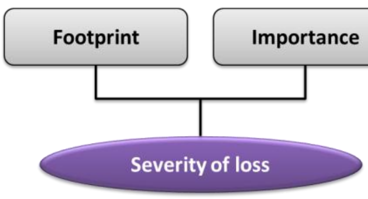


Figure 3-1 The assessment scheme for severity of loss

3.3.9 *Degree of impairment*

The degree of impairment is assessed based on the magnitude of pressure (involving intensity, duration and range) and the sensitivity of the given environmental factor (Figure 3-2). In worst case, the impairment may be so intensive that the function of the environmental factor is lost. It is then considered as loss like loss due to structures, etc.

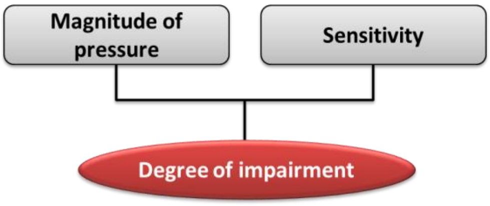


Figure 3-2 The assessment scheme for degree of impairment

As far as possible the degree is worked out quantitatively. As mentioned earlier the method of quantification depends on the environmental factor and the pressure to be assessed, and of the state-of-the-art tools available for the assessment.

No matter how the analyses of the impairment are conducted, the goal is to grade the degree of impairment using one of the defined grading scales (two or four grades). Deviations occur when it is not possible to grade the degree of impairment. The spatial distribution of the different grades of the degree of impairment is shown on maps.

3.3.10 *Severity of Impairment*

Severity of impairment is assessed from the grading's of degree of impairment and of importance of the environmental factor (Figure 3-3) using the matrix in Table 3-3. If it is not possible to grade degree of impairment and/or importance an assessment is given based on expert judgment.

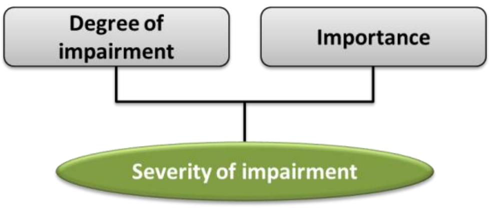


Figure 3-3. The assessment scheme for severity of impairment

In the UVS and the VVM, the results of the assessment of severity of impairment support the significance assessment. The UVS and VVM do not present the results as such.

3.3.11 *Range of impacts*

Besides illustrating the impacts on maps, the extent of the marine impacts is assessed by quantifying the areas impacted in predefined zones. The zones are shown in Figure 3-4. In addition the size of the impacted areas located in the German national waters and the German EEZ zone, respectively, as well as in the Danish national plus EEZ waters (no differentiation) are calculated. If relevant the area of transboundary impacts is also estimated.

3.3.12 *Assessment area*

The assessment area for benthic flora corresponds to the investigation area of the baseline report (FEMA 2013a). The different geographical zones are listed and described in Table 3-4, and the most important sub-regions as well as the assessment area for the tunnel and the bridge alternatives are illustrated in Figure 3-4.

Table 3-4 Geographical zones defined for spatial range of impact (section 3.1).

Name	**Definition**	**Area (ha)**	
		Tunnel	**Bridge**
Near zone	500 m around the footprint area of the alternative	2,968	2,030
Local zone	+ 10 km on both side of the alignment	38,427	39,366
DK – national + EEZ	Danish territorial waters and the Danish Exclusive Economic Zone within the assessment area	184,027	
DE – national	German territorial waters within the assessment area	169,546	
DE – EEZ	German Exclusive Economic Zone within the assessment area	48,709	
Transboundary	All areas outside DK and DE territorial and EEZ waters		

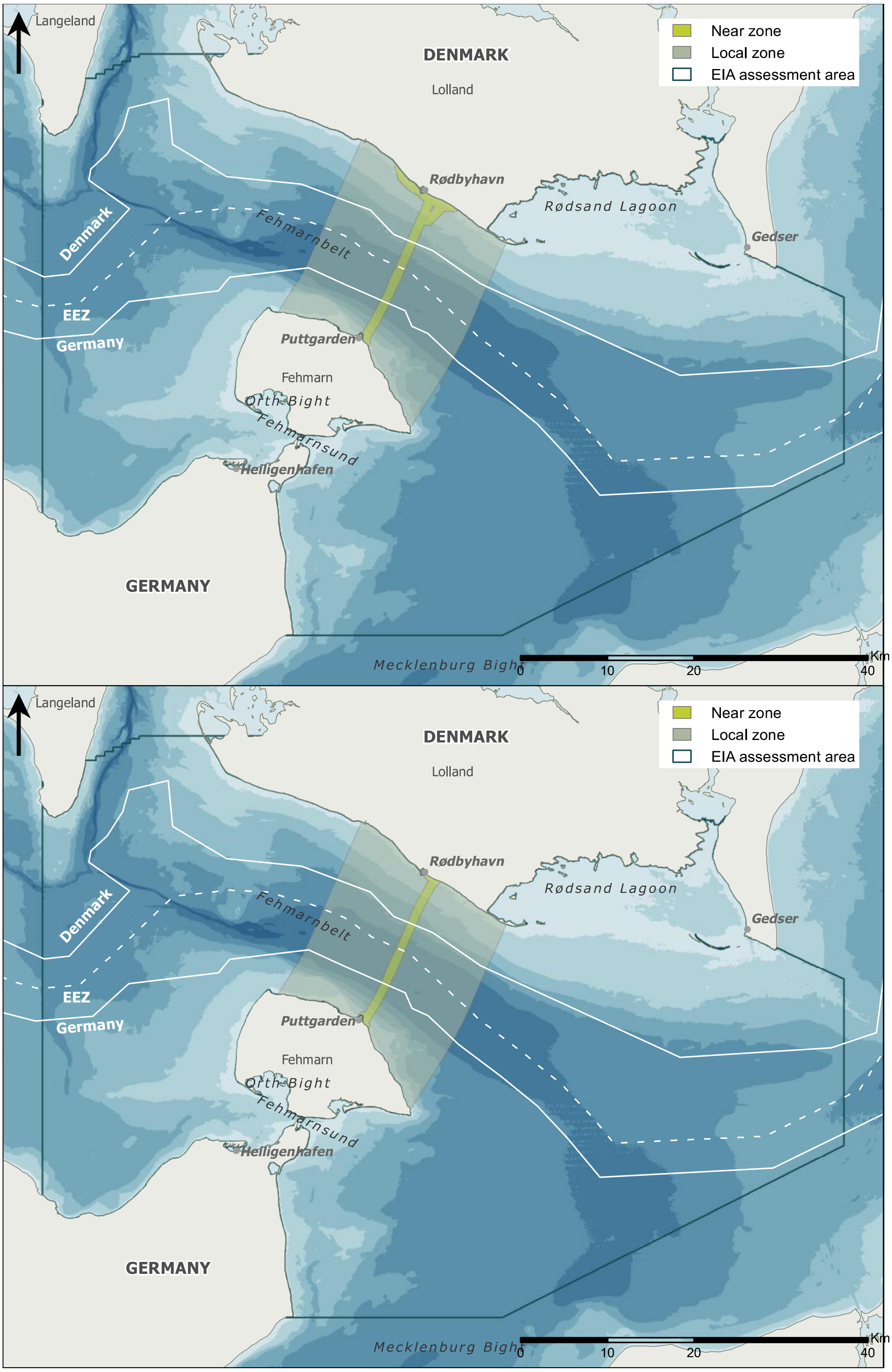


Figure 3-4 *Assessment area and defined sub-regions for the tunnel (above) and the bridge alternative (below). The near zone comprises the footprint and a surrounding 500 m band. The local zone is identical for the two alternatives. The eastern and western borders are approximately 10 km from the centre of the alignment.*

3.3.13 *Duration of impacts*

Duration of impacts (provisional loss and impairments) is assessed based on recovery time (restitution time). The recovery time is given as precise as possible; stating the expected time frame from conclusion of the pressure until pre-project conditions is restored. The recovery is also related to the phases of the project using Table 3-5 as a framework.

Table 3-5. Framework applied to relate recovery of environmental factors to the consecutive phases of the Project

Impact recovered within:	**In wording**
Construction phase+	recovered within 2 year after end of construction
Operation phase A	recovered within 10 years after end of construction
Operation phase B	recovered within 24 years after end of construction
Operation phase C	recovery takes longer or is permanent

3.3.14 *Significance*

The impact assessment is finalised with an overall assessment stating the significance of the predicted impacts. This assessment of significance is based on expert judgement. The reasoning for the conclusion on the significance is explained. Aspects such as degree and severity of impairment/severity of loss, recovery time and the importance of the environmental factor are taken into consideration.

3.3.15 *Comparison of environmental impacts from project alternatives*

Femern A/S will prepare a final recommendation of the project alternative, which from a technical, financial and environmental point of view can meet the goal of a Fehmarnbelt Fixed Link from Denmark to Germany. As an important input to the background for this recommendation, the consortia have been requested to compare the two alternatives, immersed tunnel and cable-stayed bridge, with the aim to identify the alternative having the least environmental impacts on the environment. The bored tunnel alternative is discussed in a separate report. In order to make the comparison as uniform as possible the ranking is done using a ranking system comprising the ranks: 0 meaning that it is not possible to rank the alternatives, + meaning that the alternative compared to the other alternative has a minor environmental advantage and ++ meaning that the alternative has a noticeable advantage. The ranking is made for the environmental factor or sub-factor included in the individual report (e.g. for the marine area: hydrography, benthic fauna, birds, etc.). To support the overall assessment similar analyses are sometimes made for individual pressures or components/subcomponents. It should be noticed that the ranking addresses only the differences/similarities between the two alternatives and not the degree of impacts.

3.3.16 *Cumulative impacts*

The aim of the assessment of cumulative impacts is to evaluate the extent of the environmental impact of the project in terms of intensity and geographic extent compared with the other projects in the area and the vulnerability of the area. The assessment of the cumulative conditions does not only take into account existing conditions, but also land use and activities associated with existing utilized and unutilized permits or approved plans for projects in the pipe.

When more projects within the same region affect the same environmental conditions at the same time, they are defined to have cumulative impacts. A project is relevant to include, if the project meets one or more of the following requirements:

- The project and its impacts are within the same geographical area as the fixed link
- The project affects some of the same or related environmental conditions as the fixed link
- The project results in new environmental impacts during the period from the environmental baseline studies for the fixed link were completed, which thus not is included in the baseline description
- The project has permanent impacts in its operation phase interfering with impacts from the fixed link

Based on the criteria above the following projects at sea are considered relevant to include in the assessment of cumulative impacts on different environmental conditions. All of them are offshore wind farms:

Project	**Placement**	**Present Phase**	**Possible interactions**
Arkona-Becken Südost	North East of Rügen	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
EnBW Windpark Baltic 2	South east off Kriegers Flak	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
Wikinger	North East of Rügen	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
Kriegers Flak II	Krieger's Flak	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
GEOFReE	Lübeck Bay	Construction	Sediment spill, habitat displacement, collision risk
Rødsand II	In front of Lolland's southern coast	Operation	Coastal morphology, collision risk, barrier risk

Rødsand II is included, as this project went into operation while the baseline investigations for the Fixed Link were conducted, for which reason in principle a cumulative impact cannot be excluded.

On land, the following projects are considered relevant to include:

Project	Placement	Phase	Possible cumulative impact
Extension of railway	Orehoved to Holeby	Construction	Area loss, noise and dust
		Operation	Landscape, barrier effect
Construction of emergency lane	Guldborgsund to Rødbyhavn	Construction	Area loss, noise and dust
		Operation	Landscape, barrier effect
Extension of railway	Puttgarden to Lübeck	Construction	Area loss, noise and dust
		Operation	Landscape, barrier effect
Upgrading of road to highway	Oldenburg to Puttgarden	Construction	Area loss, noise and dust
		Operation	Landscape, barrier effect

The increased traffic and resultant environmental impacts are taken into account for the environmental assessment of the fixed link in the operational phase and is thus not included in the cumulative impacts. In the event that one or more of the included projects are delayed, the environmental impact will be less than the environmental assessment shows.

For each environmental subject it has been considered if cumulative impact with the projects above is relevant.

3.3.17 *Impacts related to climate change*

The following themes are addressed in the EIA for the fixed link across Fehmarnbelt:

- Assessment of the project impact on the climate, defined with the emission of greenhouse gasses (GHG) during construction and operation
- Assessment of expected climate change impact on the project
- Assessment of the expected climate changes impact on the baseline conditions
- Assessment of cumulative effect between expected climate changes and possible project impacts on the environment
- Assessment of climate change impacts on nature, which have to be compensated, and on the compensated nature.

Changes in the global climate can be driven by natural variability and as a response to anthropogenic forcing. The most important anthropogenic force is proposed to be the emission of greenhouse gases, and hence an increasing of the concentration of greenhouse gases in the atmosphere.

Even though the lack of regulations on this issue has made the process of incorporating the climate change into the EIA difficult, Femern A/S has defined the following framework for assessment of importance of climate change to the environmental assessments made:

- The importance of climate change is considered in relation to possible impacts caused by the permanent physical structures and by the operation of the fixed link.
- The assessment of project related impacts on the marine hydrodynamics, including the water flow through the Fehmarnbelt and thus the water exchange of the Baltic Sea, is based on numerical model simulations, for baseline and the project case, combined with general model results for the Baltic Sea and climate change.
- Possible consequences of climate change for water birds are analysed through climatic niche models. A large-scale statistical modelling approach is applied using available data on the climatic and environmental factors determining the non-breeding distributions at sea of the relevant waterbirds in Northern European waters.
- The possible implications of climate change for marine benthic flora and fauna, fish, marine mammals, terrestrial and freshwater flora and fauna, coastal morphology and surface and ground water are addressed in a more qualitative manner based on literature and the outcome of the hydrodynamic and ecological modelling.
- Concerning human beings, soil (apart from coastal morphology), air, landscape, material assets and the cultural heritage, the implications of climate changes for the project related impacts are considered less relevant and are therefore not specifically addressed in the EIA.

The specific issues have been addressed in the relevant background reports.

3.3.18 *How to handle mitigation and compensation issues*

A significant part of the purpose of an EIA is to optimize the environmental aspects of the project applied for, within the legal, technical and economic framework. The optimization occurs even before the environmental assessment has been finalized and the project, which forms the basis for the present environmental assessment, is improved environmentally compared to the original design. The environmental impacts, which are assessed in the final environmental assessment, are therefore the residual environmental impacts that have already been substantially reduced.

Similarly, a statement of the compensation measures that will be needed to compensate for the loss and degradation of nature that cannot be averted shall be prepared. Compensating measures shall not be described in the impact assessment of the individual components and are therefore not treated in the background reports, but will be clarified in the Danish EIA and the German LBP (Landschaftspflegerischer Begleitplan), respectively.

In the background reports, the most important remediation measures which are included in the final project and are of relevance to the assessed subject are mentioned. In addition additional proposals that are simple to implement are presented.

3.4 Magnitude of pressure

The magnitude of pressure in general is defined by type, intensity, duration and range of each pressure and represents the abiotic component, which causes the impact on the environmental component.

Type describes the project-phase to which a pressure is related and can be divided into construction-, structure- and operation-related types.

Intensity describes the amount = the unit/dimension of the pressure, which can be measured (e.g. thickness of deposited sediment layer, reduction in light intensity, number of construction vessels, etc.)

Duration describes the period, in which the pressure affects the environment. To assess the duration of an impact a time scale with several periods was developed for the EIA assessment (section 3.2). The time periods are listed inTable 3-5. They are referring to the duration of the pressure + recovery time for community.

Range describes the spatial extent, in which the pressure affects the environment. To assess the range of an impact a spatial scale with several geographic zones (near zone, local zone, etc.) was developed for the EIA assessment. The zones are listed in chapter 3.3.12, Table 3-4.

3.5 Sensitivity

Sensitivity is dependent on the intolerance of a habitat, community or species to a pressure from an external factor and the time necessary for its subsequent recovery (Marine Life Information Network, MarLIN).

Intolerance is the susceptibility of a habitat, community or species to damage (reduced viability) from an external factor. The higher the intolerance the higher is the sensitivity for the community or species. Intolerance depends on the physiological capability to balance the pressure-specific impacts. Intolerance has to be defined per pressure and community (species).

Recovery time is the time span necessary for a habitat, community or species to return to a state close to the one before the activity or event, which caused the impact, started. The longer the recovery time the higher the sensitivity for the community or species. Recovery time depends on the particular life cycle strategies and traits (e.g. reproduction mode, fecundity, dispersal capability) and has to be defined species or community specific. It is independent of the pressure.

Different methods are used to define the community specific levels of sensitivity:

Suspended sediment
The impact of suspended sediment on benthic flora is assessed using dynamical modelling. Intolerance to a pressure and recovery are integrated functionalities of the dynamic model describing the response of benthic flora to

increased concentrations of suspended sediment. Intolerance is characterised by the light requirements of species or communities and recovery by the result of the balance between production and mortality following the release of the pressure.

Sedimentation
The communities (sub-component) are classified into four levels with regard to intolerance and recovery time (very high, high, medium, minor) using literature data and expert judgement.

Afterwards, both aspects of sensitivity were combined to determine the sensitivity of a community/species (Table 3-6). The relation between intolerance and recovery time can vary between pressures and is not linear.

At low magnitude of pressure for sedimentation, for example, benthic flora may be impacted by a reduced growth, but mortality is unlikely to occur. Under such circumstances, intolerance has the decisive influence on sensitivity. At high magnitude of pressure mortality will more likely occur and then the recovery time is much more decisive for the sensitivity than intolerance.

As the magnitude of pressure analyses (e.g. spill scenarios) showed that the communities are mostly exposed to low magnitude of pressures, intolerance is in general weighted higher than recovery in the sensitivity matrix, even for long recovery times (very high and high recovery).

Table 3-6 Linking matrix to assess the sensitivity based on the two aspects recovery time and intolerance.

Sensitivity		**Intolerance**			
		Very high	High	Medium	Minor
Recovery time	Very high	Very high	Very high	High	Medium
	High	Very high	High	Medium	Minor
	Medium	Medium	Medium	Medium	Minor
	Minor	Minor	Minor	Minor	Minor

Solid substrate

In general, sensitivity is not an appropriate term in connection with solid substrate as the main effect is new areas of benthic flora communities. Thus, benthic flora is not sensitive in terms of showing intolerance towards solid substrate. But not all kinds of solid substrates have the same potential as settling ground for macroalgae.

3.6 Assessment criteria

The general assessment criteria for the different pressures are listed in Table 3-7. Specific criteria are used for the pressures suspended sediment and sedimentation. These are described in Chapters 3.7.1 and 3.7.2.

Table 3-7 Catalogue of assessment criteria for benthic flora. Regional is defined as potentially going beyond the local zone.

Pressure	Description of assessment criteria for impact prediction	Duration	Possible Range	Impact intensity
Suspended sediment (construction-related)	High to very high reduction in biomass	Temporary	Regional	Very high
	Medium to high reduction in biomass	Temporary	Regional	High
	Minor to medium reduction in biomass	Temporary	Regional	Medium
	Negligible to minor reduction in biomass	Temporary	Regional	Minor
Sedimentation (construction-related)	High to very high reduction in growth Increased mortality in relation to mean plant height and high to very high sedimentation thickness Reduction in recruitment area compared to other criteria negligible	Temporary	Regional	Very high
	Medium to high reduction in growth Increased mortality in relation to mean plant height and medium to high sedimentation thickness Reduction in recruitment area compared to other criteria negligible	Temporary	Regional	High
	Minor to medium reduction in growth Increased mortality in relation to mean plant height and minor to medium sedimentation thickness Reduction in recruitment area compared to other criteria negligible	Temporary	Regional	Medium
	Reduction of recruitment area for macroalgae caused by coverage of hard substrates	Temporary	Regional	Minor
Nutrients and Toxic substances (construction-related)	Case-by-case criteria on basis of nutrient and substance concentrations in sediments, literature data and the natural variability of concentrations in the water column	Temporary	Near to regional zone	Case-by-case related
Construction vessels and imported mate-	Case-by-case, qualitative criteria on basis of available data	Case–by-case temporary or per-	Local to regional	Case-by-case related

Pressure	Description of assessment criteria for impact prediction	Duration	Possible Range	Impact intensity
rial (construction-related)		manent		
Footprint (structure-related)	Habitat loss. Criteria correspond to the importance levels of the different communities	Permanent or temporary	Near zone	Very high
Solid substrate (structure-related)	Case-by-case, qualitative criteria on the relation between new artificial substrate and the available hard substrate area	Permanent	Near zone	Case-by-case related
Hydrological regime and water quality (structure-related)	Case-by-case, qualitative criteria on basis of available data	Permanent	Regional	Case-by-case related
Seabed and coastal morphology (structure-related)	Habitat loss. Criteria correspond to the importance levels of the different communities	Permanent or temporary	Local	Very high
Drainage (operation-related)	Case-by-case, qualitative criteria on basis of available data	Permanent	Local	Case-by-case related

3.7 Degree of impairment

The degree of impairment has been assessed by linking the magnitude of pressure with sensitivity. The analytical methods used to link magnitude with sensitivity differ between pressures (Table 3-8). For some pressures, the magnitude of pressure is very limited for both alternatives. These pressures are described in Chapter 4. Degree of impairment has not been determined for these pressures.

Table 3-8 Overview table of methods used to assess the degree of impairment.

Pressure	Assessment methods
Suspended sediment	Modelling of reduction of benthic flora biomass; based on FEHY modelled sediment spill, resulting light reduction and the light response of benthic flora growth
Sedimentation	GIS analysis using matrix combining magnitude of sedimentation and sensitivity of benthic flora to sedimentation
Solid substrate	Calculation of biomass of potential new hard bottom communities; based on area of new substrate estimated from technical drawings

3.7.1 *Suspended sediment*

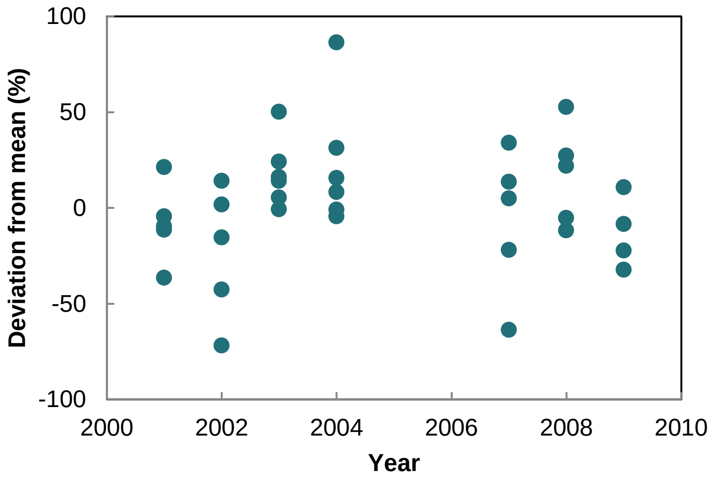
Benthic flora, at this latitude, has its main growth season between March and September. In this period light and temperature is most optimal and the plants produce the main part of the yearly new biomass. Within this period, reduced growth in periods with reduced light availability can be counterbalanced by growth in periods with sufficient light availability. The relevant measure of impairment is therefore not a short-term reduction in biomass production but rather the integrated effect during a whole growth season.

The degree of impairment for suspended sediment is described by the reduction in above ground biomass at the end of the growth season compared to the reference biomass without sediment spill.

An analysis of the natural variability in above ground biomass for Fehmarnbelt and Øresund was used to define the lower limit of impairment as well as the thresholds for the degree of impairment levels.

Natural variability
Long time series of benthic flora biomass data from the Fehmarnbelt area that could allow a thorough analysis of the year-to-year variability in biomass does not exist. However, in connection with monitoring after construction of the Nysted wind farm and at sites included in the German monitoring program macroalgal biomass was at 10 sites measured for 3 or 4 years. The yearly deviation from the mean of the 3-4 years (deviation year n = ABS(1-($Biomass_{year\ n}$ /$Biomass_{mean\ of\ 3\ or\ 4\ years}$))) was on average ±22% (Figure 3-5).

In addition, eelgrass above ground biomass was measured at 54 sites for 4 years in connection with the authorities monitoring program for the fixed link across Øresund. Using all data the yearly deviation from the mean of the 4 years was on average ±40% (Figure 3-5). Some data was collected during the construction of the fixed link and it may therefore not be optimal to include these data, although it was shown that there was no impact during construction. Using only data from control sites resulted in similar high mean yearly deviation, of ±49%. If additionally, data from sites with large year-to-year variability was excluded (e.g. biomass first year but no biomass the following three years), the mean yearly deviation was ±36%. Due to the different conditions in the areas the Øresund data was only used as a guidance to the identification of a possible general year-to-year variability in eelgrass populations. Taking a precausional approach, the natural year-to-year variability in benthic vegetation biomass (macroalgae and eelgrass) is in this study was estimated to be 10-25%.



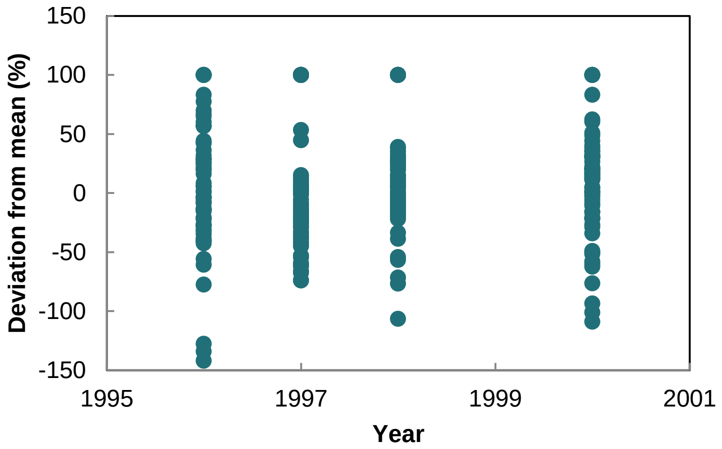


Figure 3-5 Natural variability, expressed as deviation from mean of 3-4 years, in macroalgal community biomass in Fehmarnbelt area (upper) and in eelgrass above ground biomass in Øresund (lower)

Natural variability in biomass depends on the species and the depth of the vegetation. Biomass of long-lived perennial species with a long-lived thallus like *Furcellaria* probably is less variable than ephemeral species with high growth rates.

Biomass in shallow water populations is likely to be variable over time because of physical disturbance by waves, currents and ice. Examples show that shallow eelgrass populations may disappear almost entirely following harsh winters with thick ice-cover or ice-scouring but under favourable conditions they can rapidly recover from survived shoots or dense seed stocks buried in the sediments. Similar variability does not occur in deeper water where physical disturbance is rare and light is the primary determinant factor. On the other hand, deep-growing populations will recover more slowly than shallow population as light limitation restrict the formation of new shoots and seed densities are small. Accordingly, depth should be an important factor for year-to-year stability in the presence and biomass of benthic vegetation.

The limited data on year-to-year variability does not allow determination of separate thresholds for species or depths, thus the assessment criteria thresholds for degree of impairment are the same for all communities and depths.

Table 3-9 shows the criteria for scaling the degree of impairment for the pressure suspended sediment on benthic flora. The thresholds for degree of impairment are defined for a decrease in above ground biomass at the end of the growth season assuming a natural year-to-year variability of 10-25%.

No impairment is determined as 10% or less reduction in biomass at the end of the growth season. This level is considerably below the natural variability and even in years when photosynthesis and growth are naturally reduced, the function of the communities is not affected.

Table 3-9 Grades of degree of impairment used in the assessment of impacts on benthic flora due to suspended sediment from sediment spill.

Grades of degree of impairment	**Reduction in above ground biomass at end of growth season**	**Reasoning**
Very high	> 75-100%	Even in in years with otherwise favourable conditions a reduction in biomass of this size may affect the primary production, and the structure and function of the habitat. Low biomass is present to survive the winter and produce spores for maintaining the populations. The loss of biomass may result in some fragmentation of the habitat and associated communities of epifauna, infauna or fish may be disturbed.
High	> 50-75%	Even in in years with otherwise favourable conditions a reduction in biomass of this size may influence the primary production, and the structure and function of the habitat. Less biomass is present to survive the winter and produce spores for maintaining the populations. The loss of biomass may result in some fragmentation of the habitat and associated communities of epifauna, infauna or fish may be disturbed.
Medium	> 25-50%	Reduction of this size is 0-25% above average level of natural variability. In average years the impact may be minor but under unfavourable circumstances where both natural variability will reduce the seasonal production and the suspended sediment concentrations will further deteriorate the conditions the resulting reduction in biomass may be larger.
Minor	> 10-25%	Within the level of average natural variability

Assessment method - Modelling approach

The degree of impairment is assessed by dynamic modelling using an ecological model calibrated for the Fehmarnbelt area. The key feature of suspended sediment affecting the flora is light availability. The three-dimensional eutrophication model reads the result files (concentrations of suspended sediment) from the sediment spill modelling. The suspended sediment concentration is simulated throughout the dredging period 2014-2019 and the hydrographical/meteorological forcing for each year is 2005 which represent a typical year. Light availability caused by increased concentrations of suspended sediment is modelled using a dynamic MIKE 3FM – ECO Lab model system. The driving hydrodynamic model is the MIKE 3FM (FEHY 2013a, whereas the ecological model is developed in the ECOLab model system). The ECOLab model is a differential equation solver (like MATLAB™) making it possible to define the ecosystem exactly to the degree of complexity required and still be able to transport and disperse material and substances in a highly accurate manner. A short description of the model is given below and a more detailed description is available in Appendix A. For convenience, the model is referred to as the FEMA model.

The predicted incremental suspended sediment concentration is transferred to the calculation of the light penetration through the water column, resulting in changes in the light conditions for the primary production in the model in each grid point, model layer and time step, so that the effect on macroalgae and eelgrass due to the dredging works is predicted.

The overall existing macroalgae and eelgrass formulation in ECOLab was adopted but photosynthetic production and the dependence on light availability were adjusted to represent species groups in the Fehmarnbelt based on literature and controlled laboratory experiments using specimens from the Fehmarnbelt (See Appendix E).

The model simulates above-ground biomass of four model species exemplified by the species *Furcellaria*, *Delesseria*, *Ceramium* and eelgrass. These species are key-species of benthic flora in the Fehmarnbelt area and represent different substrates (soft and hard bottom) and dominant form-functional groups within the hard bottom flora:

- Flowering plants (model species is eelgrass) on soft bottoms, growing in shallow water because of high light requirements and take up nutrients both from the sediment pore water and from water

- Filamentous macroalgae (model species is *Ceramium virgatum*) with high light requirements and most abundant in shallow water

- Coarsely branched macroalgae (model species is *Furcellaria lumbricalis*) having intermediate light requirements and living in the depth range 2 to 8-10m

- Coarsely branched folious macroalgae (model species is *Delesseria sanguinea*) having the lowest light requirements and living in the depth range 8-19 m

All three macroalgal groups require presence of hard substrate on seabed.

Growth and biomass fate in the model

Benthic flora is quantified in terms of areal biomass (e.g. g C m^{-2}). In their whole life stage benthic flora, remain fixed at the *bottom*. Loss occurs by sloughing of aged leaves (e.g. in eelgrass), by respiration (C and nutrients returned to inorganic pools) and by loss to the detritus pool.

The relationship between growth (or photosynthetic production) and irradiance (P-I relationship) describe the light requirements of a species or community. Light requirements differ between the four groups and light requirements increase with biomass density of the community.

Besides light, nutrient requirements, source of nutrients (water and pore water) and substrate are the main factors that differentiate the groups in the model.

While macroalgae only take up nutrients from the water compartment, flowering plant also take up nutrients from the upper sediment layer. The stoichiometric composition of the macrophytes remains constant (fixed ratios between nitrogen, phosphorous and carbon) and growth and nutrient uptake rates are linearly dependent.

Hard substrate is essential for colonisation of macroalgae while flowering plants only grow on soft bottom.

Sub-optimal conditions in any limiting factor will result in growth rates below the maximum. The joint dependence of nutrients, temperature and light is defined by separate growth limiting factors, that range from 0 to 1, where a value of 1 means the factor does not limit growth (i.e. light is at optimum intensity, nutrients are available in excess, etc.). The limiting factors are then combined with a maximum growth rate at a reference temperature.

The fate of macrophyte production differs between groups. Overall, flowering plants can be grazed e.g. by swans, and leaves can be shed as part of aging process and later decayed. When algal tissue die nutrients are released; either directly to the water column or by decomposition of settled dead tissue fragments.

The death rate of flowering plants is described as a function of water depth, bottom water oxygen saturation and the sulphide front in the sediment. The death rate of macroalgae is described as a function of water depth, bottom water saturation and nutrient limitation. The water depth is included to describe the physical stress on leaves due to waves.

Initially, the flowering plants and macroalgae are allowed to grow everywhere although being restricted by requirements to light, sediment quality, nutrients etc. After a model warm-up period they sustain only where sediment conditions (hard and soft substrate, low H_2S in sediments, adequate nutrient conc. in pore water) and light conditions are appropriate. Distribution and biomass of macroalgae and flowering plants are thereby intrinsic model outputs.

Model calibration results are shown in Appendix A.

Although many limiting factors are included in the model, there are still a number of limiting factors that are not included. The model area extension of the modelled benthic flora should therefore be larger than the area actually occupied. This was the case as the model predicted occurrences of macroalgae and flowering plants outside the area where they were found during the baseline mapping (FEMA 2013a). For the impact assessment of sediment spill, these areas were excluded (based on the baseline mapping of macroalgae and flowering plant communities) in the model output prior to estimates of the impacts on area distribution of biomass reduction.

Use of model data in impact assessment

The biomass at the end of the growth season is modelled for all years of the construction phases for the tunnel and the bridge solution, respectively. Each year the biomass is an integrated response of any reduction of light due to sediment spill and recovery. The relative difference to the modelled reference biomass (no sediment spill) is used in the assessment.

The model is used to predict relative reductions (%) in biomass at end of the growth season. Any subsequent calculations in absolute biomass values should use as basis the benthic flora biomass map (FEMA 2013a).

The assessment on community level is based on the modelled reduction in the total biomass of the four representative species included in the model (macroalgae (three macroalgae species) or flowering plants (eelgrass)) and the geographical distribution of the macroalgae or flowering plant community they represent (defined in the baseline study; FEMA 2013a). Thus, the modelled reduction in biomass is overlaid by the community map to determine the areas impacted for each flora community.

3.7.2 *Sedimentation*

Sedimentation with a certain persistence will impact the benthic flora communities at different degree depending on the magnitude of the pressure and the sensitivity of the key-species of the communities.

The degree of impairment is assessed by linking the sensitivity with the magnitude of pressure following the linking matrix of the scoping report (Femern and LBV-SH-Lübeck 2010), listed in Table 3-10. The higher the sensitivity and the higher the magnitude of pressure the higher the resulting degree of impairment.

For very high magnitude of pressure a loss of the community or the ecological function of the community is expected. The aspect sensitivity cannot be used in connection with loss, as obviously the sensitivity of all biological components is very high towards loss. In such cases the importance of the community is relevant and the severity of loss instead of degree of impairments are to be assessed (see chapter 3.8.1).

Table 3-10 Linking matrix to assess the degree of impairment.

Magnitude of pressure	**Sensitivity** of benthic vegetation			
	Very high	High	Medium	Minor
Very high	Loss of function, see chapter 3.8.1			
High	Very high	High	High	Medium
Medium	High	High	Medium	Minor
Minor	Medium	Medium	Minor	Minor

Quantitative relationships between sedimentation (thickness and duration) and mortality or reduced recruitment of benthic flora are few or they are not reported. Therefore, the assessment of grades of impairment is founded on qualitative expert judgments.

Table 3-11 show the criteria for grading degree of impairment for the pressure sedimentation on benthic flora.

Table 3-11 Grades of degree of impairment used in the assessment due to sedimentation.

Grades of degree of impairment	Increase in mortality/reduced growth/reduction in recruitment area
Very high	High to very high reduction in growth
	Increased mortality in relation to mean plant height and high to very high sedimentation thickness
	Reduction in recruitment area compared to other criteria negligible
High	Medium to high reduction in growth
	Increased mortality in relation to mean plant height and medium to high sedimentation thickness
	Reduction in recruitment area compared to other criteria negligible
Medium	Minor to medium reduction in growth
	Increased mortality in relation to mean plant height and minor to medium sedimentation thickness
	Reduction in recruitment area compared to other criteria negligible
Minor	Reduction of recruitment area for macroalgae caused by coverage of hard substrates

To assess the degree of impairment for sedimentation a GIS approach is used. The magnitude of pressure layer, which is the result of the magnitude of pressure analysis for sedimentation, is overlaid with the sensitivity layer, which is the result of the sensitivity analysis for sedimentation. The degree of impairment is then assessed by using the standard matrix shown in Table 3-11.

3.7.3 *Solid substrate*

This pressure primarily causes a positive impact. Criteria for grading the degree of impairment could not be developed and the degree of impairment is therefore assessed by calculating the area of new hard substrate and the possible increase of algal biomass due to colonisation of this substrate.

The areas of new solid substrate are calculated based on a number of technical drawings and divided in to vertical structures (piers and pylons) and horizontal structures (scour protection). As benthic flora show a vertical pattern of reduced biomass with depth, the new solid substrates were divided into 1 m layers up to a depth of 20 m. Below 20 m no substantial growth of algae is expected.

A possible negative effect of increased risk of introducing new species is discussed based on expert knowledge and literature.

3.7.4 *Other pressures*

Changes in toxic substances, nutrients, hydrographical regime and water quality (incl. drainage water) as well as seabed (tunnel) and coastal (bridge) morphology have been considered as potential pressures to benthic flora. The magnitude of pressures is however so low (see chapter 4) that a risk of impairment can be excluded (i.e. is below the lower limit of a possible minor degree of impairment and fall within the natural variability).

3.8 *Assessment of severity*

3.8.1 *Severity of loss*

The severity of loss is assessed, if benthic flora is affected by habitat loss or by loss of function. The severity of loss depends on the importance of a community. The rationale is that loss of a very high important community is more severe than loss of a community of minor importance.

The magnitude of pressure is by definition always "very high" for loss. Therefore the level of severity corresponds to the level of importance resulting in the linking matrix of the scoping report (Femern and LBV-SH-Lübeck 2010), listed in Table 3-12.

Table 3-12 Linking matrix to assess the severity of loss.

Magnitude of pressure	**Importance** of benthic vegetation			
	Very high	High	Medium	Minor
Very high	Very high	High	Medium	Minor

3.8.2 *Severity of impairment*

Similarly to the loss, impairment of community of very high importance is more severe than impairment of a community of minor importance. Therefore the severity of impairment is assessed by linking the importance of the flora communities with the degree of impairment following the linking matrix given in in Table 3-13. The higher importance of a community and the higher the degree of impairment, the higher is the resulting severity of impairment.

Table 3-13 Linking matrix to assess the severity of impairment.

Degree of impairment	**Importance** of benthic vegetation			
	Very high	High	Medium	Minor
Very high	Very high	High	Medium	Minor
High	High	High	Medium	Minor
Medium	Medium	Medium	Medium	Minor
Minor	Minor	Minor	Minor	Negligible

3.9 *Significance*

The assessment of significance is the last step in the EIA process with the purpose to evaluate the overall impact of the project on the benthic flora. The assessed severity of loss and impairment combined with the other knowledge collected form the basis of this evaluation.

The main function of benthic flora for coastal ecosystem is its role as providing a three-dimensional habitat. This habitat function differs on community level as described for the individual communities and considered when defining the importance of vegetation components (section 1.3, FEMA 2013a). Therefore, significance has to be assessed on community (sub-component) level and the impacted area (loss and/or impairment) is the decisive criteria for significance.

For each community, the impacted area is related to the total area of the community in an area equivalent to the near zone plus local zone; here named the Fehmarnbelt. This means that overall a 20 km corridor is the reference for the significance calculation. If the loss or impairment extends beyond that reference area, the complete EIA assessment area constitutes the reference instead. The areas (in ha) occupied by the flora communities were calculated and used as reference areas (Table 3-14).

The significance assessment is then carried out in a stepwise sequence with the following criteria:

If the impacted area per community is below 1% of the reference area, the impact is always insignificant (regardless of the duration and recovery time). This 1% rule is adopted from the strict objectives for habitat loss/impairment of Natura 2000 areas and their protected habitats (Lambrecht and Traudtner 2007). Of course, only a limited part of the impacted areas represents such valuable habitats, which are protected in the habitat directive. The 1% criteria is therefore only used to screen out all minor impacts with no significance to ecological function, but not to define which impacts are significant. For areas ≥ 1 % further decision steps are necessary:

If the impacted area is ≥ 1%, the duration of the impact (recovery time of community + recovery time for seabed or other physical factors) is taken into account. If the community is recovered within two years after end of construction (named "construction phase +"), the impact is regarded as insignificant.

If the area is ≥ 1% and the community recovers later (operation phases A, B, or C) an expert judgement is made, taking into consideration:

- level of severity of impact
- data showing the actual magnitude of the pressure
- ecological relevance of the impacted community on a regional scale

Table 3-14 Areas (ha) of benthic vegetation communities in the defined reference areas. Basis for the calculation is the benthic vegetation community map (section 1.2). Fehmarnbelt is equivalent to near zone + local zone.

Benthic flora community	Fehmarnbelt	Assessment area
Eelgrass	-	12057
Eelgrass/algae	25	2426
Filamentous algae	1544	7185
Fucus	74	589
Furcellaria	2364	3937
Phycodrys/ Delesseria	703	3064
Saccharina	778	1203
Tasselweed/ dwarf eelgrass	-	1802
Total	5488	32253
Single vegetation stands (1–10 % cover)	8732	117610
Total (with single stands)	14220	149874

3.10 Confidence/evidence

In general, the confidence in the assessment depends on the quality and robustness of the baseline data ad on available evidence for the effect of a pressure on species or communities.

The baseline investigations for benthic flora conducted in 2009–2010 provided good quality and robust baseline data for all assessments.

The confidence can be graded into three levels:

The level of confidence is high, if relationships relating to the pressure indicator (e.g. reduced light availability) to the function of the community (e.g. photosynthesis) in general are well understood and documented.

The level of confidence is moderate if the impact of a pressure is assessed by inferring/extrapolating from the effect of similar pressures or related species. Or if the pressure is very low and expert judgement has been used to assess the impact.

The level of confidence is low if the assessment is based on information on biological characters (e.g. life history, size and functional forms) of the species.

Table 3-15 Overview of confidence of impact assessments.

Pressure	Level of confidence	Comment
Suspended sediment	High	Sensitivity based on dose response relationships from the literature and experiments
Sedimentation	Low	Sensitivity defined based expert judgment considering the size and robustness of the benthic vegetation as well as the level of natural sedimentation in their specific environments.
Nutrients from spilled sediment	High	General well documented relationships between nutrients and response of benthic flora. Pressure low.
Toxic substances	High	Based on EQA
Construction vessels and imported material	Moderate	Expert judgement. Pressure low.
Footprint	High/ moderate	Loss high / recovery for temporary footprints moderate
Solid substrate	Moderate	Areas well know. Based on biomass-depth relationships from natural habitats.
Hydrographical regime and water quality	Moderate	Expert judgement. Pressure low.
Seabed and coastal morphology	Moderate	Expert judgement. Pressure low.
Drainage	Moderate	Expert judgement. Pressure low.

4 MAGNITUDE OF PRESSURE ANALYSIS

The magnitude of pressure is analyzed using different indicators, which are relevant to the flora. An overview of the indicators and methods used to estimate the magnitude of pressure is given in Table 4-1.

Table 4-1 Overview of pressure indicators and analytical methods.

Pressure	Pressure indicator	Method
Suspended sediment	Light reduction at the bottom (% reduction)	Light reduction was modelled based on sediment spill data from (FEHY 2013a).
Sedimentation	Sedimentation (cm) for a duration of 10 days or more	Post processing of sedimentation data from the dynamic sediment spill modelling (FEHY 2013c)
Nutrients from spilled sediment	Release of nutrients in water	Expert judgement based on quantifications and assessments with regard to plankton in (FEHY 2013e).
Toxic substances	Toxic substance concentration of spilled sediments	Expert judgement based on quantifications and assessments with regard to deposited sediment in (FEHY 2013e) and water quality and plankton in (FEMA 2013b).
Construction vessels and imported material	Transportation between port of loading/excavation area and alignment and number/amount of vessels/imported material	Expert judgement and literature data
Footprint	Structure- and construction-related footprint area (ha)	GIS shapes produced from technical drawings
Solid substrate	Areas (m^2) of new solid substrate in depth intervals	Areas calculated from technical drawings
Hydrographical regime and water quality	Changes in salinity, temperature, near bed currents and water quality parameter	Modelled changes in hydrographical regime and water quality (FEHY 2013a)
Seabed and coastal morphology	Changes in erosion and sedimentation areas	GIS shapes produced from seabed and coastal morphology assessment data (FEHY 2013b, d)
Drainage	Type and amount of drainage	Expert judgement based on water quality assessment (FEHY 2013a and FEMA 2013b)

For some of the pressures the magnitude is so limited in intensity, duration and range that the magnitude of pressure is below minor (e.g. below natural variability) and impacts on the flora can be excluded. The below minor magnitude of those pressures are documented in this section. As the impact is obviously negligible (below detection limit), no further assessment is conducted.

4.1 Suspended sediment

During the construction phase sediment will be spilled due to dredging and backfilling activities (e.g. dredging of working harbours or tunnel trench and backfilling at bridge pylons or tunnel trench). The sediment spill is dispersed to the surrounding areas by currents and may, after sedimentation, be re-suspended by waves and currents.

Table 4-2 and Table 4-3 list the activities and amounts, which may cause contributions to the sediment spill for the tunnel and the bridge construction, respectively (FEHY 2013c).

Table 4-2 Description of construction activities for the tunnel, which might contribute to the sediment spill.

Activity	Amount (m^3)	Remarks
Excavation of the tunnel trench	14,490,000	Main contribution for spill, but a dredging plan ensures a step wise appearance of spill
Excavation of the temporary work harbours and access channels	4,010,000	
Excavation of portal and ramp areas (Lolland and Fehmarn)	120,000 125,000	Spill minimized by temporary dikes
Cleaning of tunnel trench		Only necessary if there is a time gap between tunnel dredging and lowering of tunnel elements
Backfilling of dredged material for reclamation areas (Lolland and Fehmarn)	20,810,000 495,000	Spill minimized by temporary dikes
Filling of a gravel/rock bedding layer below the tunnel elements		Low contribution to sediment spill due to large grain sizes
Filling of a gravel/rock locking layer on both sides of the tunnel elements for anchoring and stabilisation of elements		Low contribution to sediment spill due to large grain sizes
Filling of clay till/sand general fill on both sides of the tunnel elements	800,000	
Filling of a rock protection layer on top of the tunnel elements of 1.2 m height to provide protection from grounded ships or falling anchors		Low contribution to sediment spill due to large grain sizes

Table 4-3 Description of construction activities for the bridge, which might contribute to the sediment spill.

Activity	Amount (m^3)	Remarks
Excavation of peninsulas and caissons for piers and pylons	737,000	A dredge plan ensures the step wise appearance of spill
Excavation of the temporary work harbours and access channels (Lolland and Fehmarn)	380,200 260,000	
Backfilling of dredged material for reclamation peninsulas (Lolland and Fehmarn)	0 180,000	Spill minimized by temporary dikes
Backfilling for piers and pylons	280,900 m^3	
Backfilling of dredged material for work harbours and access channels (Lolland and Fehmarn)	380,000 260,000	Spill might be minimized by temporary dikes

To the flora, a key consequence of suspended sediment spilled during dredging is the reduction in light availability at bottom caused by the absorption and scattering of light by the suspended particles. Thus, the pressure indicator is the changes in light availability caused by sediment spill.

Benthic flora, at this latitude, has its main growth season between March and September. In this period light and temperature is most optimal and the plants produce the main part of the yearly new biomass. Within this period, reduced growth in periods with reduced light availability can be counterbalanced by growth in periods with sufficient light availability. The relevant description is therefore not the short-term reduction in light but rather the integrated reduction in light during a whole growth season.

Naturally, seawater contains suspended sediments. Median values of naturally occurring suspended sediment concentrations ranged between 1.3 and 5.3 mg L^{-1} at 14 measurements at nearshore stations (3-12 m depth) measured 2 - 5.8 m above the seabed along the Danish and German coasts (not including Rødsand Lagoon, FEHY 2013e). At two stations in Rødsand Lagoon median values were 2.5 and 5.4 mg L^{-1}. Measurements of natural concentrations of suspended sediment are not available for the bottom layer.

Sediment in the whole water column contributes to the light attenuation but sediment concentrations are highest in the bottom layer due to continuous resuspension of the spilled sediment, especially near the coast. An example for the first year of the tunnel construction is shown in Figure 4-1. In 2015, the concentration of sediment spilled during the construction work is very high especially in the bottom layers Average sediment concentrations in the bottom layer during the growth season (1/3 – 1/9) are between 8-16 and 32-50 mg L^{-1} along the Lolland coast and up to 8-16 mg L^{-1} in Rødsand Lagoon. Along the coast of Fehmarn sediment spill is much smaller and concentrated in the lower layers near the bottom. More details on the sediment spill in other years and for the bridge are described in (FEHY 2010, FEHY 2013c).

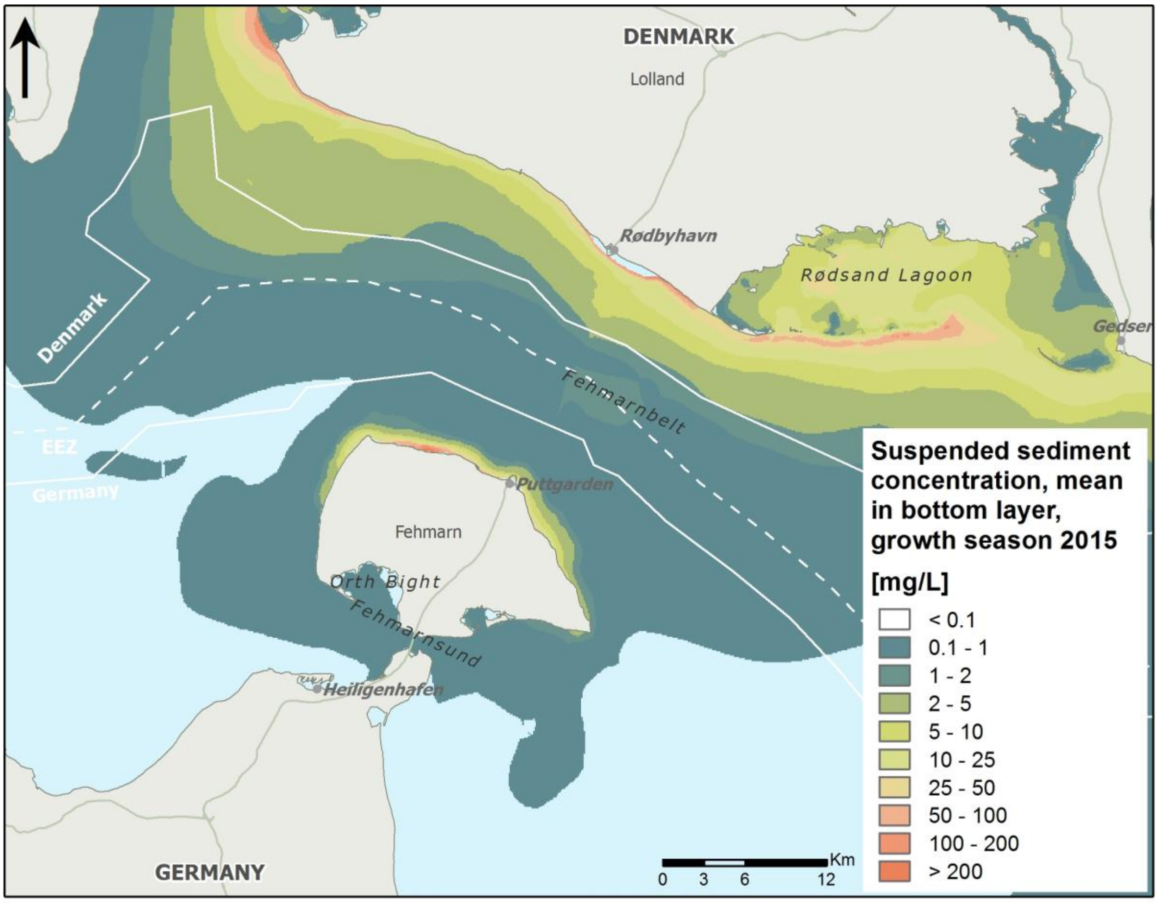


Figure 4-1 Average sediment concentrations (mg L^{-1}) in the bottom layer during the growth season (1/3 to 1/9).

Modelled light attenuation

The temporal and spatial distribution of spilled sediments in the water column has been modelled for both alternatives (FEHY 2013c) based on a provided dredging plan (Femern 2011c). The results were available in time steps of 2 hours and with a spatial resolution of 100–5000 m.

To achieve relevant data for the flora assessment, these data were used as input in a dynamical model calculating the reduction in light availability for the benthic flora.

Suspended solids differ in their optical properties and the mass-specific light attenuation depends on the organic content, size distribution and shape of particles (Baker and Lavelle 1984; Bowers and Binding 2006; Woźniak et al. 2010).

The attenuation of light is the combined effects of two processes in the water column, namely the scattering of light and absorption of light. Although scattering does not "remove" photons from the water column, scattering is considered a light extinction phenomenon because it increases the path length of photons and thus the probability of photons being absorbed by the absorbing components in the water column.

Several constituents in natural waters can absorb light. Chlorophyll pigments and other light harvesting pigments in planktonic algae have the highest the mass-specific absorption coefficients, followed by organic matter (living, dead and dissolved). Inorganic particles and water itself have lower absorption coefficients. If follows from the above, that all particles contribute both to scatter and absorption, but that absorption dominates in organic particles (especially in phytoplankton due to light-harvesting pigments), while scatter dominates in inorganic particles.

The combined effect of scatter and absorption of suspended particles on light attenuation varies between and within coastal areas, shelf and offshore seas, both as a function of differences in concentrations of chlorophyll-a, detritus, inorganic suspended solids and dissolved organic matter, but also caused by variation in the optical properties of suspended particles. In the scientific literature *in situ* mass-specific light attenuation coefficient of suspended solids (primarily inorganic) has been found to vary between 0.04 and > 0.5 $m^2\ g^{-1}$ (Bowers et al 2009, Campbell & Spinrad 1987, Devlin et al 2008, Dixon & Kirkpatrick 1995, Gallegos 2001, William et al 2002, Lund-Hansen et al. 2010), with highest values in waters dominated by small-sized particles and/or with some contribution of organic matter in the particulate pool (Hill et al 2011). With such a large range in mass-specific light attenuation coefficients "standard" coefficients cannot be applied universally to any dredging situation, as it can lead to serious bias in prediction in effects. Instead, site-specific attenuation coefficients when predicting effects of sediment spills from dredging works should be used. To this end three experiments with different sediment types from the alignment were carried out.

The experiments are described in FEMA Appendix F and the resulting absorption, scattering and mass specific light attenuation coefficients for the four particle sizes are shown in Table 4-4.

Table 4-4 Scattering, absorption and resulting mass specific light attenuation for the four particle sizes used in the ecological model

Particle size (mm)	**Absorption ($m^2\ g^{-1}$)**	**Scattering ($m^2\ g^{-1}$)**	**Mass specific light attenuation ($m^2\ g^{-1}$)**
0.0065	0.0278	2.714	0.142
0.01	0.0278	1.814	0.117
0.028	0.0278	0.756	0.078
0.064	0.0278	0.354	0.057

The results of the experiments are used in the ecological model to model the effect of increased concentrations of suspended sediment on light availability for benthic flora. The experiments represent the light attenuation of primary spill. Primary sediment spill has a higher light attenuation because it contain a larger proportion of dissolved organic material than spilled sediment that has been resuspended several times. The light description is therefore considered to result in conservative estimates.

Natural resuspension is included in the ecological model based on empirical relationships between re-suspension and water depth, wind velocity and shear stress. The resuspension is measured as NTU at 10 coastal stations. The light attenuation is included as light scattering (b) and absorption (a) estimated from NTU. The light attenuation of the spilled sediment was added to the effect of natural resuspension.

Since the natural resuspension is included as a light attenuation, the effect of the sediment spill can be seen by comparing secchi depths modelled with existing conditions and secchi depths modeled including sediment spill, an example from Rødsand Lagoon is shown in Figure 4-2.

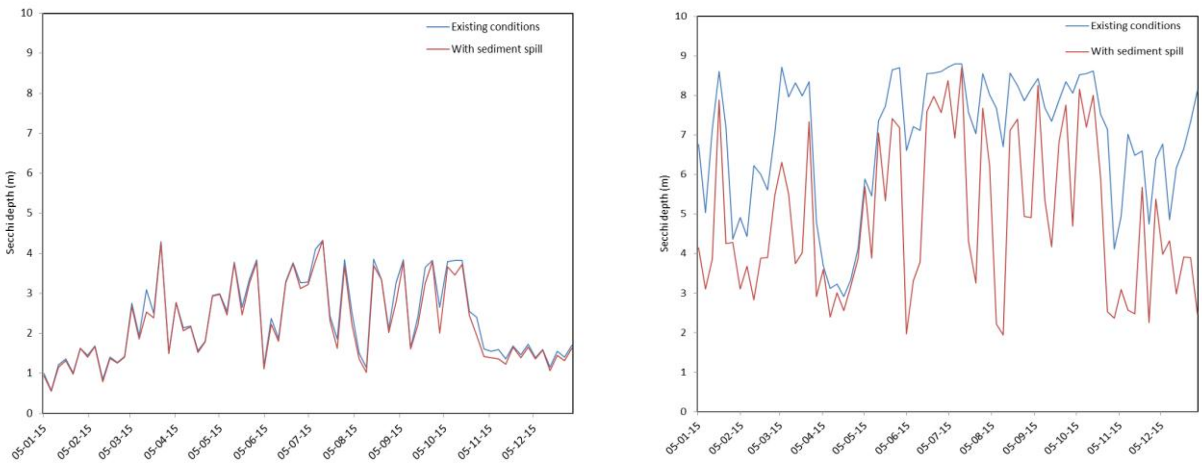


Figure 4-2 Modelled secchi-depths (5 days averages) with and without sediment spill at a site in the central part of the Rødsand Lagoon (left) and in the western part (right) of the lagoon.

Data used to illustrate the magnitude of pressure on a spatial scale are GIS layers of the light reduction (in %) for the different alternatives.

The model is forces by input on spilled sediment extracted from the sediment spill model. The sediment spill model does not include the filtering capacity of mussel as this is not state-of-the-art. Mussels are widely distributed in the area. Mussels have a large filtering capacity and should be able to reduce the effect of the spilled sediment. Further more, in oxygenated sediments infauna will continuously mix the upper layer of the sediment, reducing the amount of fine particles for resuspension. Because it has not been possible to take these aspects into account in the modelling of the sediment spill, the estimated light reductions are considered to be conservative estimates.

The resulting reduced light availability during the construction of the tunnel and the bridge is described in detail in chapter 7.1.1 and chapter 8.1.

4.2 Sedimentation

Dredging and backfilling activities (Table 4-2 and Table 4-3 during the construction of the tunnel and bridge cause sediment spill and subsequent deposition of sediment on the seabed.

The magnitude of pressure depends on the amount of deposited sediment as well as the duration and timing of the sedimentation. The important indicator is thus the specific thickness of the settled sediment, which is persistent for a certain number of days during the growth or reproductive season.

Deposited sediments (natural occurring and spilled) are recurrently resuspended by waves and currents, especially in shallow waters. Naturally the persistence of sedimentation layers is variable. The deposited sediments will regularly be resuspended and/or transported further due to currents and wave action. Model calculations from the assessment area show resuspension and bed-load transport of fine sand and silt down to 15–20 m. The frequency for such events is higher for sediment with small grain sizes (e.g. silt) and in shallow, exposed waters (< 10–15 m). Most of those events occur during autumn and winter. The frequency of resuspension events was calculated to ~ 10 % per year for the Fehmarnbelt area (Harff et al. 2005, 2006). This implies that for at least 36 days during the year the bed shear stress is high enough to enable resuspension and bed-load transport. This corresponds to a persistence of sedimentation layers of approximately 10 days on average. Natural resuspension events shorten the duration of sedimentation effects and have to be taken into account for the magnitude of pressure.

Sedimentation during winter may be as severe as sedimentation during summer because several of the key-species have their reproductive period during winter months. But since the seasonality of growth and reproduction varies between species of benthic vegetation the seasonal timing of sedimentation is not used to define the different levels of the magnitude of pressure.

The temporal and spatial accumulation and resuspension of spilled sediments have been modelled for both alternatives (FEHY 2013c) based on a provided dredging plan. The results were available in time steps of 2 hours and with a spatial resolution of 100–5000 m.

To achieve relevant data for the flora assessment, the modelled data on deposition of sediment spill was post-processed. The average thickness of the deposited sediment (cm) was extracted as well as the duration (in days) of the sedimentation to serve as a basis for the magnitude of pressure analysis.

The sediment spill from dredging and backfilling activities during the construction of the tunnel or the bridge will eventually be deposited on the seabed.

The pressure of sedimentation can be expressed by as thickness of deposited sediment layers (in cm) for a fixed duration (days). Figure 4-3 show an example of sedimentation from construction of the tunnel: the modelled sedimentation (cm) for a duration of ≥ 1 day, ≥ 10 days and ≥ 28 days considering the whole construction period. Only sediment spill from the construction activities is modelled, the modelling does not include natural sedimentation.

Highest levels (cm) for each duration of sedimentation are predicted along the alignment and in areas of the Rødsand Lagoon. In general, most of the sedimentation levels are below 1 cm independently of the duration of the sedimentation. Re-suspension events limit the duration, seen by a decreasing overall affected from 1 to 28 days of duration.

Time series from three positions of the assessment area, extracted from the spill scenario of the tunnel, indicate that the temporal development of sedimentation dependents on the location (Figure 4-4). Along the northcoast of Fehmarn only small amounts of spilled sediment are deposited and those amounts are regularly resuspended especially during winter. Along the coast of Lolland close to the alignment, sedimentation up to 1.5 cm is predicted in the beginning of the construction phase. The sedimentation is mainly the large size fraction of sediment and therefore it persists there throughout the whole construction phase. In the Rødsand Lagoon the sediment deposition is the highest of the three locations. Most of the deposition occurs during the first construction period. Although repeated re-suspension of the spilled sediment can reduce the thickness of the sediment layer by less than half of the maximum deposition during the whole construction phase, the former seabed level is not reached within the documented time interval.

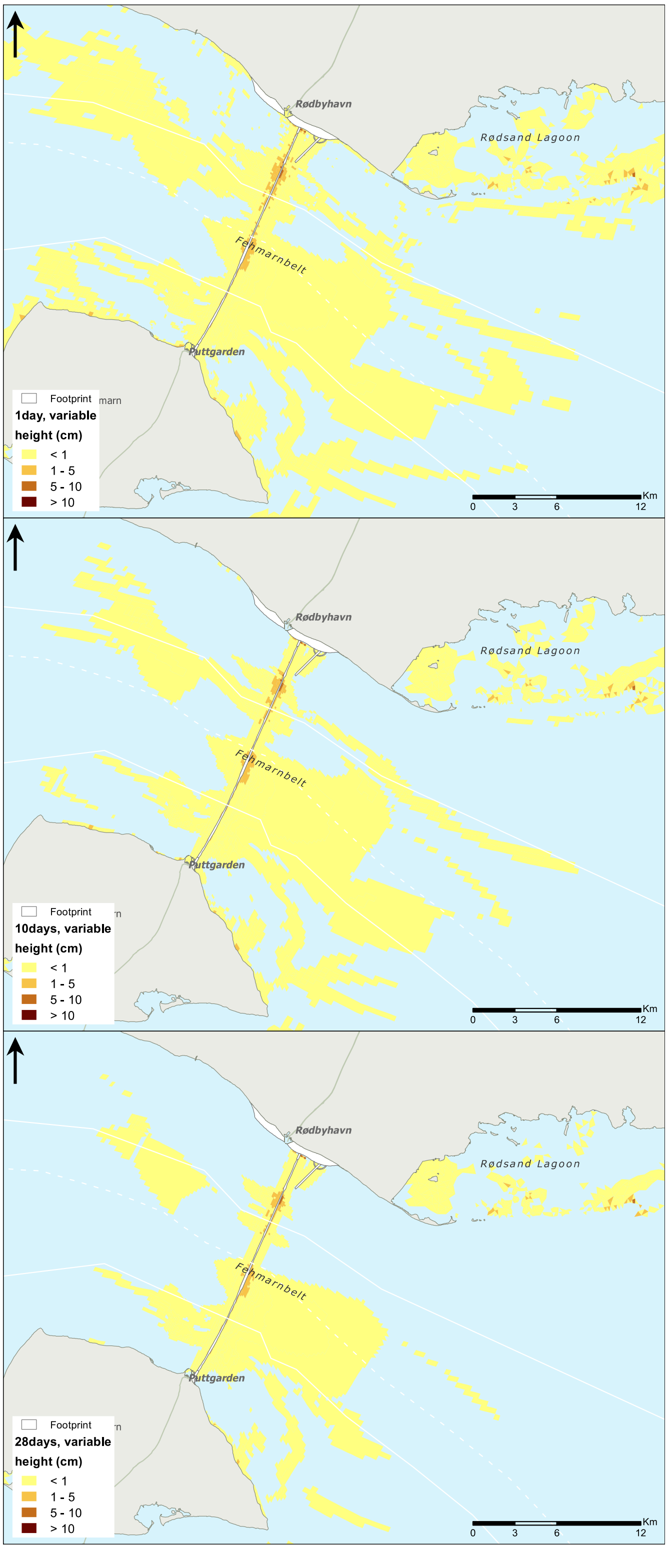


Figure 4-3 *The highest sedimentation (in cm) occurring for ≥ 1 day (upper panel), ≥ 10 days (middle panel) and ≥ 28 days (lower panel). The figure is an example that illustrates the sedimentation as a result of constructing the tunnel.*

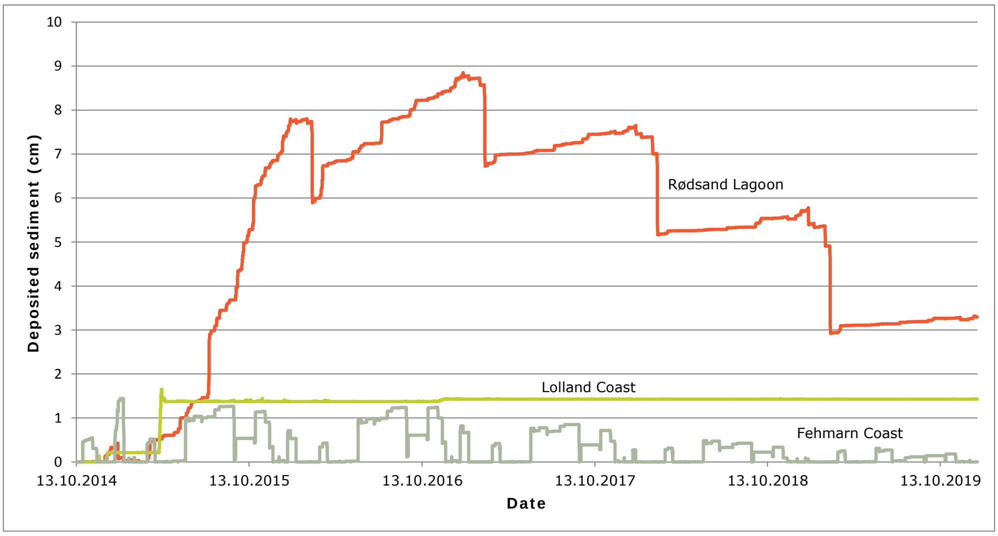


Figure 4-4 Time series illustrating the development of the deposited sediment layer over time from three different locations during the construction of the tunnel.

The sedimentation was transformed into magnitude of pressure levels, defined separately for soft and hard bottom communities, as the effects on those two elements differ too much with respect to sensitivity to deposition (e.g. to thickness of deposited sediment).

Studies documenting the quantitative relationships between sedimentation and mortality are scarce. For eelgrass a single study exists (Mills and Fonseca 2003), for macroalgae quantitative experiments or data could not be found in the international literature, although the amount of qualitative statements is huge.

The thresholds for the different levels of the magnitude of pressure have been defined based expert judgment considering the size and robustness of the benthic vegetation as well as the level of natural sedimentation in their specific environments.

This simple approach to define magnitude of pressure is used because of lack of in-deep knowledge about the impact of different magnitudes of sediment accumulation and duration of such accumulation on benthic flora communities. An obvious shortcoming is that the method does not take into account the frequency of occurrence of sedimentation events. However, the approach chosen is considered to result in central estimates. The impact could be less severe than expected for a sedimentation of only one event of 10 days but could also be more severe if there is a high frequency of occurrence of >10 days events of sedimentation.

Sedimentation during winter may be as severe as sedimentation during summer because several of the key-species have their reproductive period during winter months. But since the seasonality of growth and reproduction varies between species of benthic vegetation the seasonal timing of sedimentation is not used to define the different levels of the magnitude of pressure.

Hard bottom communities (macroalgae)

The magnitude of pressure for macroalgae is shown in Table 4-5.

Table 4-5 Magnitude of pressure levels for macroalgal communities.

Magnitude of pressure	Thickness of sediment layer (persistent ≥ 10 days)
Very high	> 10.0 cm
High	> 5.0 – 10.0 cm
Medium	> 1.0 – 5.0 cm
Minor	> 0.2 – 1.0 cm

Lower limit: Sediment layers of ≤ 0.2 cm and a persistence of less than 10 days are below the lower limit for minor magnitude of pressure. Sediment layers of 2 mm are comparable to naturally occurring sedimentation layers in deeper areas (see chapter 5.3).

Minor: Sediment layers of > 0.2–1.0 cm may affect recruitment of all macroalgae, but do not cause severe physical stress of already established macroalgae. A persistence of 10 days is short compared to the length of most macroalgal reproduction phases.

Medium: Sediment layers of > 1.0–5.0 cm may cause physical stress of small, tiny algae. Such sedimentation layers can naturally occur at exposed shallow sites, but are unusual in deeper areas (> 10 m) of Fehmarnbelt. Higher perennial algae are, to some degree, adapted to sediment layers of this thickness and can survive 10 days with this level of sedimentation.

High: Sediment layers of > 5.0–10.0 cm may cause physical stress for macroalgae of medium size. Only large, very robust macroalgae are not impacted by this level of sedimentation. Such sedimentation can occur naturally during extreme storm events at exposed shallow sites. At least some macroalgae can balance this physical stress for more than 10 days.

Very high: Sediment layers of > 10.0 cm can cause mortality and physical stress to all hard bottom vegetation components. Such sedimentation rates are not expected to occur naturally in Fehmarnbelt.

Soft bottom communities (Flowering plants)
The magnitude of pressure for flowering plants and charophytes is shown in Table 4-6.

Table 4-6 Magnitude of pressure levels for flowering plant communities (inclusive eelgrass/algae community).

Magnitude of pressure	Thickness of sediment layer (persistent ≥ 10 days)
Very high	> 20.0 cm
High	> 10.0 – 20.0 cm
Medium	> 5.0 – 10.0 cm
Minor	> 1.0 – 5.0 cm

Lower limit: Sediment layers of ≤ 1.0 cm for a persistence of less than 10 days are below the lower limit for minor magnitude of pressure. This reflects natural background conditions for flowering plants and charophytes. A sediment layer of 1.0 cm corresponds to naturally occurring sedimentation in sheltered areas.

Minor: Sediment layers of > 1.0–5.0 cm affect smaller flowering plants/charophytes and flowering plants/charophytes heavily overgrown with epiphytes by reducing the photosynthesis. Flowering plants are able to store resources and will be able to balance 10 days of reduced photosynthesis.

Medium: Sediment layers of > 5.0–10.0 cm may cause physical stress for smaller flowering plants/charophytes if they are buried up to 50% of their plant height. Such levels of sedimentation can occur naturally at shallow sites exposed to high amount of sediments during storm events, but are unusual in sheltered areas. Tall species of flowering plants are to a certain degree adapted to sediment layers of this thickness. Some flowering plants will be able to balance the physical stress of sedimentation for more than 10 days.

High: Sediment layers of > 10.0–20.0 cm cause increased mortality for small species of flowering plants and high physical stress for large species. Such levels of sedimentation may occur infrequently at exposed sites during extreme storm events but are unusual in sheltered bays and lagoons. At least large flowering plants will be able to balance the physical stress of this sedimentation for more than 10 days.

Very high: Sediment layers of > 20.0 cm of deposited layers cause mortality and physical stress to all soft bottom vegetation communities. Such levels of sedimentation will not occur naturally.

In general, although flowering plants are used to some degree of natural sedimentation, recovery may be prolonged for high degrees of sedimentation in areas with seeds and seedlings.

Data used to illustrate the magnitude of pressure (MOP) on a spatial scale are GIS layers. The post-processed spill data (sedimentation layer in cm persisting for ≥ 10 days) are combined with the plant communities. In this way the MOP thresholds can be illustrated specifically for each vegetation type (hard and soft bottom communities) and combined to one MOP map for each alternative afterwards. MOP exist only were plant communities occur

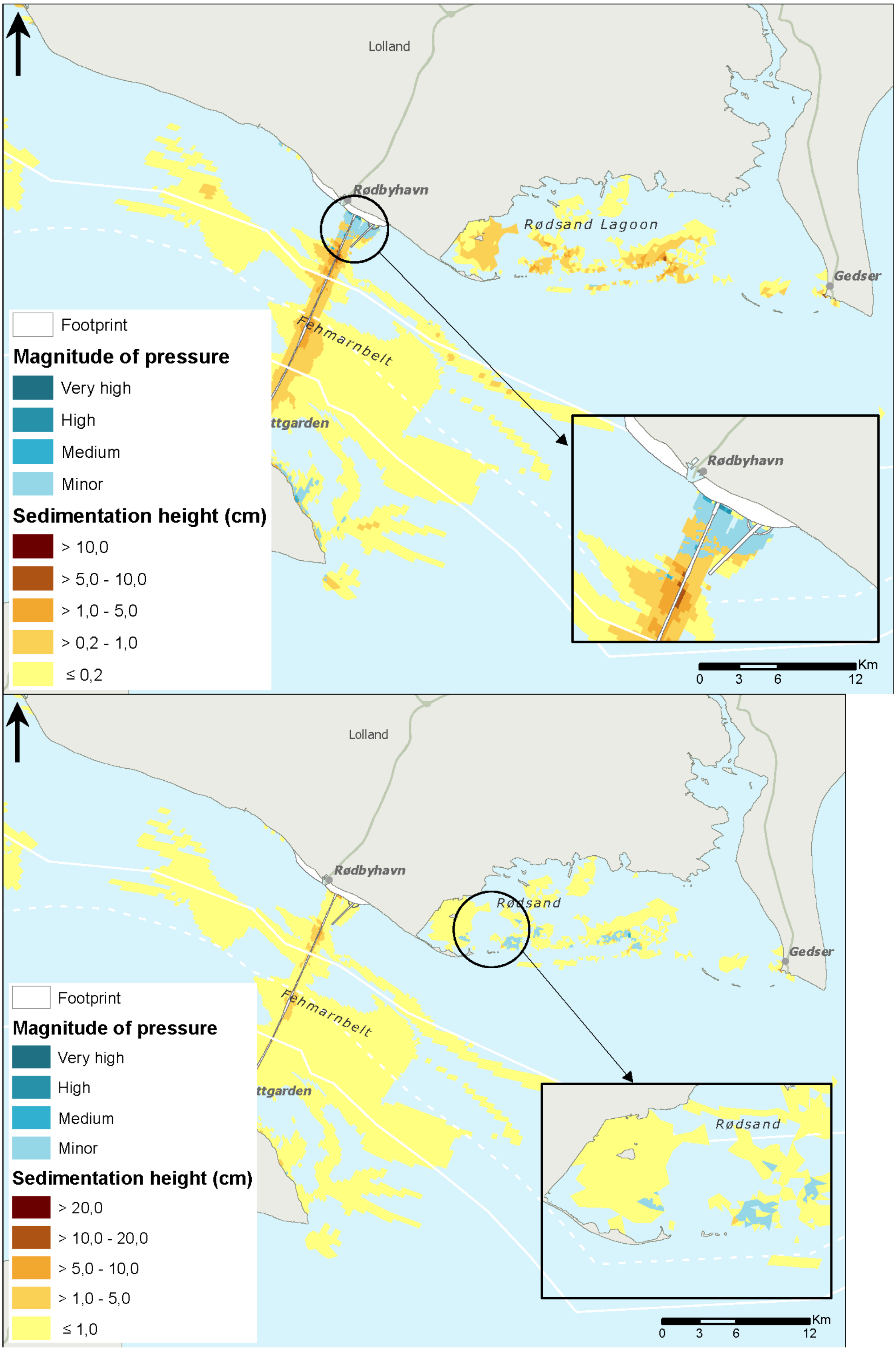


Figure 4-5 "Translation" of sedimentation layer height (with persistence of ≥ 10 days) into magnitude of pressure classes for hard bottom (top) and soft bottom communities (bottom).

4.3 Toxic substances

Measurements of heavy metal and POP concentrations in the sediment of the Fehmarnbelt showed concentrations above detection level of chromium (Cr), copper (Cu), lead (Pb), Nickel (Ni), Zink (Zn), tributyltin (TBT), polychlorinated biphenyls (PCB) and Dichlorodiphenyl trichloroethane (DDT, FEHY 2013e). However, the concentrations in the sediment were low and the conclusion was that dredging was unlikely to cause changes to the concentrations in the water column (FEHY 2013e).

In conclusion, as no changes are predicted in water column concentrations of POPs and heavy metals (FEMA 2013b) and the deposited sediment do not contain critical levels (FEHY 2013e), the impacts due to toxic substances are negligible for both tunnel and bridge alternative. Therefore no further assessment for tunnel or bridge is required.

4.4 Nutrients

Release of nutrients from dredged sediment has been evaluated and assessed as insignificant for phytoplankton growth in (FEHY 2013f). The following calculations show that these concentrations are also insignificant for benthic flora growth:

Based on elutriation studies using surface sediment from the alignment corridor the average release of nitrogen and phosphorus during dredging was estimated to about 0.5 kg N d^{-1} and 2.0 kg P d^{-1}, irrespective whether dredging takes place in shallow or in deep water (FEHY 2013f).

Assuming a 1 m stripe of vegetation stretching approximately 1500 m from the shore and outwards and growing at a mean depth of 5 m as a basis as well as a current speed of 0.1 m/s, the amount of water passing the vegetated zone can be estimated at 64.8 million m^3 d^{-1}.

Natural nutrient concentrations in the Fehmarnbelt during the two baseline years showed that the concentrations in this area varied during the year between 2 – 90 mg N m^{-3} and 2 – 20 mg P m^{-3}, with the highest concentrations during winter and lowest during summer (FEHY 2013f).

Based on the calculated daily flux of 64.8 million m^3 d^{-1} and natural concentration of N and P the amount of nutrient passing the vegetation is estimated to be between 129.6 – 5832.0 kg N d^{-1} and 129.6– 1296.0 kg P d^{-1}.

Compared to these natural daily fluxes and assuming the worst case scenario that all the potential released nutrients pass the vegetation, the estimated surplus of N (0.5 kg d^{-1}) and P (2.0 kg d^{-1}) correspond to a very small increase in available nutrient of up to 0.4% and 1.5%, respectively.

In conclusion, the estimated release of nitrogen and phosphorous is negligible compared to natural availability of N and P and too small to cause any changes in the species composition or relative abundance of the species. The impacts due to nutrients are negligible for both tunnel and bridge.

4.5 Construction vessels and imported material

The number and length of the transportation way (between port of loading and alignment) of vessels and the amount and origin (excavation areas) of imported material define the magnitude of pressure. If imported material/vessels originate from the same (Fehmarnbelt, Western Baltic) or adjacent (Belt Sea, Arkona Sea) marine areas, the risk of introducing non-indigenous species is negligible, as those marine areas inhabit comparable communities of benthic vegetation. If imported material/vessels originate from distant marine areas with different biological communities, there is a risk of an introduction of non-indigenous species.

Table 4-7 lists the structures, types, amount and origin (spatial range) of imported material for the bridge and the tunnel alternatives, respectively (Femern 2011c). Figure 4-6 illustrates the location of production sites and marine excavation areas for tunnel and bridge and the geographical range, in which nearly all of the transportation will take place.

Table 4-7 Structures with need of imported material or transportation by vessels, type and amount of needed material and its origin (Femern 2011c).

Alternative	Structures	Material type	Amount	Origin (spatial range)
Tunnel	Tunnel elements	Concrete	2,480,000 m3	Production site Rødbyhavn (near zone)
	Reinforcement	Concrete	305,000 t	
	Portal and ramps, cut and cover tunnel	Concrete	183,000 m3	
	Ballast	Concrete	386,000 m3	
	Bedding layer	Crushed rock or gravel	6,400,000 m3	Norway/Sweden or Denmark (transboundary or DK national + EEZ)
	Locking fill	Crushed rock or gravel		
	General fill	Sand, clay till		Fehmarnbelt - dredged material (near zone), Rønne Banke, Kriegers Flak (DK national + EEZ)
	Protection layer	Rock		Norway/Sweden or Denmark (transboundary or DK national + EEZ)
	Land reclamation	Sand, Clay till	2,490,000 m^2	Fehmarnbelt - dredged material (near zone)
Bridge	Piles for soil improvement	Concrete	110,000 t	Production site Lindø (DK national + EEZ)
	Reinforcement	Concrete	158,000 t	

Alternative	Structures	Material type	Amount	Origin (spatial range)
	Structural concrete	Concrete	790,000 m^3	
	Scour protection	Rock	257,000 t	Norway/Sweden or Denmark (transboundary or DK national + EEZ)
	Armour for revetments	Rock	125,000 t	
	Fill of caissons and backfill around caissons	Crushed rock	444,000 t	
	Fill for caissons and backfill around caissons	Sand	305,000 t	Fehmarnbelt - dredged material (near zone), Rønne Banke, Kriegers Flak (DK national + EEZ)
	Fill for peninsula and embankments	Sand	829,500 m^3	

Tunnel
Overall the tunnel alternative comprises a much higher amount of imported material and therefore potentially also a higher number of required construction vessels. However, most transportation will take place in the near zone, as the proposed production site will be located within the land reclamation area at Lolland; and most of the imported material with finer grain sizes will be dredged material from the alignment.

Additionally, sediments are planned to be excavated from Kriegers Flak or Rønne Banke, which are located within the neighbouring marine area Arkona Basin, which is inhabited by comparable biological communities.

Only for imported rock or crushed rock the exact port of loading is not specified yet, but it will be a port in Norway, Sweden or Denmark.

Bridge
The bridge alternative comprises a relative lower amount of imported material and therefore also a lower number of required construction vessels. As the proposed production site will be Lindø in the Odense Fjord most transportation will take place on a wider geographical scale compared to the tunnel, but still within neighbouring marine areas (Belt Sea).

For imported seabed material with smaller grain sizes the same procedure like for the tunnel will be conducted (dredged material from the alignment or additional material from Kriegers Flak or Rønne Banke). Similarly, origin of imported rock and crushed rock is not defined yet; ports of loadings in Norway, Sweden and/or Denmark are proposed.

Conclusion
Both alternatives have a low magnitude of pressure. Only transportation of rock material is planned to take place in a wider geographical range with a potential increased risk of introducing non-indigenous species. However, even the farthest port of loading (Norway) lies within adjacent marine areas. Compared to the present 47,000 vessels crossing Fehmarnbelt per year (calculation year 2006) and the predicted increase to 80,000 vessels, independ-

ent of the construction of the fixed link (Femern 2010b), the effect of increased ship traffic required for rock transportation is negligible.

No increased risk of introduction of non-indigenous species is expected and no further assessment for tunnel or bridge is required. The impacts due to construction vessels and imported material are negligible for both tunnel and bridge.

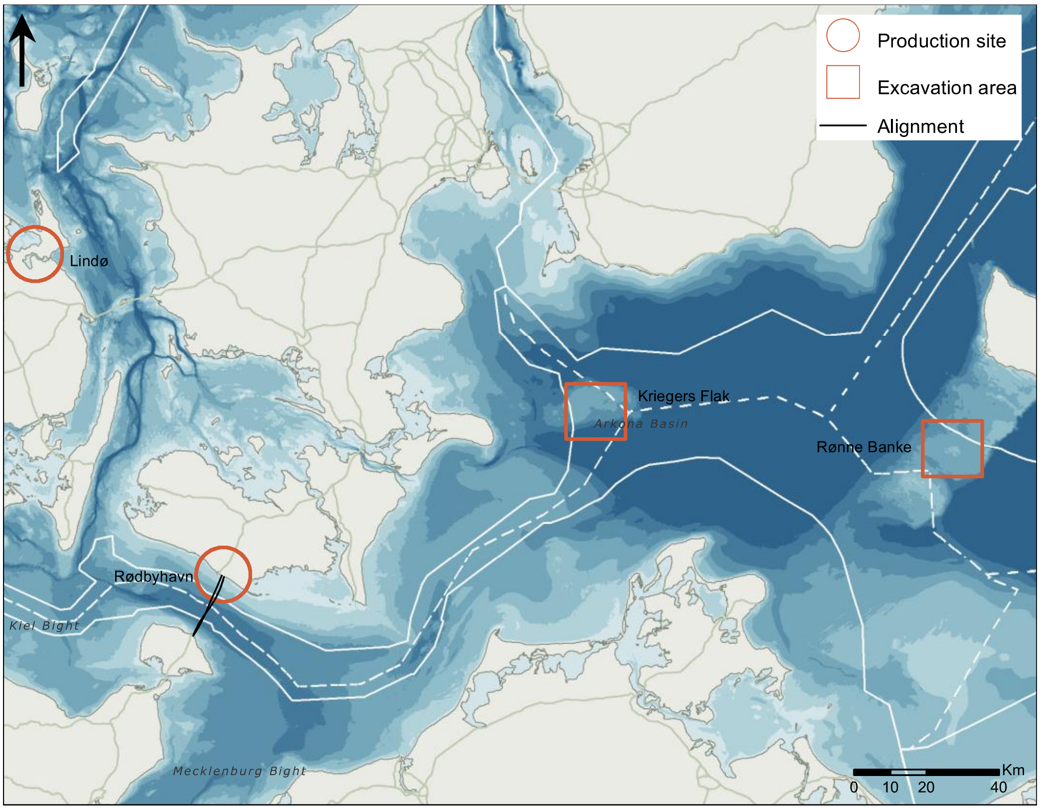


Figure 4-6 Geographical range of main vessel transportation ways with illustrated proposed production sites and marine excavation areas.

4.6 Footprint

Footprint affects benthic vegetation by loss of habitat. In case of habitat loss the magnitude of pressure is defined to be "very high". Therefore an analysis of the magnitude is not necessary for this pressure.

The pressure is divided into two footprint types, which are important for the determination of significance:

Structure-related footprint – Footprints like reclamation areas or bridge pylons are related to the structure of the Fehmarnbelt fixed link. Their duration is permanent. A re-establishment of the former seabed and community structure is not possible.

Construction-related-footprint – Footprints like working harbours or the tunnel trench are related to the construction of the Fehmarnbelt fixed link. Their duration is temporary restricted. A re-establishment of the former seabed and community structure is possible, with two separate steps influencing the time scale for re-establishment: The recovery time of the seabed and the recovery time of the impacted benthic flora communities.

The recovery time of the seabed can depend on natural processes or be improved (and therefore shortened) by project-related processes (e.g. backfilling with former sediment or sediments with comparable grain sizes). The time scales have to be discussed in detail for each footprint type and alternative for significance of the impact.

Data used to illustrate the magnitude of pressure on a spatial scale are GIS layers for the different footprint types and alternatives.

4.7 Solid substrate

New structures like piers and pylons, scour protection and rocks as protection layer in the tunnel trench provide new substrate for species requiring solid substrate for colonisation (e.g. macroalgae). The potential new area and biomass of new algal communities depend on the depth extension, the position (vertical or horizontal) and the hard substrate composition of the new structures.

Not all types of solid substrates have the same potential as settling ground. Depending on surface properties including chemical composition most artificial solid substrates are less suitable compared to natural substrates like rocks. It is not possible to assess the effect of the type of substrate quantitatively for the magnitude of pressure. Therefore, all solid substrates are regarded equally suitable, but suitability can be used in written argumentation for significance, if necessary.

The larger the area of 'new' solid substrates, the higher the colonisable area. In contrast to sealing, the area of additional substrate is not identical to the footprint area, as constructions can rise up in the water column and have therefore a third dimension compared to footprints. For vegetation also the depth zone, in which solid substrate occurs is important, as the light availability is too low for vegetation growth below a certain depth level. Solid substrate areas divided into certain depth intervals have been calculated separately for both alternatives (see Appendix B).

4.8 Seabed and coastal morphology

The magnitude of the pressure depends on the barrier effect of the specific structures and the implications to the natural erosion and sedimentation scheme. Two types of changes can be divided:

Accretion (sedimentation, accumulation) – Near bed currents and long shore drift might decrease in some areas and sediments can be deposited due to the changed current situation.

Erosion (scouring) – Near bed currents and long shore drift might increase in some areas and sediments can be eroded due to the changed current situation.

The complex of erosion, transport and deposition processes of sediments, controlled by several abiotic factors, have been modeled and assessed separately for the different alternatives (FEHY 2013b, FEHY 2013d) and these assessments are the basis for the flora assessment.

Table 4-8 gives an overview on how tunnel or bridge structures may affect the coastal or seabed morphology, the calculated spatial range of the pressure and the proposed effects to the natural current system and subsequent to the erosion and sedimentation scheme.

Table 4-8 Structures with possible changes of coastal or seabed morphology, the spatial range and the proposed effects of the impact. Source: FEHY 2013b and 2013d.

Alternative	Structures	Predicted changes	Range	Proposed effects
Tunnel	Reclamation areas and elevated protection layer (reef, near shore)	Coastal morphology	Near zone + Local zone	Sand accretion near reclamation
	Tunnel trench (0.7 m below seabed level)	Seabed morphology	Near zone	Negligible
	Access channel (up to 6 m below seabed level)	Seabed morphology	Near zone	Negligible
Bridge	Reclamation areas (peninsulas)	Coastal morphology	Near zone + Local zone	Negligible
	Bridge piers and pylons	Seabed morphology	Near zone	Changes in near bed currents > 25 %
	Access channel	Seabed morphology	Near zone	Negligible
	Working harbours	Seabed morphology	Near zone	Negligible

Tunnel
Seabed morphology: All changes of the seabed morphology take place within the tunnel trench or the access channel and are part of the footprint assessment. Only insignificant changes to the near bed currents are expected and thus, no changes of seabed morphology outside the trench and channel are detectable (FEHY 2013b). The impacts on benthic flora due to changed seabed morphology are negligible for the tunnel alternative.

Coastal morphology: Changes of the coastal morphology (sand accretion at Lolland) have been proposed by FEHY 2013d and are therefore assessed for the tunnel alternative in section 7.5.1.

Bridge
Seabed morphology: Changes of the seabed morphology (significantly changed near bed currents) have been proposed by FEHY 2013b and are therefore assessed for the bridge alternative in section 8.5.1.

Coastal morphology: The bridge alternative does not lead to any or only insignificant changes to the sedimentation transport system along the Lolland and Fehmarn coastline (FEHY 2013d). Therefore, no changes in coastal morphology are expected and the impacts on benthic flora due to coastal morphology are negligible for the bridge alternative in Danish and German waters.

4.9 Hydrographical regime and water quality

Permanent new structures like reclamation areas, bridge pylons and piers may permanently change the current patterns, the general flow of water through the Fehmarnbelt and the degree of vertical mixing of the water column. Such changes may alter salinity, temperature, nutrient concentrations and light availability. Since the distribution and abundance of benthic flora are regulated by, amongst other, these factors a change in these conditions may cause changes in the distribution and abundance of species and communities.

Tunnel
Hydrodynamic modelling of the Fehmarnbelt for the main tunnel alternative shows negligible blocking of water from new constructions (approximately 0.01 %, FEHY 2013a) and comparable small changes in temperature, salinity and bottom current speed. The water quality is closely linked to the hydrographical regime, and since only very small effects are expected for the hydrographical regime, the impact on water quality is not modelled but assumed to be negligible (FEMA 2013a).

Table 4-9 gives a summary of the effects on key hydrographical parameters, together with the mean value and standard deviation of in situ monitoring of key parameters (FEHY 2013a). The standard deviation indicates the natural variability of the presented parameters in Fehmarnbelt.

Table 4-9 Summary of magnitude of pressure for permanent key effects in the Fehmarnbelt and nearby areas of the tunnel alternative from (FEHY 2013a). The current values are based on continuous measurement at a buoy station close to the alignment at Fehmarn (MS02, 2009-2010). The remaining values are estimated from monitoring of a station N01 Fehmarnbelt (1990-2007).

Tunnel alternative	**Upper limit for estimated change in local model area**	**In situ measurement**	
		Mean value	**Standard deviation**
Bottom currents (annual mean)	Down to -0.06 m/s locally off reclamation area, elsewhere less than ±0.005 m/s	0.13 m/s	0.09 m/s
Mean bottom salinity (annual mean)	Up to ±0.2 psu locally off reclamation areas, elsewhere less than ±0.05 psu	21.9 psu	3.5 psu
Bottom temperature (annual mean)	Less than ±0.05 °C everywhere	6.6 °C	3.6 °C
Summer bottom temperature (mean)	Less than ±0.05 °C everywhere	9.9 °C	2.3 °C

Current speed
The model shows that the changes in current speed are predicted to be very small. Small reductions in current speed (max -0.06 m/s) are predicted in the immediate vicinity of the reclamation areas at the Danish and German side and around the production facility access channel at the Lolland side.

The reduction is due to a lee effect of the new constructions and the lowered seabed level at the access channel. The lee effect of the new constructions will remain but the access channel is slowly filled with sediment. After re-establishment, the current speed can be expected to remain the same as at present and communities similar to the existing will re-establish.

The small changes in current speed are assessed as being negligible insignificant for benthic flora.

Salinity and temperature
The model results show small changes in salinity. Predicted changes are up to ±0.2 psu near the alignment and less than ±0.05 in the rest of the Fehmarnbelt. The modelled temperatures are predicted to change less than 0.05°C in all areas.

Salinity and temperature are important factors for the distribution and abundance of benthic flora on regional and global scale. The benthic flora in Fehmarnbelt experience large variations in salinity and temperature on a temporal scale while the spatial variability is small within the area (FEMA 2013a).

As the species are used to large temporal changes and most species are abundant along the salinity gradient, the small changes predicted are assessed as insignificant for the benthic flora.

Bridge
Hydrodynamic and water quality modelling of the Fehmarnbelt for the bridge alternative shows that the blocking of water flow from new constructions is low (FEHY 2013a) and thus resulting in limited effects on bottom hydrography and water quality. The effects of the bridge solution are summarized in Table 4-10, together with the mean value and standard deviation of in situ monitoring of key parameters. The latter indicates the natural variability of the presented parameters in Fehmarnbelt.

Table 4-10 Summary of magnitude of pressure for permanent key effects in the Fehmarnbelt and nearby areas of the bridge alternative from (FEHY 2013a). The current values are based on continuous measurement at a buoy station close to the alignment at Fehmarn (MS02, 2009-2010). The remaining values are estimated from monitoring of a station N01 Fehmarnbelt (1990-2007).

Bridge alternative	**Upper limit for estimated change in local model area (off alignment)**	**Fehmarnbelt**	
		Mean value	**Standard deviation**
Bottom current speed (annual mean)	Less than ±0.005 m/s outside alignment corridor (±250 m)	0.13 m/s	0.09 m/s
Bottom salinity (annual mean)	East of alignment down to -0.2 psu, elsewhere less than ±0.1 psu	21.9 psu	3.5 psu
Bottom temperature (annual mean)	Less than ±0.05 °C	6.6 °C	3.6 °C
Summer bottom temperature (mean)	Less than ±0.25 °C and typically below ±0.05 °C	9.9 °C	2.3 °C
Secchi depth (annual mean and summer mean)	Less than ±0.03m everywhere	6.2m (1984-97)	1.9m (1984-97)

Current speed
The change in bottom current speed will be less than 0.005 m/s (within the standard deviation of the mean value). Given the predicted very limited alteration of the current speed along the bottom, the changes are assessed to be negligible for the benthic flora.

Salinity and temperature
The model predicts changes in bottom salinity in a restricted area east of the bridge alignment. The maximum change is -0.2 psu (< 1% change).

The largest change in water temperature is in bottom waters during summer due to increased mixing at the structures. Just east of the alignment the increase in bottom temperature is up to 0.25ºC, while in Mecklenburg Bight the temperature is reduced to a maximum of -0.2ºC. These changes are small compared to the natural temporal variation experienced by the benthic flora.

Salinity and temperature are important factors for the distribution and abundance of benthic flora on regional and global scale. The benthic flora in Fehmarnbelt experience large variations in salinity and temperature on a temporal scale while the spatial variability is small within the area (FEMA 2013a).

As the species are used to large temporal changes and most species are abundant along the salinity gradient, the small predicted changes are assessed as negligible to the benthic flora.

Secchi depth
The model results (not including sediment spill) predict changes in annual mean and summertime mean Secchi depth of less than ±0.03m.

Light is a key parameter for benthic flora but since the predicted changes are very small its impact on the benthic flora are insignificant.

Conclusion
The overall conclusion on the impacts from changes in hydrographical regime and consequently alterations of water quality on the benthic flora is that all observed changes in the pressures are resulting in negligible impacts.

4.10 Drainage

The magnitude of pressure depends on the amount of freshwater discharged per event, the number and duration of the outlet events per year and location of the outlet. The amount, number and duration of events are impossible to predict precisely, as they are dependent on the specific process (rainfall, washing).

Partly the drainage will be discharged via existing watercourses, but for both alternatives an additional outlet at each coastline is planned. The outlets to Fehmarnbelt will be positioned as far and deep at sea as possible, ensuring good mixing with surrounding waters (Femern and LBV-SH-Lübeck 2011).

A screening has revealed that the discharge rate of drainage will be below 1 m^3/s and with salinity and temperatures within normal ranges for freshwater runoff (FEHY 2013a). Efficient flushing with mean speeds of about 0.4 m/s near the outlet will dilute the freshwater immediately. Thus, no effect to the salinity and general hydrography to any significant degree close to the outlet or on larger scales are expected (FEHY 2013a).

Due to the short time scale, the small affected area and a general adaption of all vegetation communities in Fehmarnbelt to salinity changes of up to 10 psu, which can naturally occur (Schwenke 1996), neither changes in species/communities nor reduced biomass are expected. Therefore no separate assessment for tunnel or bridge alternative is needed. The impacts due to outlet of drainage are negligible for tunnel and bridge.

5 SENSITIVITY ANALYSIS

For a given community sensitivity expresses the combination of intolerance to a given pressure and the ability to recover. For the pressures suspended sediment and sedimentation, a detailed description of the sensitivity is relevant. For the pressure footprint, the habitats are lost and it is not relevant to describe sensitivity. Sensitivity to additional solid substrate is also irrelevant.

Below, recovery is described followed by the sensitivity of the benthic flora communities to the pressures sedimentation and suspended sediment. Confidence/ evidence levels for the different impact assessments are also estimated.

5.1 Recovery time

Recoverability is one aspect of the sensitivity of sub-components. Recovery time is defined as the number of years needed for a full recovery to a pre-impact state after complete or near-complete removal of the particular species, community or habitat.

Recovery time is not dependent on the kind of pressure but on the life cycle characteristics of the respective communities like growth rates, longevity and type of reproduction and dispersal capability.

Recovery time has been estimated for all key-communities and the time scales were allocated into the four levels: very high, high, medium, minor. An overview of the estimation and classification is given in Table 5-1. The background for the classification is given below.

Table 5-1 Overview of estimated recovery time for macrophyte key communities

Key-community	Recovery time	Comment
Eelgrass and Eelgrass/algae	Very high (>10 years)	Recovery may take longer, if whole eelgrass patches get lost, as dispersal capability is low.
Tasselweed/dwarf eelgrass	Medium (2–5 years)	Recovery may take longer, if whole tasselweed / dwarf eelgrass patches get lost as dispersal capability is low.
Fucus	High (5–10 years)	Recovery may take longer, if whole *Fucus* patches get lost as dispersal capability is low.
Furcellaria	High (5–10 years)	
Phycodrys/ Delesseria	Medium (2–5 year)	
Saccharina	Minor (1–2 years)	
Filamentous algae	Minor (< 1 year)	

5.1.1 *Soft bottom communities (flowering plants)*

Seagrass re-colonisation potential varies considerably among species. The potential for seagrass colonisation is a function of rhizome elongation rates, which determine path growth, seed production, seedling establishment and subsequent patch development, which determine the potential formation of new patches (Hemminga & Duarte 2000).

A successful recruitment by sexual reproduction is a very rare event in seagrasses. Low flowering probability and low survival rates of seeds are responsible for an extremely low probability of 10^{-5} % that one shoot will develop into a successfully established new patch (Hemminga & Duarte 2000). This inefficiency of sexual reproduction highlights the importance of rhizome elongation (clonal propagation) for the maintenance of seagrass beds (Olesen & Sand-Jensen 1994, Reusch et al. 1999).

Formation of new patches is not only dependent on recruitment success but also on abiotic factors. Newly settled, isolated juvenile shoots are much more vulnerable to be torn out from the sediment by water motion than adult shoots “anchored” within a well-established eelgrass bed.

The consequence is that, once seagrass is extinct from a certain area and no neighbouring patches or beds are present, the restoration of this seagrass meadow is very doubtful.

Eelgrass and eelgrass/algae community

For *Zostera marina* the horizontal growth rate of established patches is relatively low (e.g. 16 cm y^{-1} Olesen & Sand-Jensen 1994, 12.5 cm yr^{-1} Neckles et al. 2005).

Duarte (1995) has estimated the time necessary for different seagrasses to develop 95 % cover in an area, depending on their rhizome elongation rate and patch formation rate. For *Zostera marina* calculations are varying between years and decades. Field examples show that re-colonisation can be fast (Plus et al. 2003, Rask et al. 1999), moderate (Greening & Janicki 2006) or apparently no or very slow (Munkes 2005). Neckles et al. (2005) studied the recovery of *Zostera marina* after disturbance from commercial mussel harvesting and found substantial differences in eelgrass biomass between disturbed and reference sites up to 7 years after dragging. Mean recovery time was estimated to 9–11 years.

The eelgrass wasting disease in the early 1930s destroyed a large part of the eelgrass meadows and the area covered by eelgrass was only partly recovered.

Eutrophication has subsequently led to further reduction of eelgrass cover since the 1970s. Olesen & Sand-Jensen (1994) estimated that large scale recovery would take several decades after nutrient loadings has been reduced and water transparency improved.

Today, after nutrient loadings are reduced conspicuously, there is in most cases no improvement in the depth limit of *Zostera marina* supporting the suggestions of long recovery time for this species or suggesting that other environmental factors than nutrient loadings should also be considered for recovery of eelgrass.

Based on the low horizontal growth rate, the inefficiency of sexual reproduction and the observations from the field, the recovery time is estimated to >10 years. If very high mortality rates occur and only single shoots are left, the recovery may not take place and an extinction of whole patches or meadows may occur.

Tasselweed/dwarf eelgrass
No references concerning the horizontal growth rate of tasselweed are available. The horizontal growth rate for *Zostera noltii* (0.15 cm d^{-1} ~ 55 cm y^{-1}, Brun et al. 2005) is considerably higher than for *Zostera marina*. This confirms the conclusion that smaller seagrasses have faster elongation rates (Hemminga & Duarte 2000). As no data for the successful recruitment from sexual reproduction are available, it is assumed that rhizome elongation (clonal propagation) is the main factor for recovery; like for *Zostera marina*.

No field observations on recovery or re-colonisation for the tasselweed community could be found in the literature. Because this community inhabits very shallow waters with higher habitat instability due to wave actions and ice scraping causing naturally higher mortality rates, it can be assumed that they have a high recovery potential. Charophytes for example, which are important and characteristic accompanying species for this community, are known to show high year to year variability in abundance (Selig et al. 2003).

Based on the high lateral growth rate of *Zostera noltii* the recovery time is estimated at 2–5 years. If very high mortality rates occur and only single shoots are left, the recovery may not take place and an extinction of whole patches or meadows may occur.

5.1.2 *Hard bottom communities (macroalgae)*

Also macroalgal re-colonisation varies among species. Different to flowering plants, clonal propagation is more the exception and sexual recruitment the norm in macroalgae recruitment (van den Hoek 1978). Generally, the reproductive strategies are much more complex in algae and a huge variability of different combinations exists.

The recovery potential of macroalgae is dependent on the reproductive strategy, the reproductive output, the dispersal capability and the attachment/settlement success of propagules (Airoldi 2003 and references therein).

Some species have the ability of vegetative reproduction. This is comparable to clonal propagation in seagrasses and is a more effective recruitment strategy than sexual reproduction. This recruitment type is normally found in opportunistic, annual species like *Ulva* spp. (Lüning 1985). Especially red algae are known to have a very complex reproduction cycle with both asexual and sexual generations. The more complex a reproductive strategy is and the more different steps are involved in the process, the more important is an effective timing of the different phases for the success. Generally, the recovery time for species showing a vegetative or simple reproductive strategy is shorter than those with very complex strategies (Lüning 1985).

Dispersal potential of macroalgae is highly variable. Shanks et al. (2003) reviewed propagule dispersal and found that spores of *Ulva* could be transported 35 km away, *Ectocarpus* > 4 km and *Colpomenia* < 3 m. Several species also have the ability to grow from vegetative fragments. Such fragments may travel several kilometres. However, recruitment usually occurs on a much more local scale, typically within 10 m of the parent plant (Norton 1992). Recovery relies therefore on recruitment from nearby populations. As distance increases from source populations, the probability of successfully arriving spores decreases and recovery will take longer time for populations that are isolated from source populations.

References concerning the reproductive output of algae (number of propagules per reproductive season) or the attachment/settlement success of propagules are rare. The length of the reproductive season may give hints, assuming that species with a very long reproductive season can produce more propagules, and the probability to match ideal attachment/settlement conditions is higher. Therefore, the recovery potential for those species should in general be considered to be higher. High nutrient levels may prevent successful settlement of propagules from perennial species, as opportunistic, fast growing algae are more efficient in competition for space (Airoldi 2003).

Studies examining the re-colonisation and development of macroalgal communities after experimental clearing, show that communities can recover within 1–2 years (Foster 1975, Chapman & Underwood 1998, Bertness et al. 2004, Milazzo et al. 2004, Kraufvelin et al. 2006). Although the patterns of development and time of recovery may depend on the size of the disturbance (Kim & Dewreed 1996), the general conclusion is that ephemeral species re-colonise rapidly and perennial, slow growing species re-colonise slowly.

Fucus community

Fucus vesiculosus and *Fucus serratus* are relatively slow growing algae with a longevity of 5–6 years (Kautsky 1991) and a generation time of 1–2 years (Jackson 2008). Reproduction is possible during the whole year but a reproduction peak occurs in summer (Lehvo et al. 2001, Malm et al. 2001).

Fucus vesiculosus and *Fucus serratus* are highly fecund (Serrão et al. 2000, Berger et al. 2001). Vegetative reproduction has only been observed in the inner Baltic Sea, where low salinity hamper the success of sexual reproduction (Tatarenkov et al. 2005). In Fehmarnbelt, re-colinisation is expected to depend on supply of sexually produced propagules from nearby populations. *F. vesiculosus* eggs travel only 2–25 m from the mother plant (Serrão et al 1996, Eriksson & Johansson 2003, Pehlke et al. 2008). Recovery of isolated populations may therefore take very long.

Decline in abundance and depth distribution of *F. vesiculosus* has been reported for several areas around the Baltic Sea during recent decades. The depth distribution has been reduced (Kautsky et al. 1986, Torn et al. 2006) and the species has disappeared from large areas in Finland (e.g. Haahtela 1984, Kangas et al. 1982). Similar effects have been observed in Poland (Plinski & Florczyk 1984), Estonia (Martin 2000) and Germany (Schramm 1996, Fürhaupter et al. 2008). Eutrophication and pollution have been suggested as the primary causes of the decline (Schramm 1996). Although efforts have been made to reduce eutrophication and pollution, recovery has only been observed in few areas (Nilson et al. 2004), suggesting that recovery time may be long.

Moreover, indirect effects of eutrophication such as increased herbivores (Malm et al. 1999), increased amounts of filamentous algae (Worm et al. 2001, Isaeus et al. 2004) or deposited matter (Berger et al. 2003, Isaeus et al. 2004) have been suggested to reduce recruitment and therefore delay recovery.

Recovery may on the other hand be fast. Kraufvelin et al. (2006) showed that *Fucus* sp. communities recovered in mesocosmos experiments in Oslo Fjord only two years after the populations crashed.

Based on the observations from the field and the general eutrophication level the recovery time is estimated at 5–10 years. If very high mortality rates occur and only single thalli are left, the recovery may take longer and an extinction of whole patches may occur, as the dispersal capability is very low.

Furcellaria community

Furcellaria lumbricalis has a slow growth rate (Bird et al. 1979 and references therein) and takes 4–6 years to attain fertility (Austin et al. 1960a, b). Longevity is high and generation time is between 5–10 years (Rayment 2008). The species is highly fecund and has the ability to reproduce from vegetative fragmentation (Dixon & Irvine 1977, Bird et al. 1979). The dispersal capability should therefore be higher than for *Fucus*. The reproductive season lasts the whole year depending on the reproductive phase (Bird et al. 1991). Although vegetative fragmentation may occur, a complex reproductive cycle with sexual and asexual spores is the norm.

In the 1950s *Furcellaria lumbricalis* was very widespread in the coastal waters of Kiel Bight and around Fehmarn. The depth distribution has been reduced as also seen in *Fucus* in the western and central Baltic (Schramm 1996). The causes of the decrease are regarded to be the same as for *Fucus* (Schramm 1996) and recovery seems to be prevented due to competition for space with other algae.

Based on the observations from the field and general eutrophication level recovery time is estimated to 5–10 years.

Phycodrys/ Delesseria community

Growth rates of *Phycodrys rubens* and *Delesseria sanguinea* are higher than for *Furcellaria*. The species produce a large amount of spores. Red algae spores are not highly motile due to a lack of flagella (van den Hoek 1978) and dispersal range may therefore be limited. Vegetative reproduction is not observed. The reproductive strategy is very complex with sexual and asexual spores. The reproductive season lasts from September to April (*Delesseria sanguinea*) or October to April (*Phycodrys rubens*) with a peak during winter (Molenaar & Breeman 1997).

Lifespan of *Phycodrys rubens* is suggested to be 4 years (Schoschina 1999). Plants start to reproduce after one year. Recovery of a mature population will therefore take at least 1 year. Lifespan for *Delesseria sanguinea* is 5–10 years (Dickinson 1963) and age of maturity is also about 1 year (Kain 1996).

Experiments with clearings showed that red algae, and among these *Delesseria sanguinea,* colonised cleared blocks after 56-59 days (Kain 1975). Recovery time may be longer if populations are disturbed just after the reproductive season due to the complex reproductive strategy.

Based on field observations on fast recovery but taking into account the lifespan of 4–10 years and the moderate growth rate, recovery time is estimated to 2-5 years.

Saccharina community
Saccharina has a relatively high growth rate. The longevity of *Saccharina latissima* is between 2–3 years (Kain 1979). Maturity can be reached within 15–20 months (White & Marshall 2007). In the laboratory it took 8 months to reach the size of reproductive shoots in the field. Although vegetative fragmentation is not known, small juveniles attached to mussels and/or gravel may be dispersed to a larger area. The reproductive season lasts from October to March with a peak during late winter (Lüning 1985). High winter temperatures seem to have a negative effect on reproductive success as *Saccharina latissima* is adapted to Arctic conditions (Sjøtun & Schoschina 2002).

Results from experimental clearing showed that the species rapidly colonised the cleared substratum (Kain 1975). *Saccharina latissima* was abundant six months after the experiment started was cleared.

Even though the species in natural populations under suboptimal conditions may take longer time to reach maturity, it is expected that recovery to a mature reproductive community would take less than 2 years. Based on the examples of fast recovery and the high growth rates the recovery time is estimated to 1–2 years.

Filamentous algae
Filamentous species normally have very high growth rates and can have 1–2 generations during the year (e.g. *Pylaiella littoralis*, *Ulva* spp.), if sufficient nutrients and light are easily available (Lüning 1985). Generation time is therefore less than one year and age of maturity can be reached within several months (Budd & Pizzola 2008). Vegetative reproduction is possible for different filamentous species (e.g. *Ceramium tenuicorne, Polysiphonia fucoides* and *P. fibrillosa* (Eriksson & Johanson 2005)). Reproductive season lasts from early spring to autumn and peaks are dependent from nutrient availability.

Filamentous species are known to generate spatial dominance in patches cleared at all times of the year (Airoldi 1998). In field experiment done in Italy, cover of algae turfs was re-established within months from clearing (Airoldi 2003). Filamentous species are known to colonise newly imported solid substrates at first and very rapidly. Different experiments show a high competitive potential for space of filamentous algae and a higher recovery rate, if high nutrient concentrations are available (Airoldi 2003).

Due to field observations, the reproductive strategy and the higher dispersal capability recovery time is estimated to < 1 year.

5.2 Suspended sediments

The sensitivity analyses have focused on the key parameters describing the sensitivity and being essential inputs to the FEMA model (see section 3.9.1).

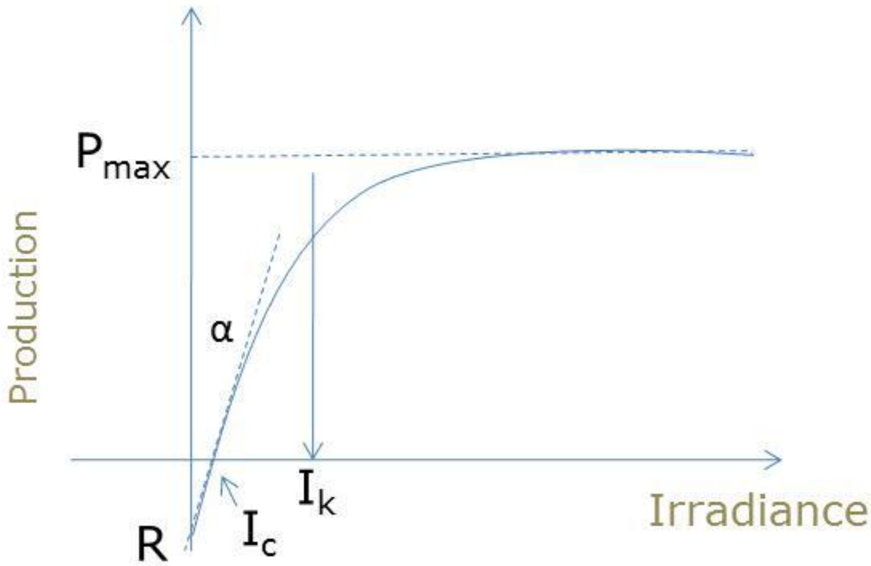


Figure 5-1 *Characteristic parameters describing the PI relationship between photosynthetic production (P) and irradiance (I). P_{max} = maximum production at high light, α = light use efficiency at low light, R = dark respiration, I_c = light compensation irradiance and I_k = irradiance at light saturation.*

The PI curve expresses the relationship between photosynthesis (P) and irradiance (I, Figure 5-1). Photosynthetic rates increase with increasing light until saturation intensity (I_k) where the maximum photosynthetic rate (P_{max}) is reached. The other characteristics of the PI relationship are the respiration in dark (R), the light use efficiency at low light (α) and the compensation point of photosynthesis (I_c) at which the respiratory losses equal photosynthetic gains.

The impact of the reduced light availability depends on whether the algae are already light limited (i.e. irradiance less than I_k, see Figure 5-1) or grow under sufficient light conditions (i.e. irradiance above I_k Figure 5-1) and this will depend on where in the depth range of the vegetation occurs.

In shallow water it can generally be expected that increased concentrations of suspended sediment has no or little impact as the occurrence and production of vegetation are not assumed to be light limited (Irradiance > I_k). However, high concentrations of suspended sediment will reduce light availability below I_k and if this occurs over longer periods during the growth season, it will result in reduced biomass production of these communities.

In deeper water, photosynthesis and biomass production is generally light limited (irradiance between I_c and I_k). At these depths, where light availability for production is at the initial part of the light-production curve, a linear relationship between light availability and new biomass production is expectable.

The depth limit of the vegetation, in areas where suitable substrate is not setting the depth limit, is assumed to be equivalent to the depth where light is just enough for the vegetation to maintain a positive balance between production and loss processes (Irradiance= I_c). Reducing light penetration over longer periods may result in an upward movement of the depth limit and therefore temporary loss of the benthic flora.

Sensitivity of sub-components

The parameters I_c and I_k of the PI relationship can be used to describe the difference between species in sensitivity to reduced light availability. I_c and I_k values have been collected from literature and from experiments on community scale with algae from Fehmarnbelt (Appendix F, Table 5-2). The experiments were carried out to ensure that the values used in the model are representative for the benthic vegetation in Fehmarnbelt and to determine the effect of self-shading in the populations. The light response of a species may vary depending on the light conditions at the growth site of the species, but despite these differences, a general pattern of decreasing light requirements with depth can be seen.

Table 5.2 gives an overview of the light compensation (I_c) and light saturation (I_k) value of species in different form-functional groups frequently occurring in Fehmarnbelt. The model cannot include all species and therefore four key species, *Zostera* and three dominating macroalgae are representatives for the dominant form-functional species groups observed in Fehmarnbelt. The growth rates, irradiance at light compensation I_c and light saturation I_k are important parameters for calibration of the model. The accepted range of I_c and I_k values were determined from values for different species of the algae groups extracted from the literature and experiments, and the appropriate values used for the modelling was determined through calibration. For the corticated, sheet formed algae it was accepted to used an I_c value slightly lower than the range in order to obtain sufficient biomass in deeper water. The growth rates, irradiance at light compensation I_c and light saturation I_k used in the model are listed in Table 5-3.

Table 5-2 Irradiance at light compensation (I_c) and light saturation (I_k) for thallus pieces of dominant species in the key-communities and for communities of selected species.

Form-functional group	Species representing the form functional group in model	Other species in form-functional group	I_c µmol photons m^{-2} s^{-1}	I_k µmol photons m^{-2} s^{-1}	References
Flowering plants	Zostera	Zostera marina	10 18.5-47.3 15-25	100	1, 2, 5
		Ruppia maritima	11-88	45-1200	8, 9
		Potamogeton spp	10-25	20-312	10, 11
Corticated algae	Furcellaria	Fucus vesiculosus	34-60	195-317	3
		Fucus serratus	48, 71	158, 329	6, 3
		Furcellaria lumbricalis, thallus	16-19, 8	116-164, 102	3, 7
		Furcellaria lumbricalis, community	19-34	142-162	7
		Coccotylus	21	69	3
Corticated, sheet formed algae	Delesseria	Phycodrys rubens	11	44	3
		Delesseria sanguinea, thallus	6	73	7
		Delesseria sanguinea, community	10-33	134-180	7
		Saccharina	5-23	10-80	4
Filamentous algal species	Ceramium virgatum	Ceramium virgatum, thallus	32, 17	107, 178	3, 7
		Ceramium virgatum, community	27-43	232-287	7
		Polysiphonia fucoides	23	100	3

1. Olesen & Sand-Jensen 1993,
2. Dennison and Alberte 1985,
3. Johansson & Snoeijs 2002
4. Davidson et al 1991
5. Dennison and Alberte 1982
6. Middelboe & Binzer 2004
7. FEMA experiments, community scale, see Appendix E.
8. Evens et al 1986
9. Koch and Dawes 1991
10. Madsen et al 1991
11. Madsen & Adams 1989

Eelgrass and eelgrass/algae community
Zostera marina is growing between 1 and 5 m depth. The species has a relatively high light requirement and is therefore sensitive to reduced light availability. The minimum light requirement for this species is 10-50 µmol photons m^{-2} s^{-1} and photosynthesis is saturated at approximately 100 µmol photons m^{-2} s^{-1}. *Zostera marina* is able to store carbohydrate reserves and can survive periods of low light (Burke et al 1996).

Tasselweed/ dwarf eelgrass community
In the shallow water *Ruppia maritima, Zostera noltii* and *Potamogeton* species may occur. As for *Zosters marina* the light requirements for these species are high. Minimum light requirement being 11-88 µmol photons m^{-2} s^{-1} and photosynthesis is saturated at approximately 20-312 µmol photons m^{-2} s^{-1}.

Fucus community
This genus has high light requirements. *Fucus vesiculosus* and *F. serratus* are living in shallow water (1-5 m) and are among the macroalgae species with the highest requirement for light. The minimum light requirement for *Fucus vesiculosus* and *F. serratus* is 34-60 µmol photons m^{-2} s^{-1} and 48-71 µmol photons m^{-2} s^{-1}, respectively. Photosynthesis is saturated at about 195-317 µmol photons m^{-2} s^{-1} for *F. vesiculosus* and at 158-329 µmol photons m^{-2} s^{-1} *F. serratus*. The thick thallus and a canopy structure where the biomass is concentrated in the upper part makes the species able to utilize high light levels.

Furcellaria lumbricalis community
Furcellaria lumbricalis is growing between 2 and 8m in the Fehmarnbelt area. The minimum light requirement is 8-22 µmol photons m^{-2} s^{-1} and irradiance at saturation is 90-160 µmol photons m^{-2} s^{-1} . *Furcellaria* has a stiff thallus and many small branches. This structure is favourable for distributing light in the canopy and the species should be able to sustain dense populations.

Phycodrys /Delesseria community
Phycodrys rubens and *Delesseria sanguinea* are sublittoral species found mainly between 5 and 19 meter. The minimum light requirement for *Phycodrys* and *Delesseria* is *6-19* µmol photons m^{-2} s^{-1} and photosynthesis is saturated at about 44-134 µmol photons m^{-2} s^{-1}. The fine, thin thallus with low thallus specific carbon and low respiration rates makes this species able to grow in low light. The thin blade-like thallus is optimal to capture and utilise the low amount of light in the deep water.

A species like *Delesseria sanguinea* is adapted to life with low light availability and very sensitive to high light levels (Hanelt et al 1993). The species has the ability for thallus growth early in spring when temperature is still suboptimal for growth (Molenaar and Breeman 1997) and form new blades in darkness by using reserve material that has accumulated in the midribs (Kain 1984, Lüning and Schmitz 1988).

Saccharina community
Saccharina are growing deepest in the water between 12 and 19 m in Fehmarnbelt. The minimum light requirement for this species is 5-33 µmol photons m^{-2} s^{-1} and photosynthesis is saturated at about 10-80 µmol photons m^{-2} s^{-1}. The species are known to be able to grow in the dark using stored reserves (Dunton 1996).

Filamentous algae community
Filamentous species are found along most of the depth range and often grow epiphytic on other species. The minimum light requirement for selected species in this group is 15-23 µmol photons m^{-2} s^{-1} and photosynthesis is saturated at about 90-325 µmol photons m^{-2} s^{-1}.

Table 5-3 Overview of growth and light requirement characteristics used for the functional groups of benthic flora in the model. I_k: Irradiance at light saturation and I_c: Irradiance at light compensation.

Functional group	**Represented by**	**Max growth rate (d^{-1})**	**I_k (µmol photons m^{-2} s^{-1})**	**I_c (µmol photons m^{-2} s^{-1})**
Filamentous algal species	*Ceramium*	0.255	107	22
Corticated algae	*Furcellaria*	0.0694	116	16
Corticated, sheet formed algae	*Delesseria*	0.1516	93	3
Flowering plants	Eelgrass	0.09	150	12

The light compensation and saturation used in the model defines the sensitivity of the benthic flora and makes a sensitivity classification irrelevant for suspended sediment.

5.3 Sedimentation

Resuspension and deposition of sediments are a natural processes in coastal shallow water habitats driven by degree of exposure, wind and wave actions, bed shear stress, coastal current regime and substrate composition. Sedimentation layers up to 5 cm thickness can be noticed at exposed sites during or after strong wind events (Figure 5-2). Such depositions can be resuspended or transported further, if shear stress is high enough. Vegetation communities/species, characteristic for shallow water exposed sites, are therefore adapted to a certain degree to sedimentation events and the physical stress this implies.


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Figure 5-2 Furcellaria lumbricalis (left side) and Ahnfeltia plicata (right side) buried within a sand layer of ~ 5 cm thickness. Both species are natural vegetation components of exposed shallow water sites and have rounded thalli with a stiff, robust surface structure. Growth heights vary between 15-20 cm for Furcellaria and 5–10 cm for Ahnfeltia.

Sedimentation is also occurring naturally at deeper waters with limited near-bottom currents (Figure 5-3). Deposited layers are thinner (1–2 mm) and grain sizes of deposited sediments are smaller (silt, clay, organic matter) compared to shallow waters. Sedimentation in deeper waters is mainly caused by an accumulation of organic matter, which origins in the photic zone. Vegetation communities/species, characteristic for deeper water sites, are therefore adapted to a certain degree to silt sedimentation events and the physical stress this implies.

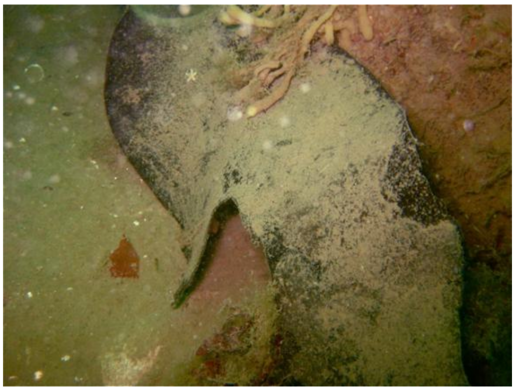


Figure 5-3 *Phycodrys rubens (left side) and Saccharina latissima (right side) covered with a fine silt layer of 1–2 mm thickness. Both species are natural vegetation components of deeper waters and have foliose thalli.*

The sensitivity of a species towards sedimentation is linked to its physical intolerance and reproductive strategy (Airoldi 2003). Several parameters have influence on physical intolerance and reproductive strategy:

Plant size and growth form: High, erect growing macrophytes can withstand thicker sediment layers than smaller growing forms or forms lying on the substratum (Littler et al. 1983). Macrophytes with thick, leathery or corticated thalli are robust and more resistant to physical stress than thin, fragile thalli. Rounded, low-branched thalli offer less surface area for sedimentation than blade-like forms or fine filamentous, highly branched thalli (Airoldi 1998).

Storage capacity (biomass per volume): Perennial species with a high biomass per single plant have the ability to build up resources and can compensate periods with reduced production better than species without resources (Lüning 1985).

Photosynthesis/Growth rates: Species with a high production rate can compensate unfavourable time periods faster than species with low production rates (Lüning 1985).

Length of growth period: Species with long or repeated growth periods can compensate unfavourable time periods better than species with a distinct short growth period.

Length of recruitment period: Species with long or repeated recruitment periods are not as sensitive to sedimentation as species with short restricted periods of recruitment, simply because of the longer time available for recruitment.

Reproductive modus: Species with more than one reproductive modus (vegetative and sexual reproduction) have a higher dispersal capability and are most tolerant to sedimentation (Eriksson & Johansson 2005) and species with very complex reproductive strategies are more sensitive than species with simple strategies (Lüning 1985).

This reveals how complex it is to define the sensitivity of macrophytes with regard to sedimentation. For most of those parameters only qualitative expert statements are available, often only for single species or for other marine areas than the Baltic. As the environmental components in the Baltic are already living under a high stress regime due to the reduced salinity, each additional stressor has more severe effects making it difficult or even impossible to adopt references from other marine areas. Growth reduction and a reduced vitality is a general attribute of Baltic organisms compared to fully marine areas (Remane & Schlieper 1958).

The different vegetation communities are classified separately into four levels of physical intolerance and recovery, respectively, based on expert judgment of the available knowledge. The classification is described in Table 5-4.

Table 5-4 Definitions of intolerance to sedimentation and classification of communities into four classes of physical intolerance

	Intolerance
Very high	Small, erect macroalgae (< 10 cm), fragile structure with no ability to store resources, which are affected by low degree of sedimentation. Filamentous algae community
High	Medium sized, erect macroalgae (> 10 cm), fragile foliose structure, a resulting high effective surface area and a low ability to store resources, which are affected by medium degree of sedimentation. *Phycodrys/Delesseria* community or Medium sized, erect angiosperms/charophytes (>10 cm), fragile structure, a medium effective surface area, low ability to store resources, which are affected by medium degree of sedimentation. Tasselweed/ dwarf eelgrass community

	Intolerance
Medium	Medium sized, erect macroalgae (> 10 cm), robust structure, a low effective surface area and a certain ability to store resources, which are affected only by high degree of sedimentation. *Furcellaria* community or Bottom lying macroalgae (less than 10 cm height above seabed), robust, foliose plant structure, a resulting high effective surface area and a high ability to store resources, which are affected by high degree of sedimentation. *Saccharina* community or Large, erect angiosperms (> 40 cm) with a fragile plant structure, ability to store resources and affected only by very high degree of sedimentation. *Eelgrass, Eelgrass/algae* community
Minor	Large (> 40 cm height) and erect plants, robust structure, a low effective surface area and a high ability to store resources, which are affected only by very high degree of sedimentation. *Fucus* community

Eelgrass and eelgrass/algae community: The key species (*Zostera marina*) is erect growing and can reach mean plant heights of 50 cm in the Baltic (Jegzentis 2005). The plant body has a low surface area, as it is a low-branched form with a narrow flattened thallus. The thallus is very thin and the structure fragile. In sheltered areas eelgrass is often overgrown by epiphytic algae. These epiphytic algae increase the area exposed to sedimentation significantly. Eelgrass has the ability to store resources within its rhizomes. The photosynthetic rate is low (41 µmol O_2 kg^{-1} DW s^{-1}, Lee et al. 2007) and growth has a long break during winter (Sand-Jensen 1975). The physical intolerance of the *eelgrass* and *eelgrass/algae* community is classified as medium.

Filamentous algae community: The key species of this community are erect growing but seldom reach mean sizes > 10 cm (Pankow 1990). The plant bodies have a high surface area, as they are highly branched with rounded thalli. The plant surface/thickness is thin and fragile. Their storage capacity is low (Lüning 1985). The photosynthetic rate is very high (up to 181 µmol O_2 kg^{-1} DW s^{-1}) and growth can take place from early spring until late summer or even autumn (King & Schramm 1976). The physical intolerance of the *filamentous algae* community is classified as very high.

Fucus community: The key species of this community are erect growing and can reach mean plant heights of 50 cm (Pankow 1990). The plant body has a low surface area, as it is a low-branched form with narrow flattened thalli. The plant bodies are very robust, thick and leathery. They have a high storage capacity and a high biomass per volume. The photosynthetic rate is low (56 µmol O_2 kg^{-1} DW s^{-1}, Johansson & Sneoijs 2002), but growth can take place throughout the year (Lehvo et al. 2001). The physical intolerance of the *Fucus* community is classified as low.

Furcellaria community: The key species of this community is erect growing and can reach mean plant heights of 15–20 cm in the Baltic (Pankow 1990, Fürhaupter – own observations). The plant body has a low surface area, as it is a low-branched form with rounded thalli. The plant surface is thick and stiff. The biomass per volume value is lower than for *Fucus* but still one of the highest for Baltic macrophytes (mean biomass 528 g DW m^{-2}, baseline investigation data). The photosynthetic rate is very low (21 µmol O_2 kg^{-1} DW s^{-1}, Johansson & Sneoijs 2002), but growth can take place throughout the year (King & Schramm 1976, Dixon & Irvine 1977). The physical intolerance of the *Furcellaria* community is classified as medium.

Phycodrys/Delesseria community: The key species of this community are erect growing and can reach mean plant heights of 10–15 cm in the Baltic (Pankow 1990). The plant body has a high surface area, as they are branched forms with broad flattened, blade-like thalli. The plant surface is thin and fragile. The biomass per volume value is medium (mean biomass 295 g DW m^{-2}, baseline investigation data) and the photosynthetic rate is also medium (82 µmol O_2 kg^{-1} DW s^{-1}, King & Schramm 1976, Johansson & Sneoijs 2002). Growth shows a short break during summer (King & Schramm 1976, Bird et al. 1991, Molenaar & Breeman 1997). The physical intolerance of the *Phycodrys/Delesseria* community is classified as high.

Saccharina community: The key species of this community is lying on the bottom and is therefore only reaching up to 10 cm above the sea bottom (although the medium plant length is about 70 cm, Fürhaupter – own observations). The plant body has a high effective surface area, as it is unbranched with a broad flattened, blade-like thalli. The plant surface is thick and leathery. The biomass per volume value is low (mean biomass 167 g DW m^{-2}, baseline investigation data) and the photosynthetic rate is also low (37 µmol O_2 kg^{-1} DW s^{-1}, Johansson & Sneoijs 2002). Growth can take place throughout the year (John et al. 1970). The physical intolerance of the *Saccharina* community is classified as medium.

Tasselweed/dwarf eelgrass community: The key species of this community are erect growing and can reach mean plant heights of 15–20 cm in the Baltic (Fürhaupter – own observations). The plant bodies have a small effective surface area, as they are low-branched forms with very narrow thalli. But overgrow with epiphytic algae may increase the effective surface area significantly. The plant surface is thin and fragile. The biomass per volume value is the lowest of all communities (mean biomass 85 g DW m^{-2}, baseline investigation data). The photosynthetic rate is high (112 µmol O2 kg^{-1} DW s^{-1}, Lee et al. 2007) and growth has a long break during winter (Malea et al. 2004). The physical intolerance of the tasselweed/dwarf eelgrass community is classified as high.

In chapter 5.1 the second aspect of sensitivity, recovery time, has been described in detail. Results for the different communities are listed in Table 5-1 and Table 5-4.

Using the linking matrix for intolerance and recovery time, described in chapter 3.5 the vegetation communities in the assessment area are classified as shown in Table 5-5. Figure 5-4 show the the community-specific sensitivity levels of the benthic vegetation communities (section 1.2)

Table 5-5 Sensitivity of benthic flora communities towards sedimentation.

Recovery time	**Intolerance**			
	Very high	**High**	**Medium**	**Minor**
Very high (very long)	Very high	Very high	High **Eelgrass** **Eelgrass/algae**	Medium
High (long)	Very high	High	Medium ***Furcellaria***	Minor ***Fucus***
Medium (medium)	Medium	Medium **Tasselweed/ dwarf eelgrass** ***Phycodrys/ Delesseria***	Medium	Minor
Minor (short)	Minor **Filamentous algae**	Minor	Minor ***Saccharina***	Minor

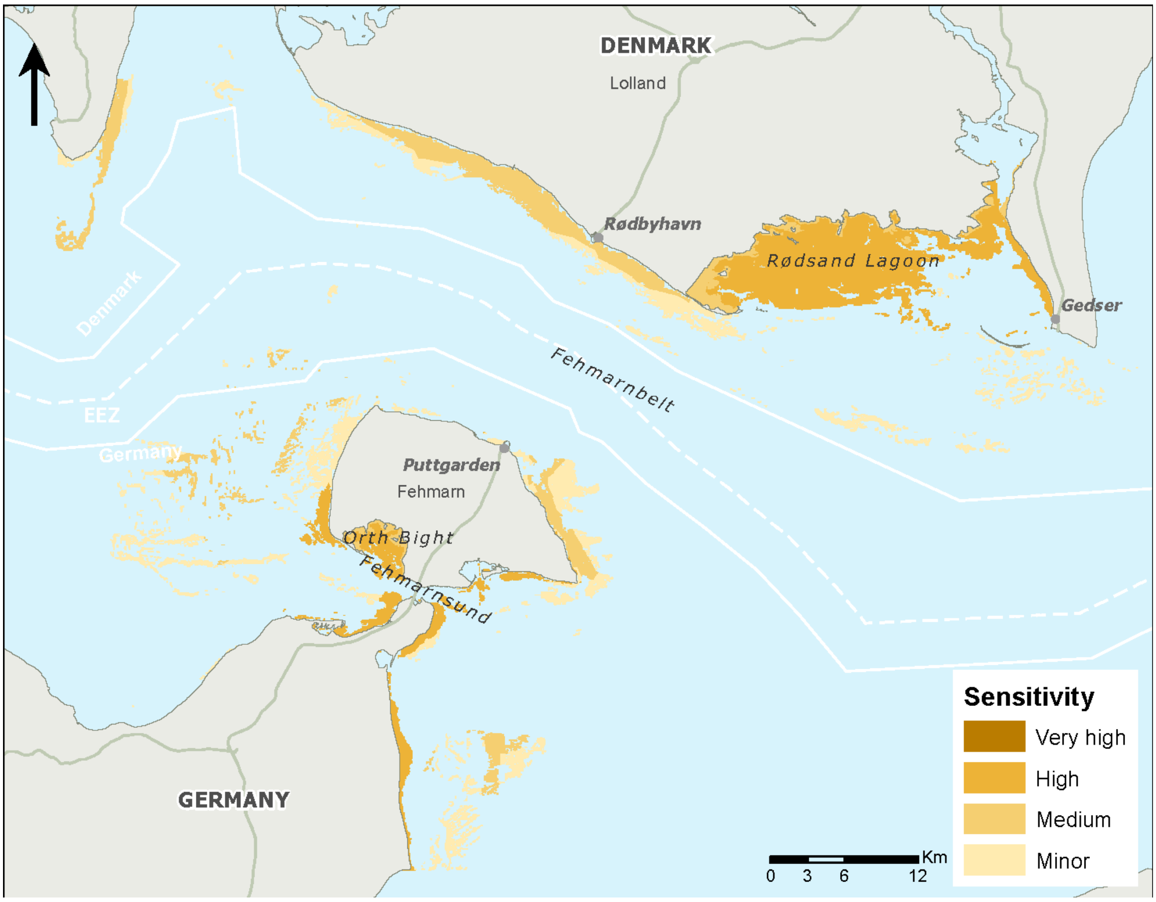


Figure 5-4 Illustration of the sensitivity classes depending on the distribution of flora communities.

5.1 *Confidence/ evidence*

In general, the confidence in the assessment depends on the quality and robustness of the baseline data ad on available evidence for the effect of a pressure on species or communities.

The baseline investigations for benthic flora conducted in 2009–2010 provided good quality and robust baseline data for all assessments.

The confidence can be graded been in three levels:

The level of confidence is high, if relationships relating to the pressure indicator (e.g. reduced light availability) to the function of the community (e.g. photosynthesis) in general are well understood and documented.

The level of confidence is moderate if the impact of a pressure is assessed by inferring/extrapolating from the effect of similar pressures or related species. Or if the pressure is very low and expert judgement has been used to assess the impact.

The level of confidence is low if the assessment is based on information on biological characters (e.g. life history, size and functional forms) of the species.

Table 5-6 Overview of confidence of impact assessments.

Pressure	Level of confidence	Comment
Suspended sediment	High	Sensitivity based on dose response relationships from the literature and experiments.
Sedimentation	Low	Sensitivity defined based expert judgment considering the size and robustness of the benthic vegetation as well as the level of natural sedimentation in their specific environments.
Nutrients from spilled sediment	High	General well documented relationships between nutrients and response of benthic flora. Pressure low.
Toxic substances	High	Based on EQA
Construction vessels and imported material	Moderate	Expert judgement. Pressure low.
Footprint	High/ moderate	Loss high / recovery for temporary footprints moderate
Solid substrate	Moderate	Areas well know. Based on biomass-depth relationships from natural habitats.
Hydrographical regime and water quality	Moderate	Expert judgement. Pressure low.
Seabed and coastal morphology	Moderate	Expert judgement. Pressure low.
Drainage	Moderate	Expert judgement. Pressure low.

6 ASSESSMENT OF 0-ALTERNATIVE

All impacts from the construction phase are compared to the baseline conditions without forecasting as described in (FEMA 2013a). The baseline conditions serve as the 0-alternative. Thus, the assessment of the 0-alternative is identical to the description of the baseline conditions (FEMA 2013a).

If there will be no tunnel or bridge construction the ferry operation will continue. No adverse effects on benthic flora are predicted from continuing the ferry operation.

7 ASSESSMENT OF IMPACTS OF MAIN TUNNEL ALTERNATIVE

7.1 Suspended sediment

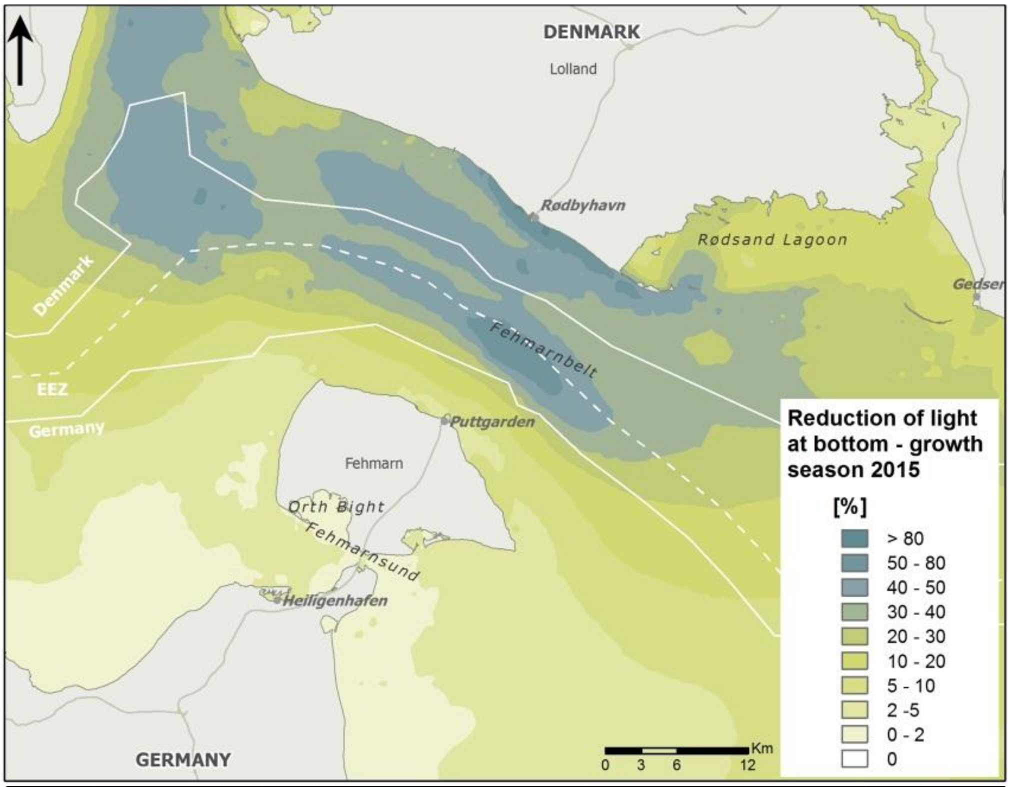
7.1.1 *Magnitude of pressure*

Reduced light availability due to sediment spill is highest during the first approx. 1½ years of the construction phase. The following years the dredging and thus the sediment spill is smaller and causing only small or no reductions in average light availability for the benthic flora.

Timing of the dredging is important for the degree of impairment. The assumption of this impact assessment is that dredging will start in October 2014 and end in 2019. Should the dredging start at another time of the year the outcome of the impact assessment may change.

The overall pattern in the spatial and temporal reduction in light availability to the benthic flora during the dredging period is shown in Figure 7-1 and Figure 7-2. Near the alignment at the Lolland coast, the spilled sediment is transported along the shoreline and regular re-suspension results in high concentrations of suspended sediment in the bottom layers and a high reduction of light available for growth of benthic flora. The average reduction of light in the growth season (March – September) is between 20% and >80% along the Lolland coast during the 2015 between 10% and 30-40% in 2016 and between 0-2% and 5-10% in 2017 (see Figure 7-1).

West of the alignment the reduction in light extends into the deeper parts of the Great Belt (Figure 7-1). The complete extent of the suspended sediment spill can be seen in (FEHY 2013c). The FEHY sediment spill modelling and FEMA vegetation model are in principle covering this area. However, the benthic vegetation model has not been calibrated for this area and the results therefore have to be used with caution. If benthic vegetation occur just outside the assessment area reduction are predicted to be between 0 and 20% at the end of growth season the first year, cause a minor degree of impairment. The impact is expected to gradually decrease with distance from the Fehmarnbelt, the impact on the benthic flora communities outside the comparison area will be minor to negligible and insignificant.


DENMARK
Lolland
Rødbyhavn
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Denmark
EEZ
Germany
Puttgarden
Fehmarn
Orth Bight
Fehmarnsund
Heiligenhafen
GERMANY
0 3 6 12 Km
Reduction of light at bottom - growth season 2015
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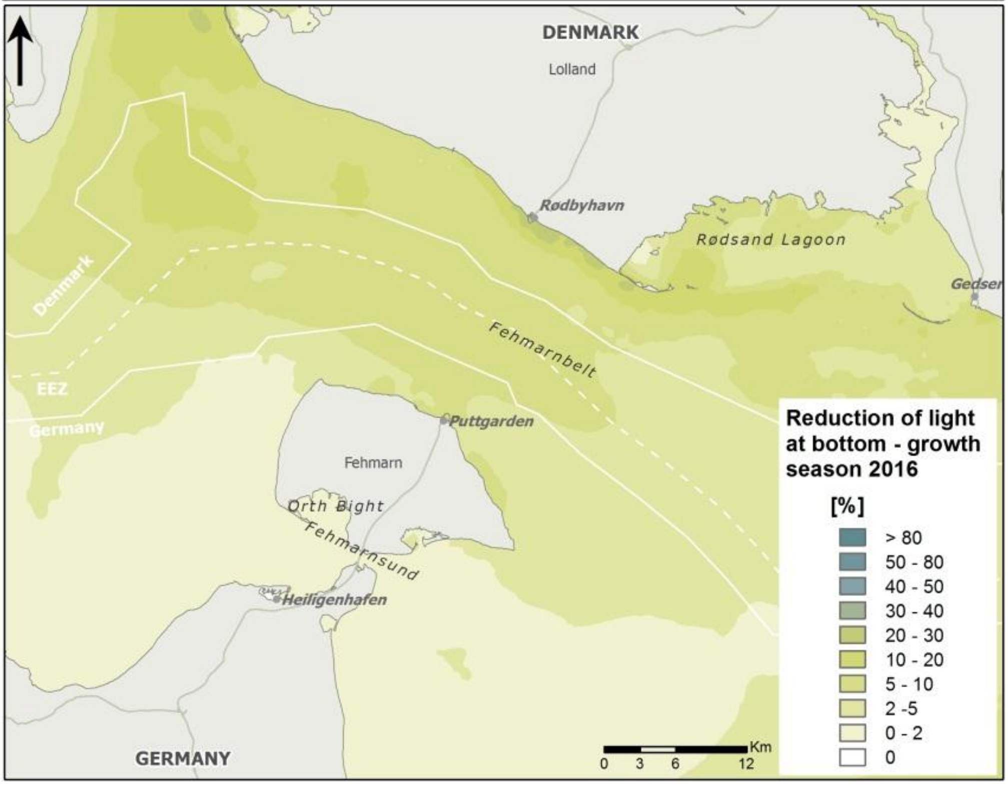
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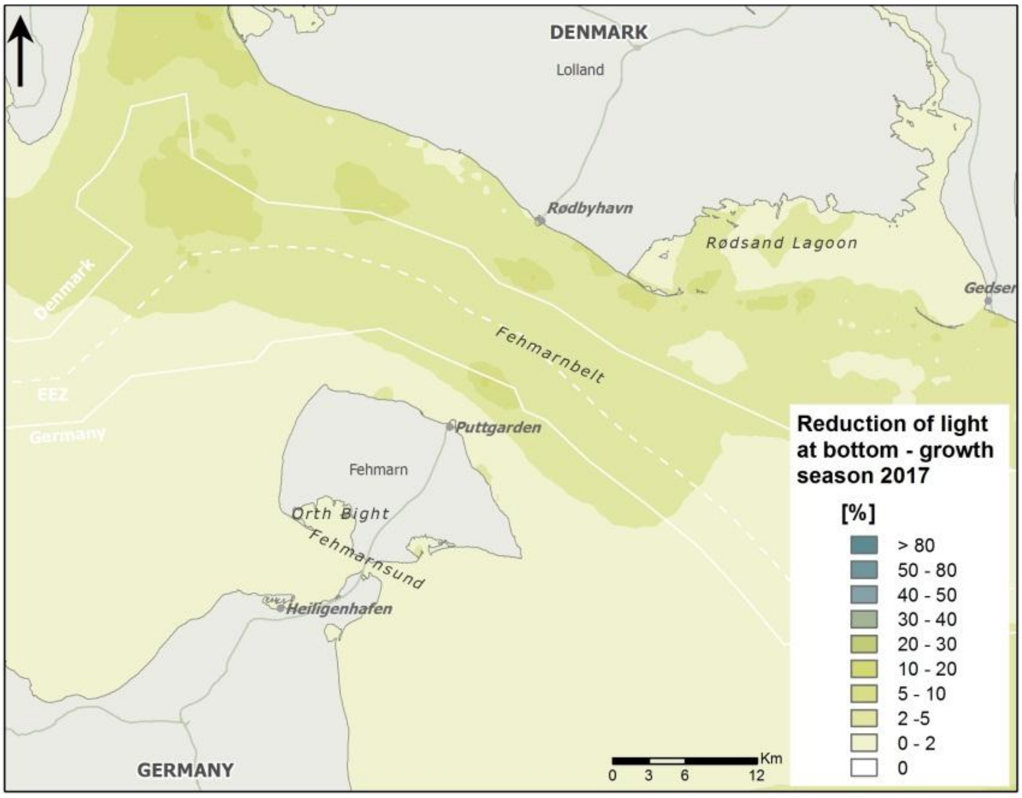


Figure 7-1 Reduction of light availability (%) for benthic flora in the Fehmarnbelt area during the growth season (May-September) 2015 (top), 2016 (middle) and 2017 (lower).

Light reduction is also relatively high in Rødsand Lagoon because the sediment that enters here is continuously being re-suspended until it finally is transported out of the lagoon; or it settles in the deeper sedimentation areas in the western part of the lagoon. Thus, reductions in light are between 5-10% and 30-40% in 2015 and between 0-2% and 10-20% in 2016.

Along the German coast, the reductions in light is very limited; 2-10% reduction in 2015 and 2016 and 0-2% in 2017. A low reduction in light is related to limited construction activities on the German coast; in contrast, activities on the Danish side is major including establishment of large reclamation areas and an access channel to the production site.

In the remaining part of the construction phase dredging activities are much lower and the reduction in light available for the benthic flora smaller compared to the first and second year (see Appendix B).

Comparing the temporal development in the light availability at selected positions during the dredging period with the reference situation (no dredging) corroborates the pattern (Figure 7-2). The highest reductions occur in 2015 along the Lolland coast, while the effect along Fehmarn is very limited. In the second year the magnitude of change is markedly reduced, resulting in reductions compared to the reference at 5.6-9.3% at the selected positions. The following year the reduction in light availability is only small.

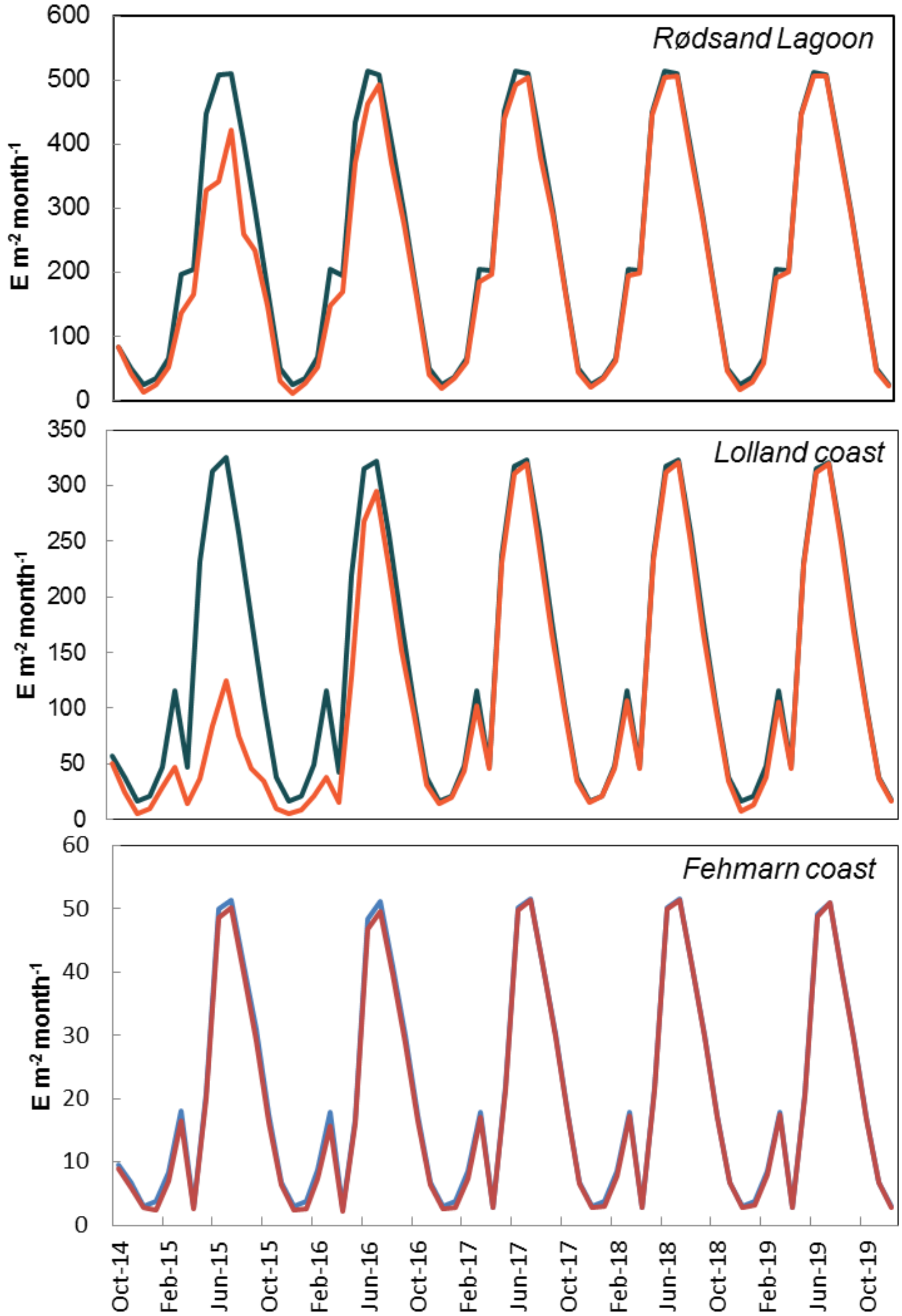


Figure 7-2 *Time series showing the light availability (E m^{-2} $month^{-1}$) at seabed at reference conditions (no sediment spill, blue lines) and during construction of the tunnel (red lines). The time series are extracted from selected positions in Rødsand Lagoon (upper), at the Lolland coast (middle) and at the Fehmarn coast (lower).*

7.1.2 *Degree of impairment*

The FEMA model simulations predict that the response of benthic flora to increased concentrations of suspended sediment is highest in the two first years of the tunnel construction phase. During the following years (2017-2019), the benthic flora have recovered to a state close to the for the reference situation with no sediment spill.

The reduction in above ground biomass (% of reference biomass modelled without sediment spill) as well as the degree of impairment is illustrated in Figure 7-3 for 2015 and in Figure 7-4 for 2016. The impairment is describe in more details below and in Appendix C additional figures can be seen showing predicted reduction in biomass (%) and the corresponding degrees and severity of impairment for the years 2017 to 2019.

The degree of impairment from 2015–2019 is summarized in Table 7-1. The areas of reduced biomass occupied by different benthic flora community are estimated in Table 7-2.

Near the alignment along the Danish coast, macroalgal biomass at the end of the growth season 2015 will be reduced with 0 to 60% compared to the reference conditions (Figure 7-3). The impact is decreasing with distance to the alignment. The highest reductions (50-60%) occur in small areas close to the alignment. Farther away from the alignment, the maximum biomass reductions are between 25 and 50% and in a larger area east and west of the alignment, the biomass are predicted to be reduced with maximally 10-25%. In Rødsand Lagoon, eelgrass biomass is predicated to be reduced by between 0 and >50 % in 2015. Along the German coast, the reductions in biomass are 0-10% and occur in limited areas.

The pattern of reduction is similar in 2016, but with lesser impact as a consequence of the reduced dredging (Table 7-1 and Figure 7-4). However, in the deeper areas the reductions in biomass is higher than in 2015 and on the Langeland reef and in the deeper areas of Staberhuk biomass there are biomass reductions up to about 16%. In general, a slow return to the reference level is predicted in accordance with the expectation that deep-growing populations should recover slowly due to permanent light limitation of plant growth.

In the following growth seasons (2017-2019), benthic flora biomass is recovering (Table 7-1, Table 7-2 and figures in Appendix C). At the end of the growth season in the third year most of the macroalgal biomass is at the same level as the reference with the exception of some of the deeper areas where recovery as mentioned above is slower.

The biomass reductions correspond to minor to high degree of impairment of the benthic flora in 2015 and 2016. In 2015, an area of 257 ha along the Danish coast near the alignment and in Rødsand Lagoon is impacted with a high degree of impairment (Table 7-1). The areas of medium and minor degree of impairment are also primarily found along the Danish coast; areas with medium impairment are calculated to 4226 ha, while minor degree of impairment occurs in an area of 10258 ha is in 2015. Along the German coast minor degree of impairment are predicted in 1082 ha in the national zone and 80 ha in the German EEZ. No areas are impaired to a very high degree.

In the impacted areas along the Danish coast, *Furcellaria* and filamentous species communities dominate the benthic flora (Figure 1-3). These communities are thus affected by a minor to high degree of impairment in 2015 and

2016 (Table 7-2). The area affected by a high degree of impairment are however small for the both the *Furcellaria* community (143 ha in 2015 and 33 ha in 2016) and the filamentous species community (11 and 3 ha). Minor and medium degree of impairment is predicted in larger areas in 2015. In 2016, integrated effect of recovery of biomass and reduced impact from dredging results in reduction of impacted areas; about 1/3 to ½ of the area impacted in 2015.

The largest impact in the areas of the deep growing benthic flora consisting of *Phycodrys/ Delesseria* and *Saccharina* communities is predicted during the second growth season (2016). These communities are for example growing in the deep water on the east coast of Fehmarn and on Langeland reef (Figure 1-3). The reductions in biomass in these areas correspond to minor degree of impairment and are predicted to occur in a total area of 487 ha.

Table 7-1 Degree of impairment (areas in ha) caused by suspended sediments for the tunnel alternative. The geographical zone Transboundary is left out as no impacts occur in this zone.

	Total	Near zone	Local zone	DK national + EEZ	DE national	DE EEZ
2015						
Very high						
High	251	138	21	251		
Medium	4215	309	1063	4215		
Minor	12322	100	1449	10263	1979	80
Total	**16788**	**547**	**2533**	**14729**	**1979**	**80**
2016						
Very high						
High	53	36	2	53		
Medium	1974	192	178	1974		
Minor	7843	259	1205	7162	600	82
Total	**9870**	**487**	**1385**	**9189**	**600**	**82**
2017						
Very high						
High						
Medium	79	1	13	79		
Minor	2702	15	234	2434	223	45
Total	**2781**	**16**	**247**	**2513**	**223**	**45**
2018						
Very high						
High						
Medium	5	1	2	5		
Minor	1328	0	155	1180	123	26
Total	**1333**	**1**	**157**	**1185**	**119**	**26**
2019						
Very high						
High						
Medium						
Minor	879	1	61	806	60	13
Total	**879**	**1**	**61**	**806**	**60**	**13**

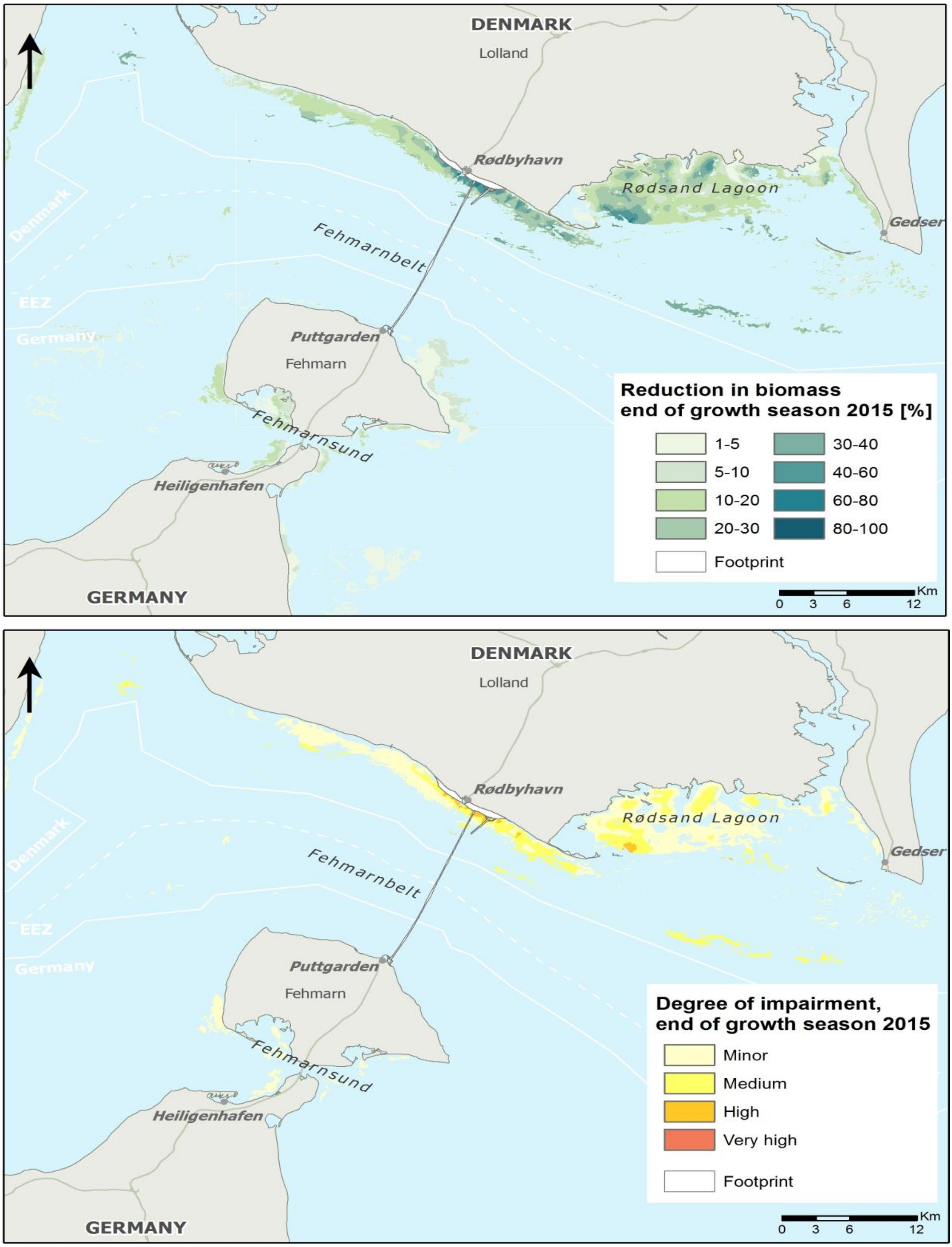
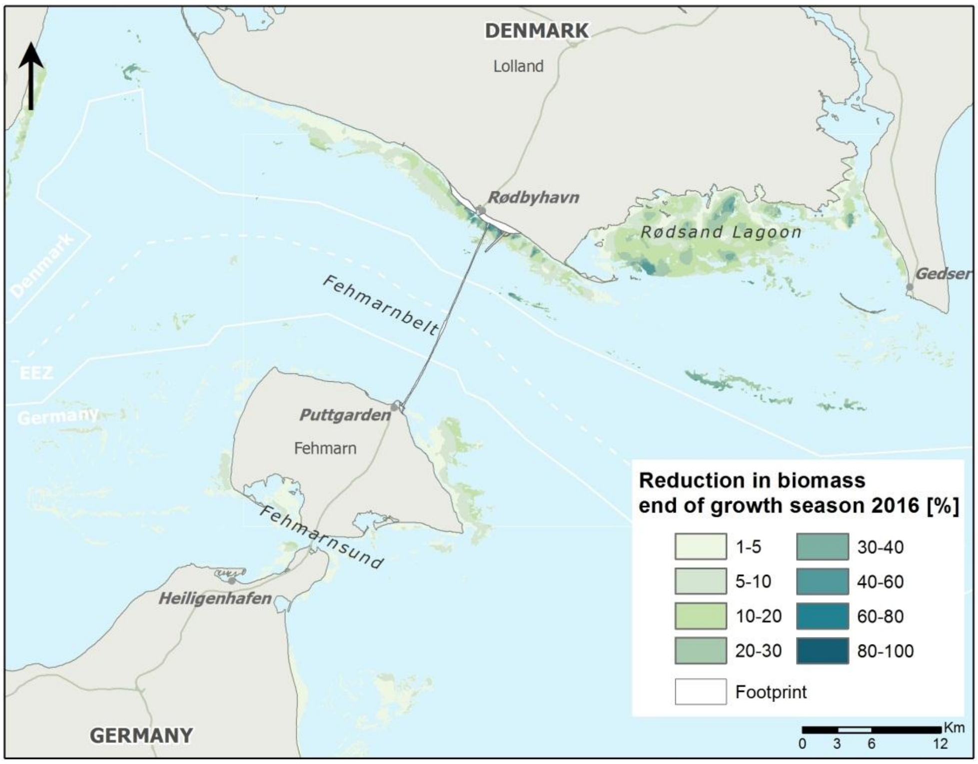


Figure 7-3 Spatial distribution of reduction in benthic flora biomass(above ground) and degree of impairment at the end of the growth season 2015. Similar figures illustrating the impacts in the years 2017, 2018 and 2019 can be seen in Appendix C.



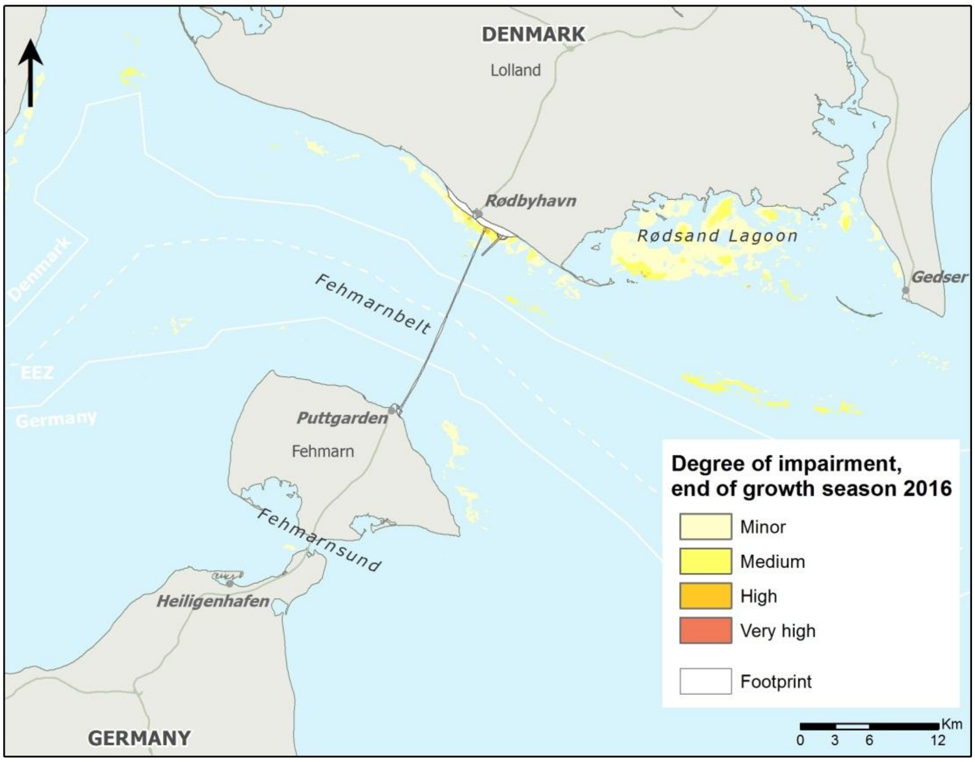


Figure 7-4 Spatial distribution of reduction in benthic flora biomass (above ground) and degree of impairment at the end of the growth season 2016. Similar figures illustrating the impacts in the years 2017, 2018 and 2019 can be seen in Appendix C.

Table 7-2 *Degree of impairment (areas in ha) per community caused by suspended sediment for the tunnel alternative for the period 2015–2019. Calculations are based on reduction of above ground biomass at the end of the growth season (1st of September) compared to the reference conditions with no extra concentrations of suspended sediment.*

Degree of impairment	**Community area, ha**				
	2015	**2016**	**2017**	**2018**	**2019**
Eelgrass					
Very high					
High	98	16			
Medium	1922	912	62	2	
Minor	7206	5438	1471	537	353
Eelgrass/ algae					
Very high					
High					
Medium					
Minor	891	34	13	4	
Tasselweed/dwarf eelgrass					
Very high					
High					
Medium	22	14			
Minor	135	60	6		
Filamentous species					
Very high					
High	11	3			
Medium	1667	834	17	3	
Minor	1354	722	867	595	411
Furcellaria					
Very high					
High	142	33			
Medium	604	208			
Minor	2127	631	3		
***Phycodrys/ Delesseri*a**					
Very high					
High					
Medium		0.8			
Minor	487	446	128	82	65
Saccharina					
Very high					
High					
Medium					
Minor	122	508	215	110	49

At the end of the growth season of the first and second year of the tunnel construction (2015 and 2016), eelgrass above ground biomass is predicated to be reduced by between 0 and >50% (max app. 60%) in the Rødsand Lagoon. The largest reductions are predicted in small areas close to the western opening where spilled sediment enters the lagoon. In the main part of the lagoon, the reduction in biomass is between 10 and 20%. Such reduction corresponds to minor to high degree of impairment of the eelgrass community in Rødsand Lagoon in 2015. The model also predicts a small reduction in biomass of eelgrass south of Fehmarn corresponding to a minor degree of impairment. In 2016, the impact shows the same pattern but smaller areas are impacted.

Recovery of eelgrass is slower than for other benthic flora, and the reduction in biomass takes several years to recover. In 2019 most of the biomass has recovered and minor degree of impairment is predicted in an area of 353 ha.

In the tasselweed/ dwarf eelgrass community small areas are impacted in the Rødsand Lagoon in 2015 and 2016. Medium degree of impairment occurs in 22 ha and minor degree of impairment in 135 ha in 2015. In 2017, degree of impairment never exceed minor and the minor impaired area constitutes 6 ha. In the following years, impacts are not predicted. The very small impact is expected, as this community is restricted to the shallowest eastern parts of the sheltered lagoons. Light is not be the main limiting factor for growth in these shallow waters, where physical disturbance from waves or grazing by birds is much more important for biomass variations.

Model results compared to expectations

The modelled pattern of benthic flora biomass reduction and recovery are in accordance with expectations. In general, if macrophytes are exposed to the same relative reduction in light availability, the impact on biomass should be smallest for species with low light requirements or shallow water communities that normally are less light limited. Contrary, biomass reductions should be highest in populations of species with high light requirements and in communities growing in deep water where light availability is constantly limiting photosynthesis and growth.

Flowering plants with roots and rhizomes have a higher light requirement than macroalgae and should thus be the most sensitive species to reductions in light availability. This is also evident from the model results as the eelgrass was sensitive to the relatively small reductions in light availability. The response of eelgrass is also in accordance with literature (Dennison and Alberte 1982, Moore and Wetzel 1999, Bintz and Nixon 2001, Ochieng et al 2009), although direct comparison of reductions is not possible.

The largest reduction in benthic flora biomass is predicted in communities along the Lolland coast, where the concentrations of suspended sediment in the water column are expected to be high during the first year of the construction phase. These shallow water communities are under normal conditions not limited by light availability and biomass/coverage is often high despite high loss rates in shallow water due to exposure. Although biomass reductions are high in the first year, a very fast recovery of biomass is predicted in these areas following improved light conditions, reflecting the low sensitivity of these shallow water communities to temporary reduced light availability.

In deep growing macroalgal populations, the light energy absorbed is just enough to sustain a positive balance between production and loss (Markager 1992). Most of the energy is used to maintain the existing biomass and only a small part to increased biomass. Recovery of biomass may therefore be slow due to constant light limitation. As the model only predict small reductions in light availability, only minor reductions of biomass are predicted for these communities, but slow recovery result in slow alleviation of the minor reduction, as expected.

In general, the modelled recovery time is a conservative estimate because the ability of some species to store and use reserves later for maintenance of biomass and growth are not included in the model.

Community structure during recovery
Differences in growth rates may cause differences in relative abundance of the species during recovery. The three macroalgal species included in the ecological model represent species with different light requirements and growth rates. Small ephemeral species have high growth rates. Perennial species have lower growth rates and especially the perennial red algal species *Furcellaria* are known to have a very low growth rate compared to other macroalgae (Austin 1960, Bird et al 1979, Martin et al. 2006).

Figure 7-5 shows the relative abundance of the three model functional groups at three sites dominated by the *Furcellaria* community, close to the alignment at the Lolland coast. The sites are at 4-5 m depth and chosen to represent different degree of impairment. During recovery predictions are a relative higher abundance of filamentous and folious corticated species (*Delesseria*) and a slower recovery of corticated species (*Furcellaria*). However, in all cases the relative abundance is progressing towards the initial composition of the community.

Compared to the natural communities characterised by interaction and competition between many species the ecological model is simple and only including some aspects of interactions between the three model species. Thus, the model is not an optimal tool to predict precise changes in species composition. However, the model results indicate that although the total macroalgal biomass are predicted to recover quite fast from the impact the relative contribution of species in the communities may take longer to return to a state close to the pre-impact.

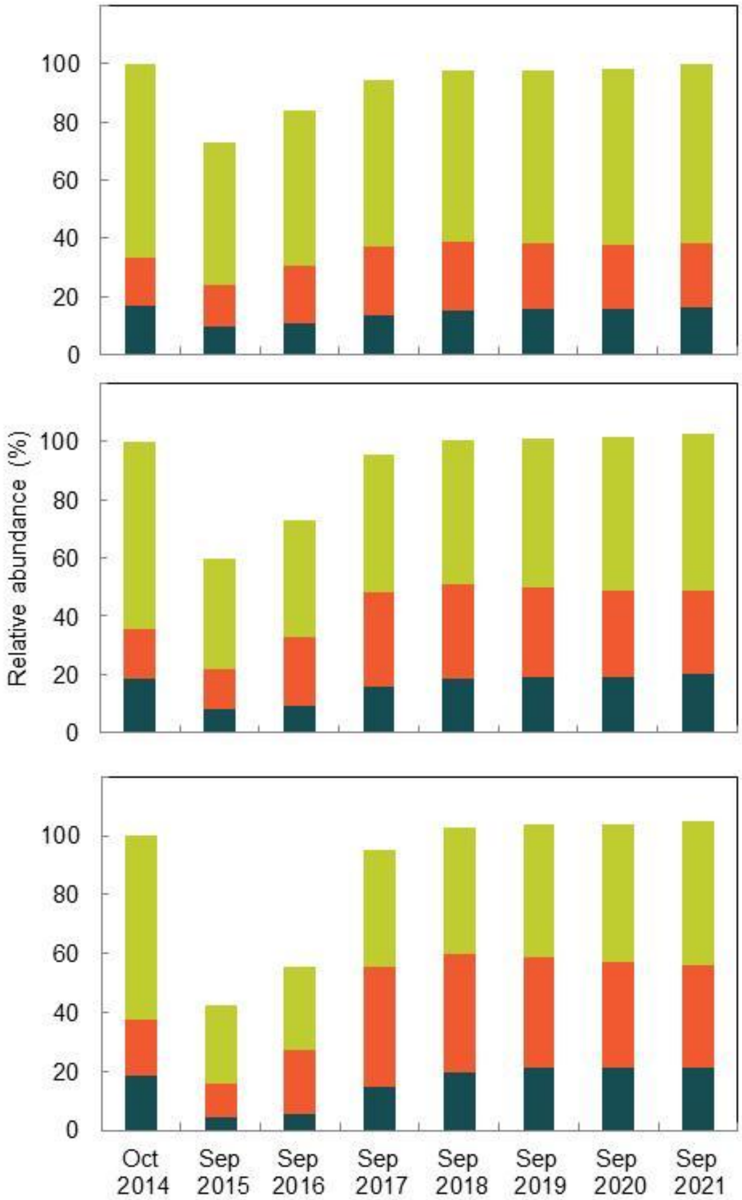


Figure 7-5 Relative abundance of corticated, corticated folious and filamentous species before impact (2014), after impact (primarily in 2015) and during recovery of biomass (2016-2019) at three sites of different depth along the Lolland coast. Green: corticated species, red: folious corticated species and blue: filamentous species.

Eelgrass in Rødsand lagoon

Rødsand lagoon is a protected area and benthic vegetation is an important component of the ecosystem in the lagoon. Special focus is therefore on assessing the risk for the eelgrass population in the lagoon.

The largest sediment spill and thus also the largest light reductions occur during the first 1 ½ years of the construction phase. Correspondingly, it is in this period the largest impact on eelgrass is expected, possibly with a slightly longer temporal extent as a result of the gradual recovery of biomass. As shown in Figure x and y, this is also what the model predicts.

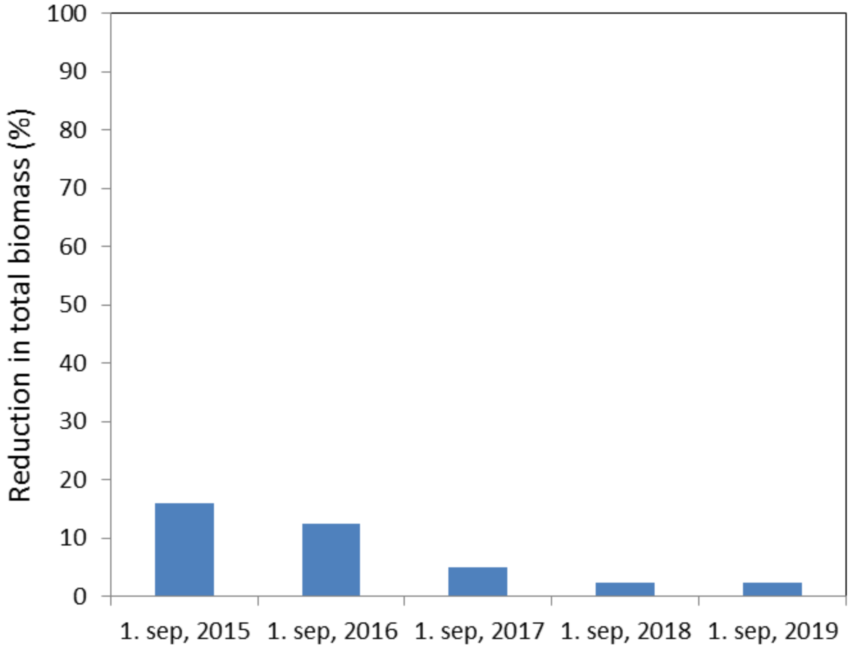


Figure 7-6 Expected reduction in total above-ground biomass of eelgrass in Rødsand Lagoon. The reduction in biomass at the end of the growth season in 2015 is related to the total biomass estimated for baseline conditions.

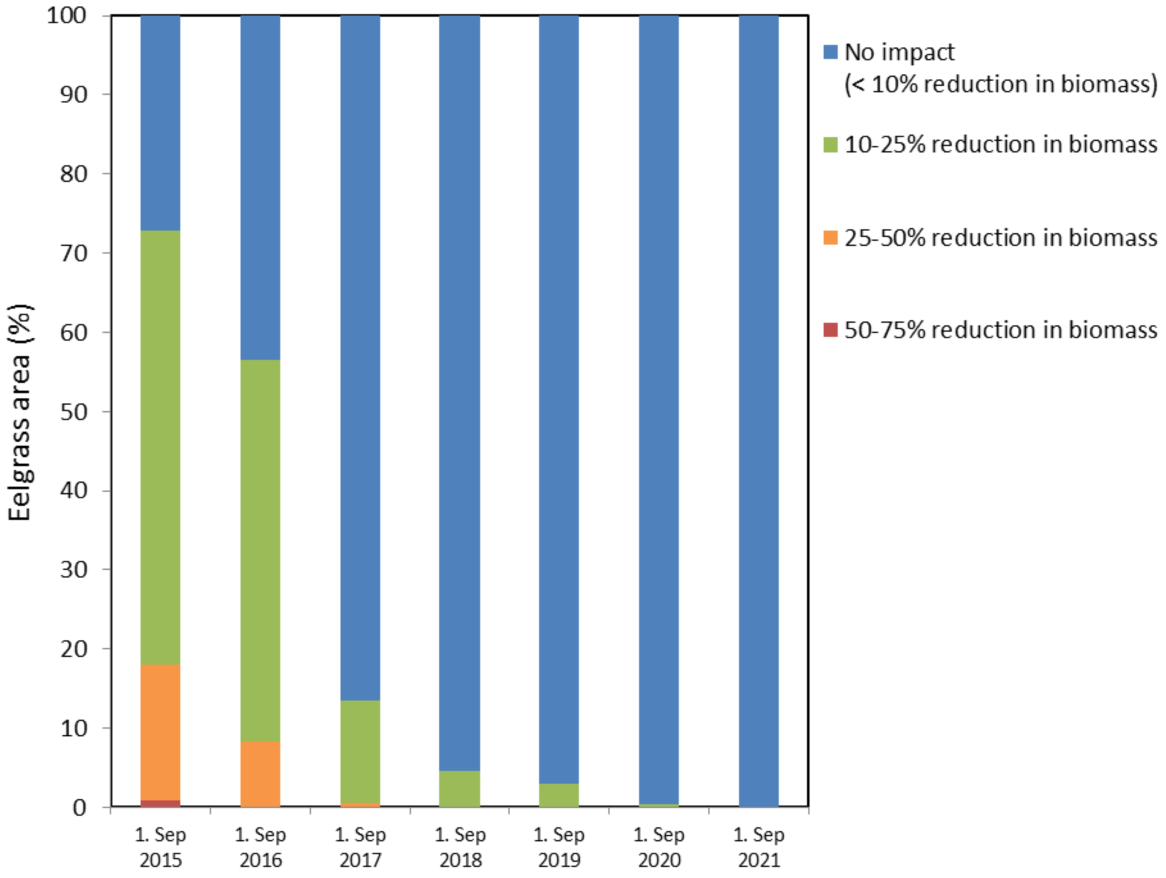


Figure 7-7 Extend of impairment of eelgrass in Rødsand Lagoon due to increased suspended sediment in 7 years after start of the construction phase. The extend is described as % of eelgrass area with a given expected reduction in above ground biomass of eelgrass. The years 2020 and 2021 is after the construction phase and are representing restitution.

The effect of increased sediment on eelgrass biomass can be described by area or by the total biomass. The effect on the total biomass depends on how eelgrass biomass is distributed in the areas with highest impacts.

The largest impact on eelgrass occurs in 2015, when the largest sediment spill and thus the highest impact on the light conditions occur . After this year, there is a substantial improvement of the light conditions and thus also of the growth conditions for eelgrass, and the biomass reduction, that is foreseen in the first year, is being restored.

Although the spill is largest in 2015, the impact is small. The expected reduction in total eelgrass biomass is less than 20% (estimated to be approx. 16%), see Figure 7-6. It is expected that about 25% of the eelgrass area is unaffected (biomass reduction 0-10%), while in approx. 55% of the area the predicted biomass reduction is 10-25%, see Figure 7-7. In less than 20% of the area the expected reduction is 25-50%. Larger reductions (approximately 50-60%) is expected in <1% of the eelgrass area.

By the second year, the effect of sediment spill on the light conditions and thus on growth of eelgrass is reduced. For the total biomass, the expected impact is reduced to less than 15% in the second year and in the third year to approx. 5% relatively to the estimated existing biomass in the lagoon (Figure X). In terms of area, the expected impact in the third year is approx. 13% of the area. In the majority of the area the predicted biomass reduction is 10-25%.

In view of the above, the shading effect of suspended sediment is not, except as described for the first 1 ½ years, expected to influence the general growth conditions of eelgrass. It is therefore considered unlikely, that the temporary effect in the longer term (beyond the first year) will affect the stability of eelgrass in the area.

As described in the previous section, primary respond of eelgrass to reductions in light is reduced growth and thus a reduction in biomass. The expected temporary reduction in eelgrass biomass is not assumed to cause prolonged or permanent effects. The main reason for this assumption is that the reduction in biomass is caused by reduced shoot density and not by a total or partly die out of both leaf and rhizomes.

However, if reductions in light are large or long-termed, there is a risk of eelgrass die out. This means that both the green leaves above the sediment and the rhizomes in the sediment die. Recolonisation will in such case require seed dispersal or rhizome growth into the 'dead' area. Experience show that, if eelgrass dies in larger areas, it can take many years before recolonisation happens. In the following section it is assessed whether the modelled reductions in light can cause completely or partly die out of eelgrass from Rødsand lagoon.

The impacts on eelgrass of reductions in available light depends on how much light the specific stands already have available and this is often very much dependent upon water depth. Eelgrass in Rødsand Lagoon grows from shallow water down to 4-5 m depth. In Denmark the depth limit of main abundance (10% coverage limit) is used to assessments related to the WFD. The maximum depth limit as well as the depth limit of main abundance may be light limited in Rødsand Lagoon and are effected in the same way by changes in light availability. Thus the following assessments related to the depth limit is valid for both depth limits.

Plants growing in shallow water are exposed to nearly full sunlight, while plants growing deeper only receive a fraction of this light due to attenuation in the water column. Thus the plants grow at different levels of available light.

Figure 5-10 in the baseline report provides an overview of the depth variations observed during the baseline study of Fehmarnbelt. The variations are typical of eelgrass. Overall, eelgrass shoot density show a characteristic pattern with increased depth (Krause-Jensen et al 2000). Going from shallow to deep water the upper limit for shoot density in eelgrass is decreasing, suggesting that the maximum shoot density is determined by available light. At a given depth, the shoot density varies below the upper limit, suggesting that in many cases factors other than light determine the actual shoot density. The shoot biomass increases with decreasing density in deeper water, the biomass therefore do not follow the same clear pattern as shoot density with depth.

Dennison et al. (1993) estimated from different observations of the maximum depth to which eelgrass grows, that the minimum light requirement for maintaining eelgrass populations is 18-20% of surface irradiance (%SI).

The survival of eelgrass under different light conditions has also been investigated under experimentally manipulated light conditions. These studies were done in situ or in mesocosms (VKI report 1994, Dennison and Alberte 1982, 1985, van Katwijket al 1998, Moore & Wetzel 2000, Lent et al 1995). The long duration of the experiments, tidal range, fouling and weather makes shading experiments difficult to compare. In addition, it is often difficult to set up more than one or a few replicates at each light level and only selected light levels are tested. Such experiments are therefore not sufficiently accurate to provide solid estimates of light requirements.

However, in summary the shading experiments show that the results depend on the light availability prior to the start of the experiment (e.g. light availability at the depth of the population). Eelgrass growing in shallow water with plenty of light is least sensitive to reductions in light. Only massive shading will lead to light levels below the minimum requirement.

In contrast, eelgrass that is growing in deep water, near the minimum light requirement will be most sensitive to reductions in light availability as even moderate shading may result in insufficient light availability.

Below the risk of population die out due to reduced light availability is assessed in relation to the baseline light conditions and the minimum light requirement of eelgrass in the area.

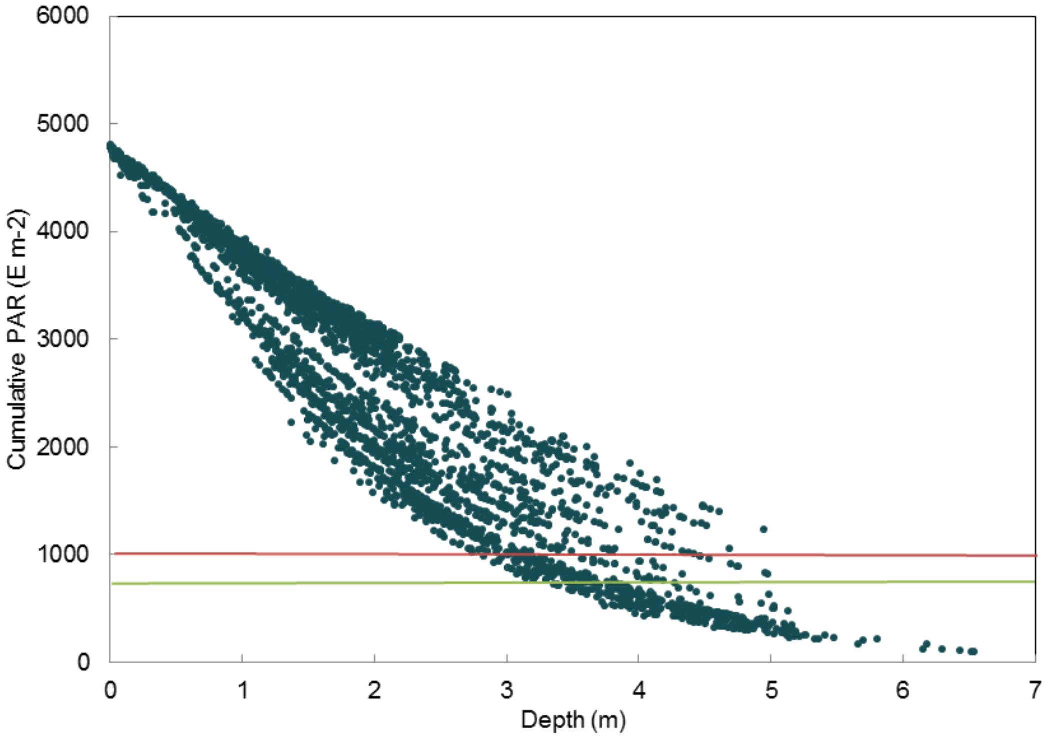
To assess the risk, that the predicted reductions in light will cause eelgrass die out, the light availability for eelgrass growth under baseline conditions have been analysed in more detail. Figure 7-8 shows the modelled cumulative photosynthetic active radiation (PAR) during the growth season (March – September) at the bottom in the eelgrass population in Rødsand Lagoon at baseline conditions. Assuming a minimum light requirement of 15-20% of surface irradiance (%SI, Dennison et al 1993) the minimum light requirement can be estimated to be 750 -1000 E m^{-2} in Rødsand Lagoon (Figure 7-8).

The largest part of the eelgrass is growing in the western part of Rødsand Lagoon. This part of the lagoon is shallow and cumulative PAR during the growth season is well above 750 -1000 E m^{-2} (Figure 7-9, Table 7-3). As explained earlier it is in this part of the lagoon the largest reductions in light are expected (Figure 7-10). Because there is plenty of light in this area, also when light is reduced due to the sediment spill, it is unlikely that the light reductions will cause increased die off where both leaf density and rhizomes are affected. Regrowth the following seasons will ensure that biomass will return to baseline conditions.

The eastern part of the lagoon is deeper and in some areas, eelgrass is growing at light levels close to its minimum light requirement. The area where eelgrass grows below 750-1000 E m^{-2} correspond to app. 8-12% of the area under reference conditions (Table 7-3). This area increases with about 1 % to app. 9-13% during the first year of the construction phase due to shading from spilled sediments.

Table 7-3 Eelgrass areas in ha and % of total eelgrass area below 10% SI, 16% SI and 21% SI.

Cumulative PAR (E m^{-2})		**Reference**		**Tunnel scenario**	
E m^{-2}	**% SI**	**ha**	**%**	**ha**	**%**
<500	10	540	3.7	648	4.5
500-750	16	618	4.3	631	4.4
750-1000	21	552	3.8	575	4.0
>1000		12774	88.2	12629	87.2



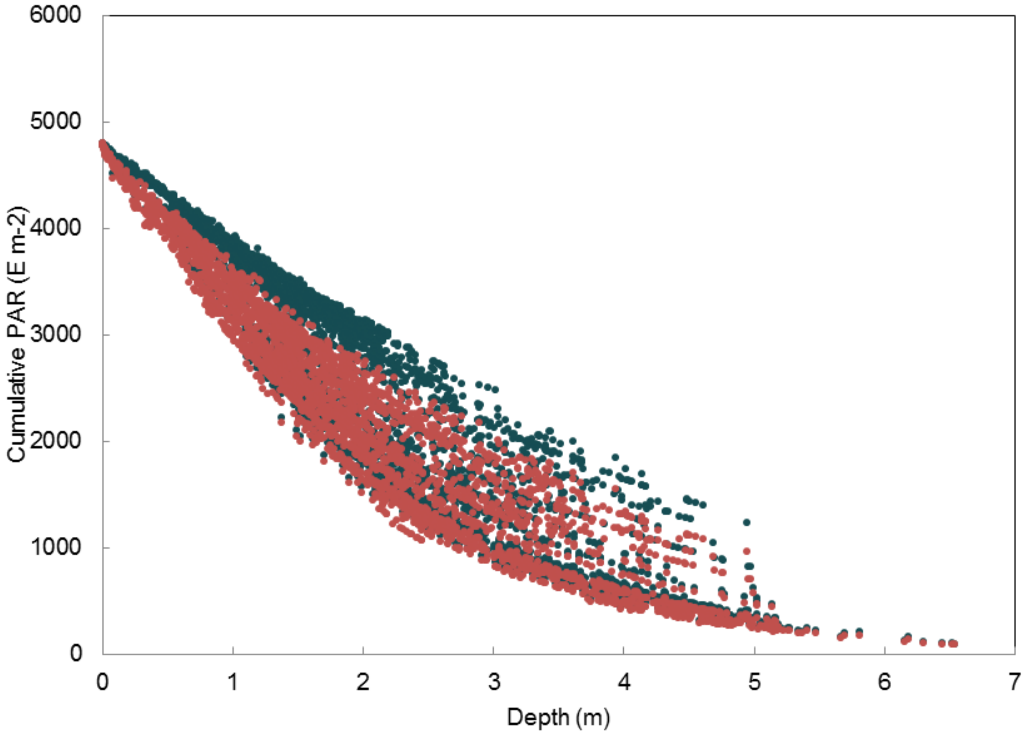
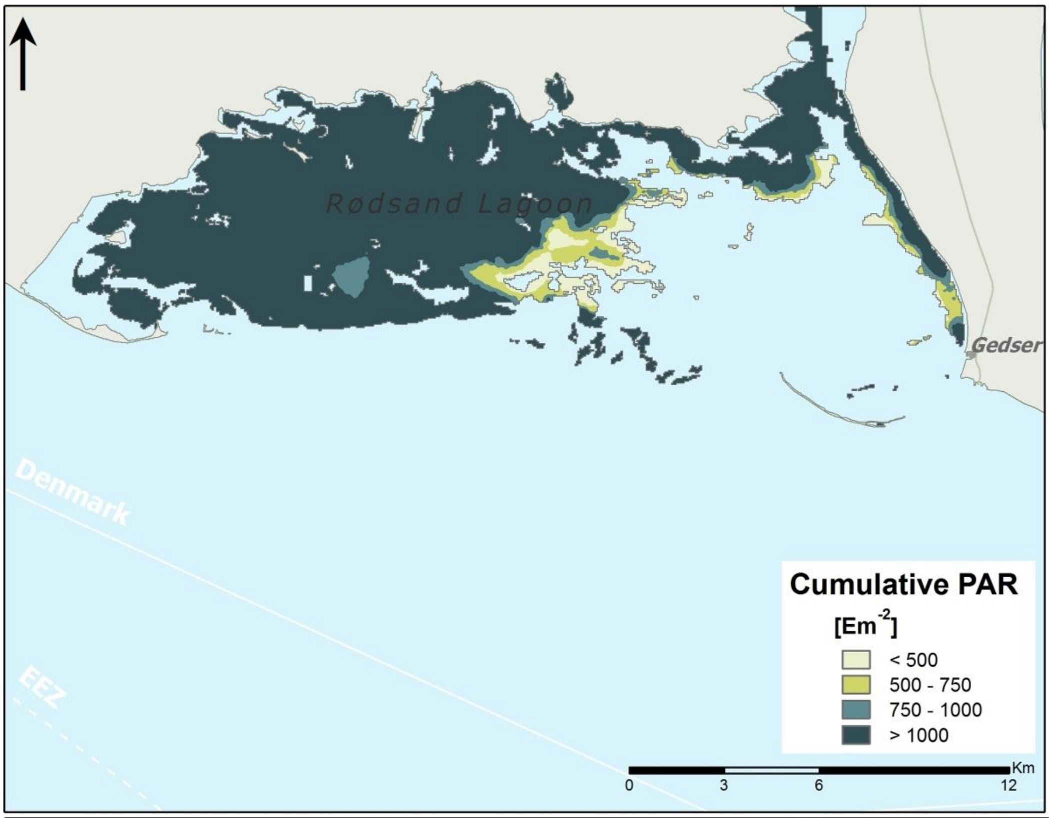


Figure 7-8 Cumulative PAR (modelled) for the growth season (Mar – Sep) 2015, Upper figures shows baseline and lower both baseline (green) and first year of construction phase (red). Horizontal lines delineate 750 (green) and 1000 (red) E m^{-2}.



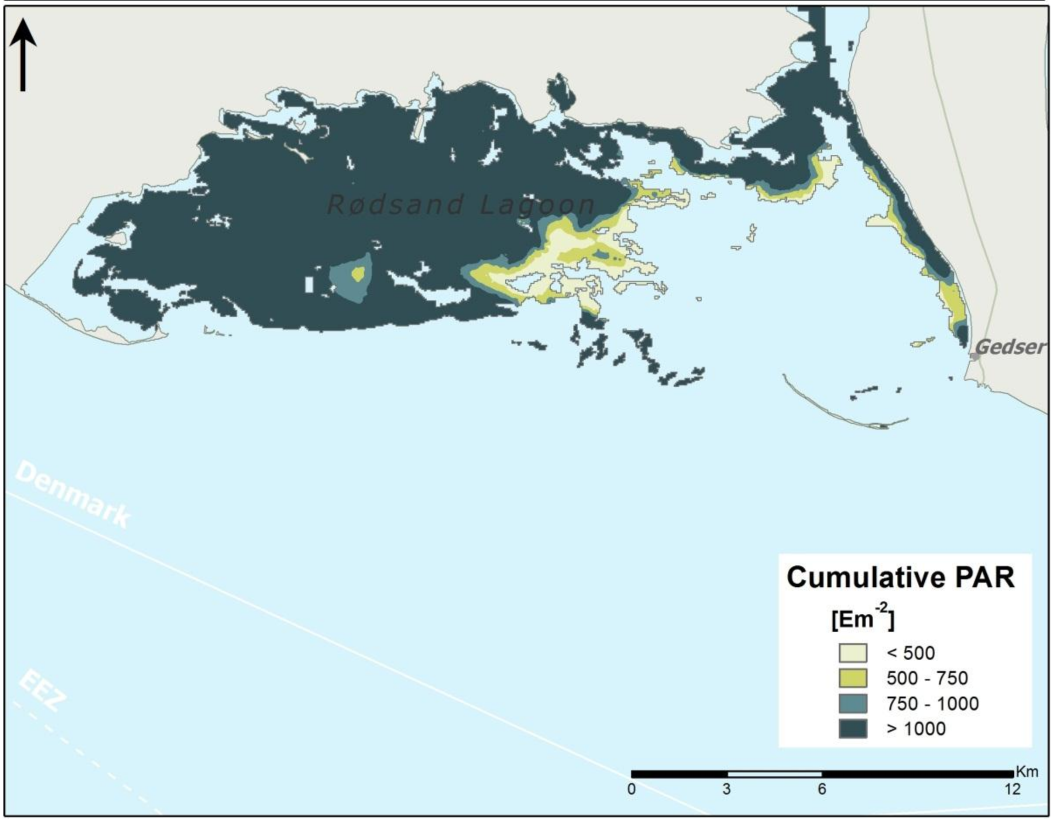


Figure 7-9 Cumulative PAR for the growth season (Mar-Sep) in the eelgrass area in Rødsand Lagoon. The upper figure shows baseline conditions and lower the results for tunnel scenario.

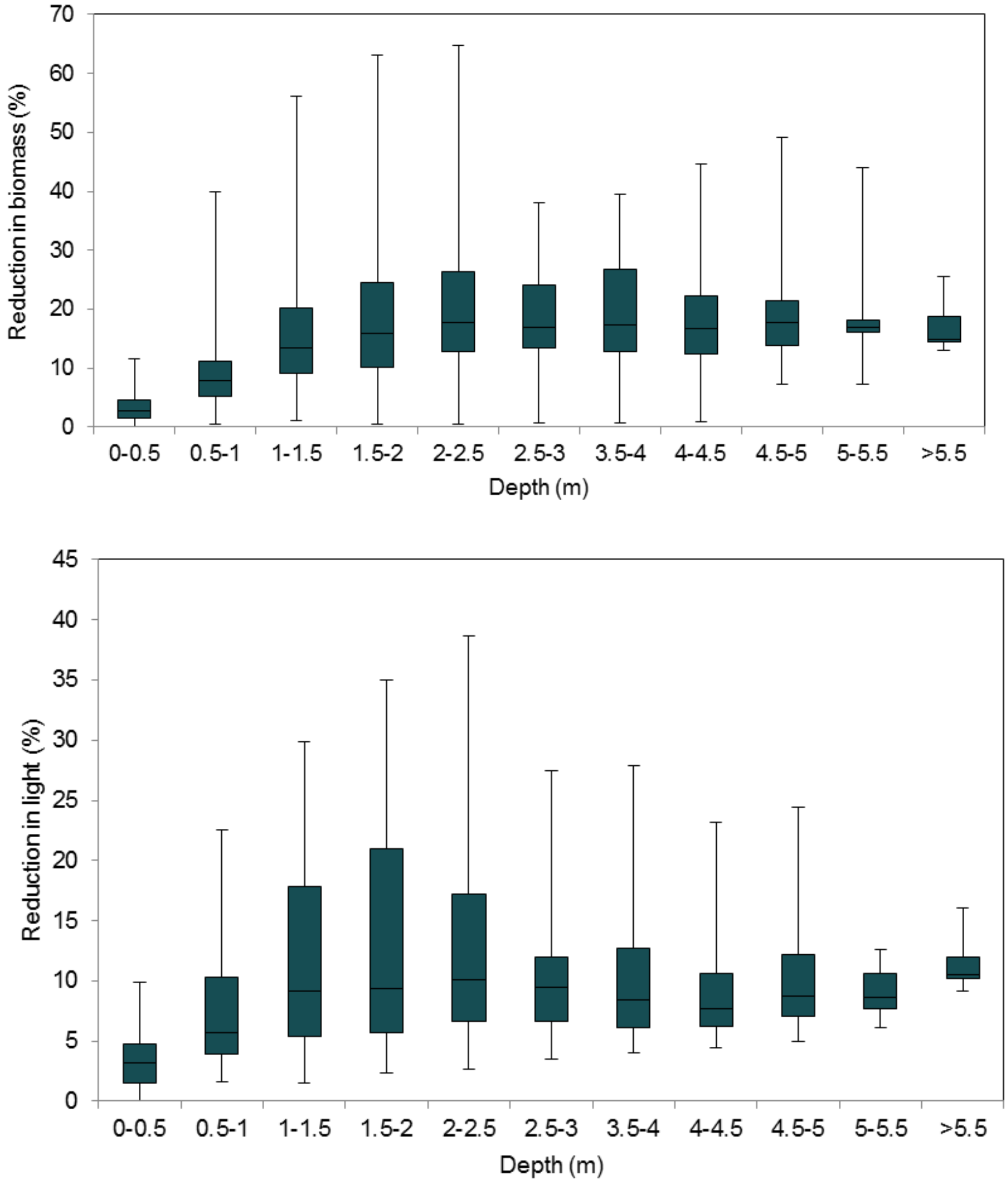


Figure 7-10 Modelled reduction in light availability at bottom (%,) in the first growth season of the construction phase (upper) and modelled reductions in above ground biomass (%), at the end of growth season (lower). Boxes outline 50% of the data, whiskers minimum and maximum values, the horizontal lines show the median reduction at the given depth.

The areas which are most sensitive to light reduction are thus limited. In addition, it is in the 'low-light' areas the expected reductions in light availability are smallest, median = < 10% reduction in light availability (Figure 7-10). Naturally, the light received at the depth limit is variable during the year but also between years as the conditions for phytoplankton growth and irradiance at the surface vary between years. Light measurements in the open waters during the baseline years 2009 and 2010 show an average Secchi depth (±standard deviation) in the growth season between March and September of 7.6 (±0.89) m in 2009 and 6.9 (±1.1) m in 2010 (FEMA 2013d). Assuming that 15% of surface irradiance is available at the Secchi depth, average light availability during the growth season at 4 and 5 m depth is

10% and 12% lower, respectively, in 2010 compared to 2009. Thus, eelgrass at the depth limit is naturally growing under varying light conditions.

However, a small impact due to the light reductions in the first construction year cannot be excluded. Assuming that light is the only factor determining the depth limit, and that eelgrass is responding instantaneous to changes in in light, a reduction of about 10% in light availability would reduce the depth limit with about 0.2 m or ca. 5% (Table 7-4) in the year of the construction phase with the highest sediment spill.

As no long-term data series exist of depth limits in Rødsand Lagoon it is not possible to estimate the year-to-year variability in light at the depth limit. A series in the nearby Nakskov fjord shows that the depth limit of eelgrass varies between 3.1 m and 5.5 m from 1989 to 1997. If it can be assumed that light at the depth limit is fairly constant and there is a close relation between light availability and depth limit, the data indicates large year-to-year variations in light availability.

The large differences in the depth limit observed in Nakskov Fjord, suggest that other factors than light are also important for the depth limit. The importance of light for determining the depth limit in Rødsand Lagoon is not known. A depth limit reduction of 5% is however assessed to be within the natural variability.

In conclusion it is assessed that the temporary impact will be recoverable in almost all areas within few years and the construction will not change the long-term underwater light conditions in Rødsand Lagoon. Therefore the project is not expected to cause permanent impact on the depth limit.

Table 7-4 Possible reduction in depth limits expecting reduction of light of 10% at the depth limit.

Depth limit -reference	**Cumulative PAR at depth limit**	**% surface irradiance (SI) at depth limit**	**New depth limit**	**% reduction in depth limit compated to reference**
m	E m^{-2}		m	
2.5	1000	20.8	2.34	6%
3.5	750	15.6	3.31	5%
4.5	400	8.3	4.32	4%

Macroalgal depth limits

The temporary reduction in light availability is not expected to influence the general depth limit of benthic flora in the assessment area as light reductions are only small in areas where light is limiting depth distribution and the flora in deep water should be adapted to considerable year-to-year variations in light availability.

With regard to macroalgae lack of hard substrate are limiting the depth distribution in most places (for example along the Lolland coast, FEMA 2013a). An exception is the macroalgae at Langeland reef, the deep areas of the west coast of Fehmarn and at Staberhuk, where depth distribution are likely to be light limited.

Benthic macroalgae is growing to about 26 m depth at Langeland, 20 m depth of the west coast of Fehmarn and to 17-19 m depth at Staberhuk. At such depths, biomass is very small. Light requirement for growth of macroalgae has been shown to correspond to the light available at their depth limit, and therefore there is no or little surplus of energy to balance grazing and mechanical losses (Markager & Sand-Jensen 1992). Thus, light should be the main factor determining growth and biomass of vegetation at the depth limit.

Naturally, the light received at the depth limit is variable during the year but also between years as the conditions for phytoplankton growth and irradiance at the surface vary between years. Light measurements in the open waters during the baseline years 2009 and 2010 show an average Secchi depth (±standard deviation) in the growth season between March and September at 7.6 (±0.89) m in 2009 and 6.9 (±1.1) m in 2010 (FEMA 2013d). Assuming 15% of surface irradiance is available at the Secchi depth, average light availability during the growth season at 20 m depth is 40% lower in 2010 compared to 2009. Thus, benthic flora growing at these depths is probably adapted to an environment with considerable year-to year variations in light availability.

In Fehmarnbelt the deepest growing communities are *Phycodrys/ Delesseria* and *Saccharina* (FEMA 2013a). The key-species of these communities are adapted to grow at low light levels. They have low light requirements, thallus that are optimal for capturing light and/ or they are able to grow in dark using stored reserves (Kain 1984, Lüning and Schmitz 1988).

As these communities are adapted to life in a variable and low light environment and the predicted light reduction for the communities are small, the depth limit for macroalgae is not expected to be impacted.

7.1.3 *Severity of impairment*

The severity analysis takes the importance of the areas assessed to be impaired (in section 6.1.2) into consideration.

The severity of impairment from 2015-2019 is summarized in Table 7-5, the severity of impairments on community level are listed in Table 7-6 and illustrated in Figure 7-11 for 2015 and 2016.

In the first construction year, the severity ranged between minor and high in a total area of 14455 ha. Due to minor importance, the severity is considered negligible in 2245 ha (about 13%) of the total impaired area.

The only macroalgal community with severities above minor is the *Furcellaria* community. High severity of this community is predicted for small areas (20 ha) near the dredging and reclamation activities along the Lolland coast. Medium severity is predicted in 727 ha and minor severity of impairment is expected in an area of 2126 ha.

In the second construction year the impacted area will be smaller (total 9115 ha) with severity still range from minor to high. The area where severity is assessed as negligible due to minor importance of the inhabiting flora community constitutes 755 ha; equal to approximately 8% of the area impaired.

In the following years (2017 to 2019) small areas of medium and minor severity are predicted for the *Furcellaria* community. Summing up to a total severity area of 468 to 1901 ha.

Table 7-5 Severity of impairment (areas in ha) caused by suspended sediments for the tunnel alternative for the period 2015–2019. The geographical zone Transboundary is left out as no impacts occur in this zone.

	Total	Near zone	Local zone	DK national + EEZ	DE national	DE EEZ
2015						
Very high						
High	115	20	0	115		
Medium	2689	353	382	2689		
Minor	11751	104	1813	10588	1083	80
Total	**14555**	**477**	**2195**	**13392**	**1083**	**80**
2016						
Very high						
High	20	5		20		
Medium	1171	198	47	1171		
Minor	7924	214	1006	7289	553	82
Total	**9115**	**417**	**1053**	**8480**	**553**	**82**
2017						
Very high						
High						
Medium	62			62		
Minor	1839	4	155	1583	210	45
Total	**1901**	**4**	**155**	**1645**	**210**	**45**
2018						
Very high						
High						
Medium	2			2		
Minor	732	1	90	592	114	26
Total	**734**	**1**	**90**	**594**	**114**	**26**
2019						
Very high						
High						
Medium						
Minor	468	0	33	401	54	13
Total	**468**	**0**	**33**	**401**	**54**	**13**

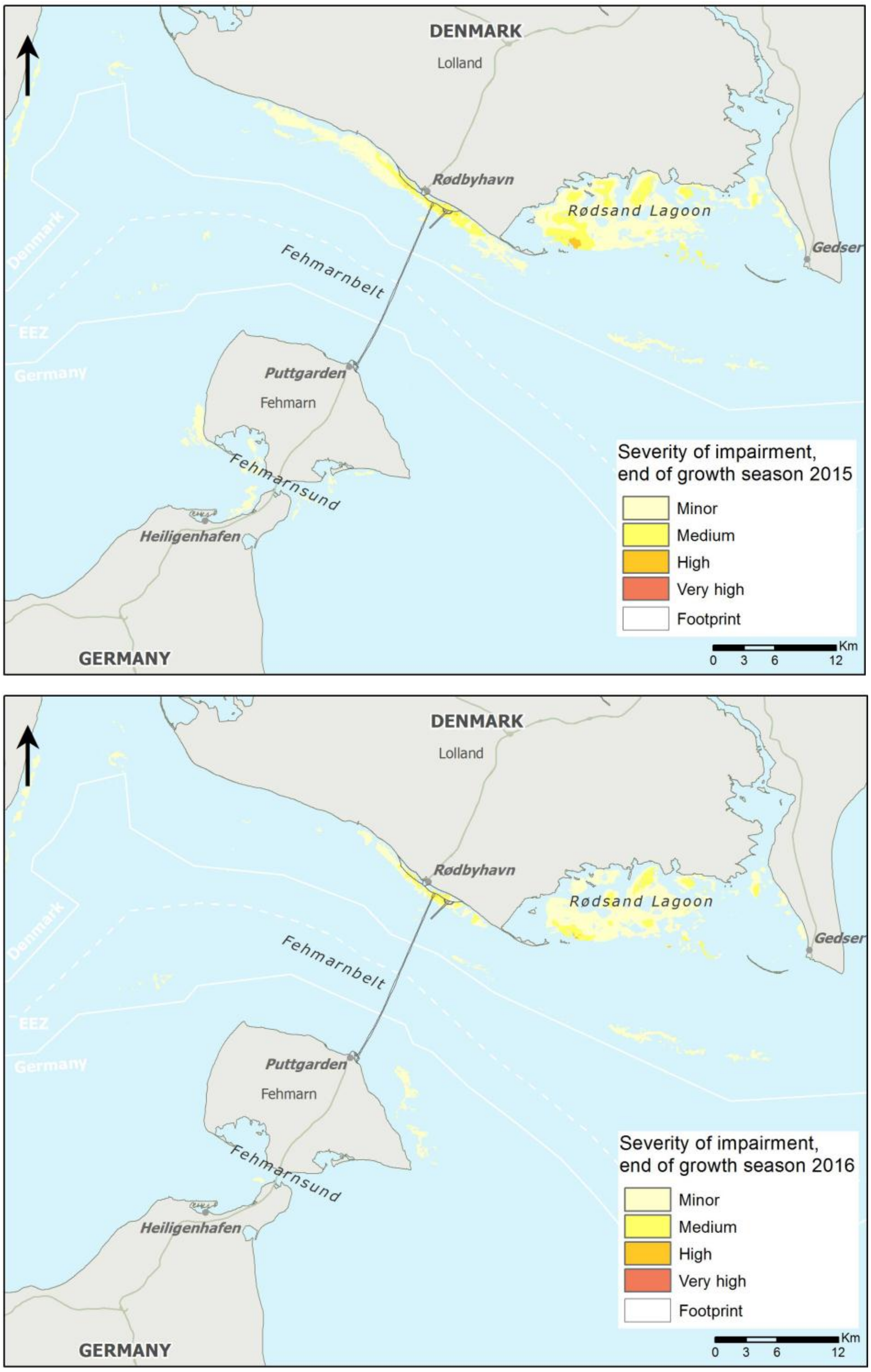


Figure 7-11 Severity of impairment for benthic flora biomass reduction due to suspended sediment from dredging spill at end of growth season 2015 (upper) and 2016 (lower). Figures illustrating the severity of impairment for the years 2017 to 2019 can be seen in Appendix C.

Eelgrass (primarily in Rødsand Lagoon) is impacted by minor to high severity of impairment in the first two years of the construction phase. High severity is predicted in the first year and second years in 96 and 16 ha. The severity of the impairment decreases in intensity and area during the five construction years from a total area of 6124 ha in 2015 to 339 ha in 2019.

Table 7-6 Severity of impairment (areas in ha) per sub-component (community) caused by suspended sediment for the tunnel alternative for the time period 2015–2019. Calculations are based on reduction of biomass at the end of the growth season (1st of September) compared to the reference conditions with no extra concentrations of suspended sediment.

	2015	2016	2017	2018	2019
Eelgrass					
Very high					
High	96	16			
Medium	1925	912	62	2	
Minor	6315	5404	1458	533	352
Eelgrass/ algae					
Very high					
High					
Medium					
Minor	891	34	13	4	0
Tasselweed/dwarf eelgrass					
Very high					
High					
Medium	22	14			
Minor	135	60	6		
Filamentous species					
Very high					
High					
Medium					
Minor	1679	837	17	3	
Furcellaria					
Very high					
High	20	5			
Medium	727	237			
Minor	2126	631	3		
Phycodrys/ Delesseria					
Very high					
High					
Medium		0.8			
Minor	487	446	129	82	65
Saccharina					
Very high					
High					
Medium					
Minor	118	503	213	110	49

7.1.4 *Significance*

The predicted impact on benthic flora biomass of the pressure suspended sediment is temporary and in combination with a relatively fast recovery impacts it is not expected to cause significant effects on the function of the local or regional ecosystem. Results for the significance evaluation are summarized in Table 7-7 and Table 7-8.

No areas are expected to be impacted with very high severity of impairment and loss of benthic flora is not expected from impacts of the pressures suspended sediment.

Macroalgal communities are expected to be temporarily impacted with minor to high severity of impairment on the Danish coast near the construction sites. The benthic flora in the German national zone is expected to be impacted with minor severity in a very small area east of the alignment.

The most severe impacts are located in the Danish near zone of the construction area. Totally, the high severity area constitutes <1% of the total impacted area. The impact is occurring in the *Furcellaria* community.

Looking at the total distribution of the *Furcellaria* community, the share impacted is 87% of the distribution in the Fehmarnbelt area and 73% of the distribution in the assessment area. The severity is mainly minor (54% and 53%) to medium (33% and 18%).

The macroalgal communities is expected to recover fast in the shallow waters along the coast and after the two first years full recovery biomass is expected in the near zone, although in areas where biomass reduction was highest in the first year the relative biomass of species in the community may differ from the pre-impact state.

The *Furcellaria* communities are common along Danish and German coasts and widespread in the whole Baltic Sea area. The considerable reduction in biomasses in the first two construction years is likely to cause temporary significant effects on the function of the ecosystem (e.g. lower oxygen and detritus production). However, as recovery is fast; nearly complete after the first three years and full recovery is expected within two years after end of construction, the long-term impact is considered to be non-significant.

The expected impact on the deep growing communities (*Phycodrys/ Delesseria* and *Saccharina*) are small and of minor severity. However, since the distrubutionof these communities in the Fehmarnbelt and the assessment area are small, 10% to 69% of the area is impacted in 2016. In 2021, the biomass in the *Saccharina* and *Phycodrys/ Delesseria* communities are fully recovered. The model predicts that a small area of 0.25 ha (minor severity, not in Natura 2000 areas) is still not fully recovered, but this is within the model uncertainty. Thus, although recovery is slow in the deeper areas, recovery is predicted within two years after the end of construction and the long-term impact considered to be non-significant.

For eelgrass, impact with minor to high degree of severity is predicted in 69% of the eelgrass area in 2015 and 52% in 2016. High severity of impairment is predicted in small areas. Most areas with minor or medium severity of impairment are recovered within the first two years.

The small reductions in biomass cannot be expected to cause any significant impact on the function of the eelgrass ecosystem. Eelgrass populations are naturally variable over time because of physical disturbance by waves, currents, ice and variations in light availability in deeper populations. It is not likely that the predicted short-term reduction in light availability should cause any undesired long-term effect on the function of the ecosystem.

No severe impacts are persisting to 2021 and full recovery is achieved no later than two years after end of construction.

In conclusion, the *Furcellaria* community is expected to be temporary impacted at high severity levels as temporary high reductions in biomass are predicted. However, recovery is predicted within two years after the construction and therefore long-term impacts are considered to be insignificant.

Table 7-7 Severity of impairment in percentages (in % of area) per community at end of growth season 2015 caused by suspended sediment for the tunnel alternative.

	Eelgrass		**Eelgrass/algae**		***Filamentous species***	
	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area
Very high						
High		0.7				
Medium		16				
Minor		52		37	50	23
Total		**69**		**37**	**50**	**23**
	Furcellaria		***Phycodrys/Delesseria***		***Saccharina***	
	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area
Very high						
High	0.8	1				
Medium	30	18				
Minor	48	54		16	0.1	10
Total	**79**	**73**		**16**	**0.1**	**10**
	Tasselweed/dwarf eelgrass					
Very high						
High						
Medium		1				
Minor		8				
Total		**9**				

Table 7-8 Severity of impairment in percentages (in % of area) per community at end of growth season 2016 caused by suspended sediment for the tunnel alternative.

	Eelgrass		**Eelgrass/algae**		***Filamentous species***	
	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area
Very high						
High		0.1				
Medium		8				
Minor		45		1	10	12
Total		**53**		**1**	**10**	**12**
	Furcellaria		***Phycodrys/Delesseria***		***Saccharina***	
	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area
Very high						
High	0.2	0.1				
Medium	10	6				
Minor	26	16	10	15	50	42
Total	**36**	**22**	**10**	**15**	**50**	**42**
	Tasselweed/dwarf eelgrass					
Very high						
High						
Medium		>1				
Minor		3				
Total		3				

7.2 Sedimentation

7.2.1 *Magnitude of pressure*

The magnitude of pressure depends on the amount of deposited sediment as well as the duration and timing of the sedimentation. The important indicator is thus the specific thickness of the settled sediment, which is persistent for a certain number of days during the growth or reproductive season.

The maximum thickness of sediment layers persisting ≥ 10 days is 8 cm and occur directly at the alignment area as well as in the Rødsand lagoon (Figure 4-3). Time series for the Rødsand Lagoon showed, that the sediments are resuspended from time to time and that therefore the overall thickness of deposited sediments will be reduced, but at the chosen site the sedimentation was not totally resuspended (Figure 4-4).

Figure 7-12 illustrates the spatial range and Table 7-9 lists the areas (ha), for the different levels of magnitude of pressure (Table 7-10 and Table 7-11).

Table 7-9 Magnitude of pressure (areas in ha) of sedimentation for the tunnel alternative. The geographical zone Transboundary is left out as no impacts occur in this zone.

	Total	**Near zone**	**Local zone**	**DK national + EEZ**	**DE national**	**DE EEZ**
Very high	0					
High	4	4		4		
Medium	22	7	9	13	9	
Minor	738	259	206	521	217	
Total	764	270	215	538	226	

Table 7-10 Magnitude of pressure levels for macroalgal communities.

Magnitude of pressure	**Thickness of sediment layer (persistent ≥ 10 days)**
Very high	> 10.0 cm
High	> 5.0 – 10.0 cm
Medium	> 1.0 – 5.0 cm
Minor	> 0.2 – 1.0 cm

Table 7-11 Magnitude of pressure levels for flowering plant communities.

Magnitude of pressure	**Thickness of sediment layer (persistent ≥ 10 days)**
Very high	> 20.0 cm
High	> 10.0 – 20.0 cm
Medium	> 5.0 – 10.0 cm
Minor	> 1.0 – 5.0 cm

Sedimentation occurs at 5929 ha seabed, but only at 764 ha the sedimentation exceeds the threshold value defined for flora. 270 ha of the area exceeding the threshold levelis predicted to occur in the near zone, 215 ha in the local zone and 279 ha outside of the local zone.

In Danish waters 538 ha are affected by sedimentation, in German national waters 226 ha and in German EEZ waters 0 ha.

In the 764 ha affected by sedimentation, no very high magnitude of pressure occurs as the sedimentation layers never exceeded 10 cm (threshold is > 10 cm for macroalgae and > 20 cm for flowering plants.

The high magnitude of pressure area constituted 0.5% of the total affected area. The affected area is restricted to Danish waters and near zone (4 ha). High magnitude of pressure corresponds to a deposited sediment thickness of 5–10 cm for macroalgae and 10–20 cm for flowering plants.

Medium magnitude of pressure occurs in Danish waters at 13 ha and in German national waters at 9 ha. Of the 22 ha affected, 6 ha is located outside the local zone. Medium magnitude of pressure corresponds to a deposited sediment thickness of 1–5 cm for macroalgae and 5–10 cm for flowering plants.

Far the most of the affected area, 97%, is opposed to minor magnitude of pressure. Of the 738 ha 259 ha (35%) occur in the near zone, 206 ha (28%) in the local zone and 273 ha (37%) outside the local zone. The size of the affected areas is more than twice as large in Denmark (521 ha) compared to Germany (217 ha); Minor magnitude of pressure corresponds to a deposited sediment thickness of 0.2–1 cm for macroalgae and 1–5 cm for flowering plants.

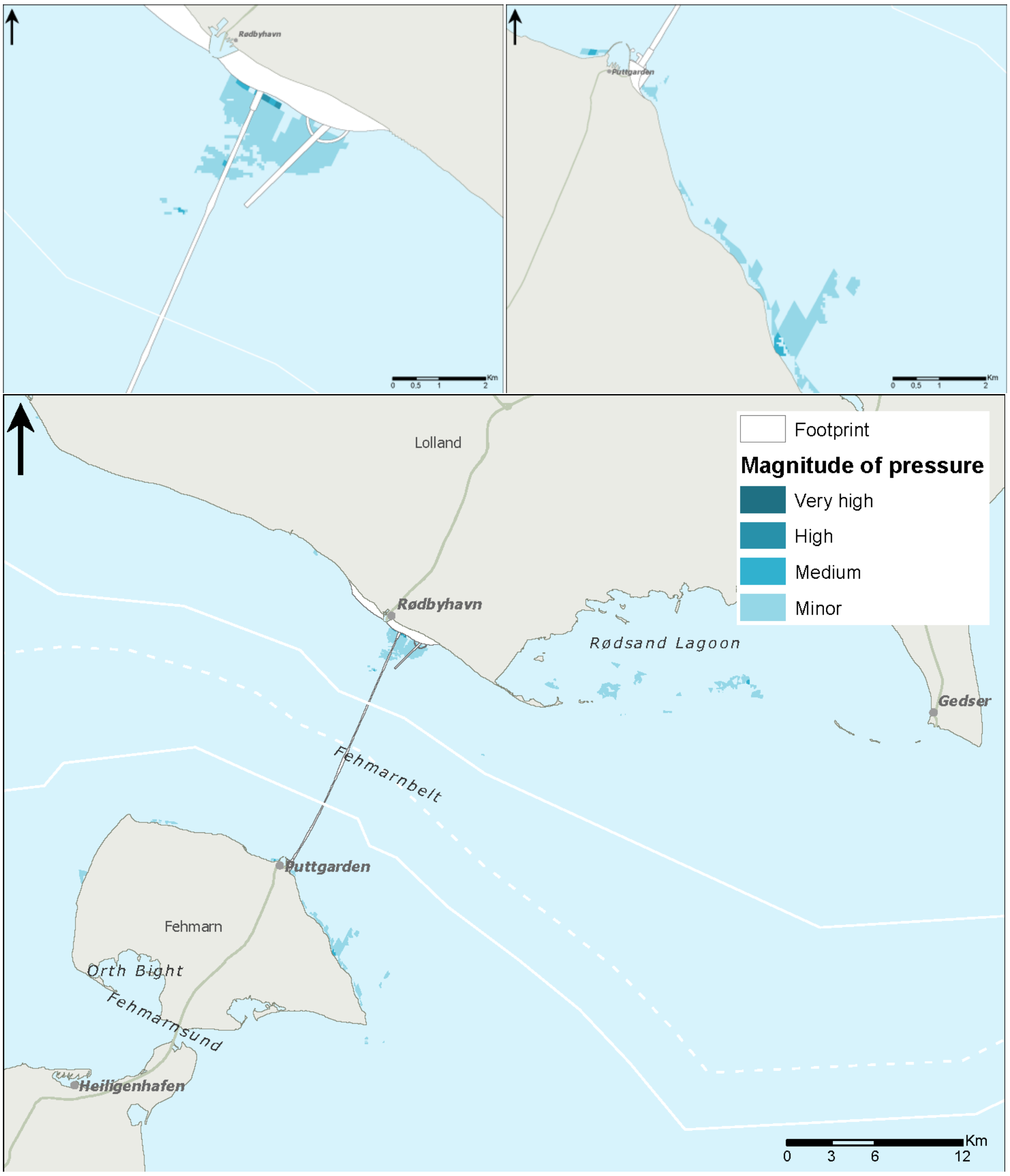


Figure 7-12 Magnitude of pressure caused by sedimentation for the tunnel alternative in detailed zones (above, left: Lolland coastline, right: Fehmarn coastline) and as overview (below).

7.2.2 *Degree of impairment*

To assess the degree of impairment the area for high, medium and minor magnitude of pressure is intersected with sensitivity following the matrix of chapter 3.7 by GIS analysis. The results of the analyses are presented in Figure 7-13, Table 7-12 and *Table 7-13*.

Table 7-12 Degree of impairment (areas in ha) caused by sedimentation for the tunnel alternative. The geographical zone Transboundary is left out as no impacts occur in this zone.

	Total	Near zone	Local zone	DK national + EEZ	DE national	DE EEZ
Very high	0					
High	10	4		10		
Medium	253	5	9	244	9	
Minor	501	261	206	284	217	
Total	**764**	**270**	**215**	**538**	**226**	

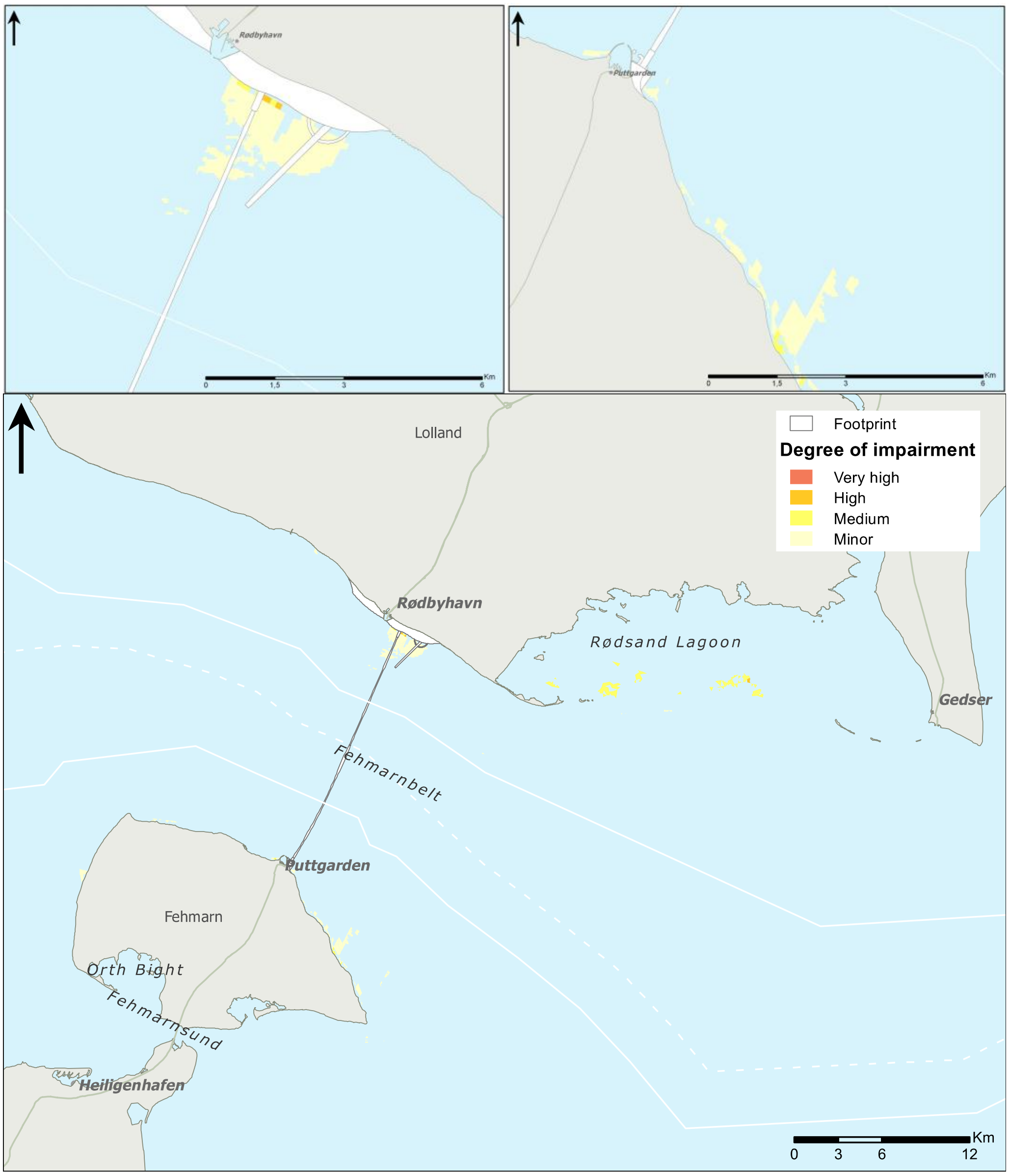


Figure 7-13 Spatial distribution of the degree of impairment caused by sedimentation for the tunnel alternative in detailed zones (above, left: Lolland coastline, right: Fehmarn coastline) and as overview (below).

Of the 764 ha of impaired benthic flora (Table 7-12) 35% (270 ha) are located within the near zone, 28% (215 ha) within the local zone and 37% (279 ha) outside of the local zone.

Most of the impaired areas, 70%, are located within Danish waters. Of the 226 ha are impaired along the German coastline all is located in German national waters.

No very high degree of impairment occurs due to sedimentation.

High degree of impairment appears exclusively along the Lolland coastline. Of the 10 ha high degree impairment area 4 ha occur in the *Furcellaria* community in the near zone and 6 ha in the eelgrass community outside the local zone (Rødsand Lagoon).

Similarly, medium degree of impairment appears nearly exclusively in Danish waters (244 ha) and only to a small extent in German national waters (9 ha). Most of the medium impaired Danish area is located outside the local zone, in the Rødsand Lagoon (239 ha); meaning that primarily the eelgrass community is affected. The remaining 5 ha impaired in Danish waters is located in the *Furcellaria* community of the near zone. In German national waters several communities are impacted by medium degree of impairment in the local zone, but all are small areas: Eelgrass/algae community 2 ha and *Furcellaria* community 7 ha.

Minor degree of impairment is distributed between Danish waters (284 ha) and German national waters (217 ha). Several communities are affected by minor degree of impairment, as minor degree of impairment comprise both minor magnitude of pressure affecting communities with medium or minor sensitivity and medium magnitude of pressure affecting communities with minor sensitivity. Those combinations are the most probable as the minor magnitude area has the largest extension and many communities have medium or minor sensitivity towards sedimentation.

The distribution of impairment on flora communities are summarised in Table 6.10. In total 32% of the impairment concerns the eelgrass community; 27% the *Furcellaria* community, 25% the filamentous species community, 7% the *Phycodrys/ Delesseria* community, about 4.5% the *Fucus* and *Saccharina* communities and >1% the eelgrass/algae community. The filamentous algal, the *Fucus*, the *Phycodrys/Delesseria* and the *Saccharina* communities are never opposed to more than minor degree of impairment. The predicted impairment for the eelgrass community is medium to high and for the eelgrass/algae community medium degree of impairment. Only the *Furcellaria* community are predicted to have from minor to high degree of impairments.

Most of the affected filamentous algae community area occurs in near zone (74% ~ 142 ha). The impairment is almost constrained to Danish waters (155 ha; opposite to only 37 ha in German national waters).

The affected *Fucus* community comprise a limited area, 33 ha, corresponding to 7% of the total *Fucus* community extent and 4% of the total impaired area. All of the impaired area is located in German national waters. Only a very small fraction is impaired near zone (< 1 ha), 10 ha are impaired in the local zone and 23 ha outside the local zone (along the west coast of Fehmarn).

The impaired *Phycodrys/Delesseria* community (51 ha) and *Saccharina* community (34 ha) areas occur exclusively in German national waters and all in the local zone.

The *Furcellaria* community is affected in minor to high degree but with most impairment being of minor degree (92%/191 ha). 129 ha of the impaired area occur in Danish waters, and of these 119 ha in near zone and 10 ha in the local zone. In German national waters 62 ha are impaired, all in the local zone.

Table 7-13 Degree of impairment (area loss in ha) per community caused by sedimentation for the tunnel alternative. The geographical zone Transboundary is left out as no impacts occur in this zone.

	Eelgrass						**Eelgrass/algae**						**Filamentous algae**					
	Total	Near zone	Local zone	DK	DE nat.	DE EEZ	Total	Near zone	Local zone	DK	DE nat.	DE EEZ	Total	Near zone	Local zone	DK	DE nat.	DE EEZ
Very high																		
High	6			6														
Medium	239			239			2		2		2							
Minor													192	142	39	155	37	
Total	245			245			2		2		2		192	142	39	155	37	

	Fucus						***Furcellaria***						***Phycodrys/Delesseria***					
	Total	Near zone	Local zone	DK	DE nat.	DE EEZ	Total	Near zone	Local zone	DK	DE nat.	DE EEZ	Total	Near zone	Local zone	DK	DE nat.	DE EEZ
Very high																		
High							4	4		4								
Medium							12	5	7	5	7							
Minor	33	<0.01	10		33		191	119	72	129	62		51		51		51	
Total	33	<0.01	10		33		207	128	79	138	69		51		51		51	

	Saccharina					
	Total	Near zone	Local zone	DK	DE nat.	DE EEZ
Very high						
High						
Medium						
Minor	34		34		34	
Total	34		34		34	

7.2.3 *Severity of impairment*

To assess the severity of impairment caused by sedimentation, the area for very high, high, medium and minor degree of impairment is intersected with importance following the matrix of chapter 3.8.2 by GIS analysis. The results are presented in Figure 7-14 and in Table 7-14 and Table 7-15.

Of the 572 ha of benthic flora affected by minor to high severity of impairment the largest share is located outside of the local zone (44% ~ 267 ha; primary Rødsand Lagoon). 24% (129 ha) of the impairment are predicted for near zone, and 32% (176 ha) for local zone. No areas are affected by very high severity of impairment. Most severity of impairment occur in Danish waters; 67% (383 ha), contrary to 33% (189 ha) in German national waters. No impairment is predicted for the German EEZ waters.

Compared to the results of degree of impairment, the consideration of importance identifies 192 ha where both degree of impairment and importance are minor and thereby the severity is predicted as negligible. Most of this area is located in the near zone of Danish territorial waters. The flora of these areas are in all cases filamentous algae.

For all other communities there is no (Eelgrass/algae, *Fucus*, *Phycodrys/Delesseria*, *Saccharina*) or only slight changes in area (< 1 ha; Eelgrass, *Furcellaria*) when comparing degree and severity of impairment. The reason is that most of the communities were impaired to a minor degree and at this degree importance does not affect the severity of impairment.

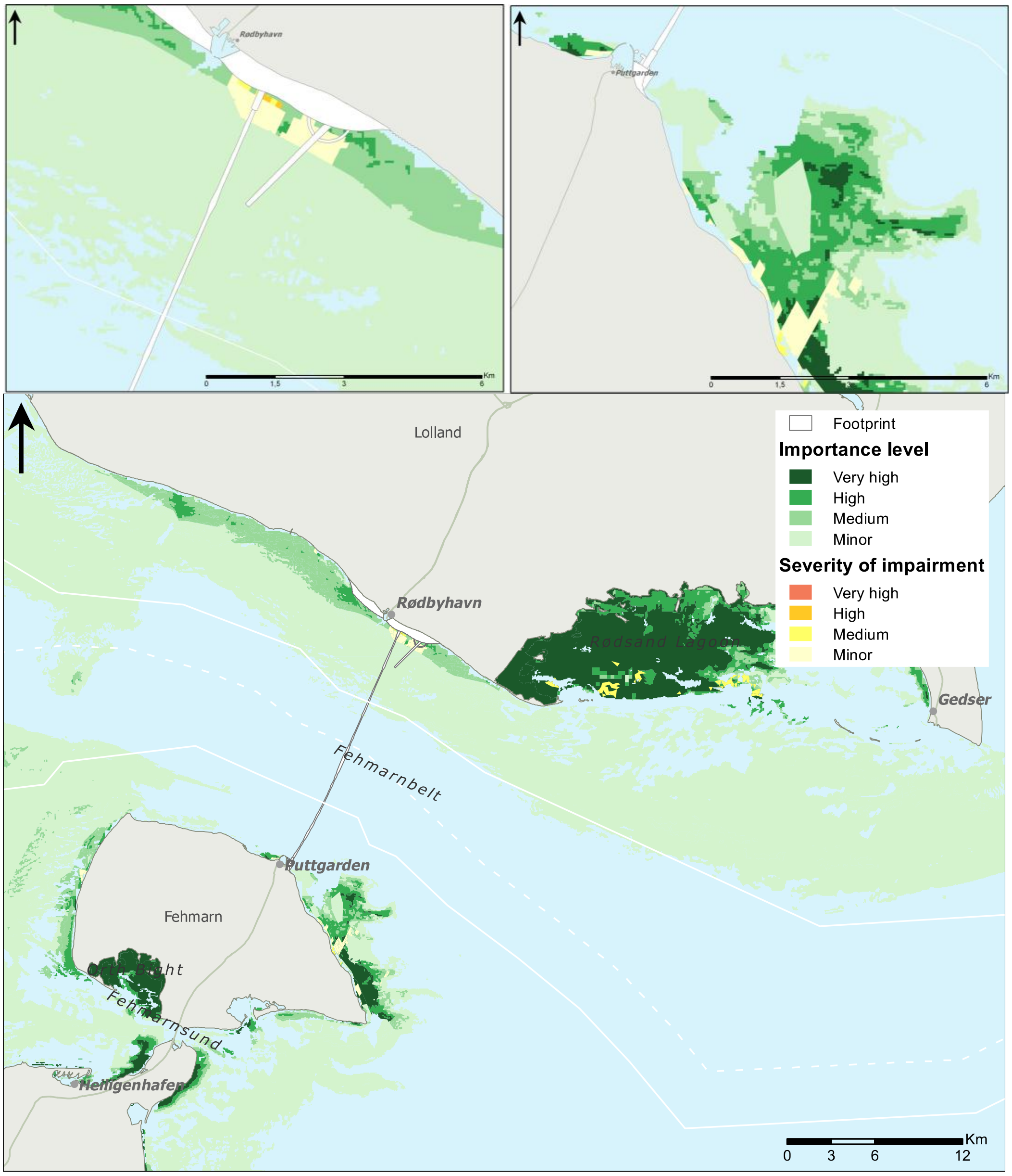


Figure 7-14 Spatial distribution of severity of impairment caused by sedimentation for the tunnel alternative in detailed zones (above, left: Lolland coastline, right: Fehmarn coastline) and as overview (below). The severity is in this figure overlaying the importance levels.

Table 7-14 Severity of impairment (areas in ha) caused by sedimentation for the tunnel alternative. The geographical zone Transboundary is left out as no impacts occur in this zone.

	Total	**Near zone**	**Local zone**	**DK national + EEZ**	**DE national**	**DE EEZ**
Very high	0					
High	1	1		1		
Medium	262	9	9	253	9	
Minor	309	119	167	129	180	
Total	**572**	**129**	**176**	**383**	**189**	**0**

Table 7-15 Severity of impairment (area loss in ha) per sub-component (community) caused by sedimentation for the tunnel alternative. The geographical zone Transboundary is left out as no impacts occur in this zone.

	Eelgrass						Eelgrass/algae						*Fucus*					
	Total	Near zone	Local zone	DK	DE nat.	DE EEZ	Total	Near zone	Local zone	DK	DE nat.	DE EEZ	Total	Near zone	Local zone	DK	DE nat.	DE EEZ
Very high																		
High																		
Medium	244			244			2		2		2							
Minor													33	<0.01	10		33	
Total	244			244			2		2		2		33	<1	10		33	

	Furcellaria						*Phycodrys/Delesseria*						*Saccharina*					
	Total	Near zone	Local zone	DK	DE nat.	DE EEZ	Total	Near zone	Local zone	DK	DE nat.	DE EEZ	Total	Near zone	Local zone	DK	DE nat.	DE EEZ
Very high																		
High	1	1		1														
Medium	16	9	7	9	7													
Minor	191	119	72	129	62		51		51		51		34		34		34	
Total	208	129	79	139	69		51		51		51		34		34		34	

This means that as for degree of impairment, the community with the largest impaired area is the eelgrass community; constituting ca. 43% of the total severity of impairment area. All eelgrass area is impaired at medium degree of severity and is located outside the local zone primarily in Rødsand Lagoon. The severity for the eelgrass/algae community is assessed as medium but only in 2 ha (German waters).

The severity of the *Fucus*, *Phycodrys*/*Delesseria* and *Saccharina* communities are all minor and constituting ca. 6-9% of the total severity of impairment area (33, 34 and 51 ha). All impairment occur in German waters, as this is the area with the highest occurrences of these communities.

For the *Furcellaria* community the severity varies from minor to high but far the largest share of the impairment is assessed to be of minor severity (ca. 92% of the impaired area). Most impairment occur in the near zone (ca. 62%); and in the Danish waters (ca. 67%).

7.2.4 *Significance*

Significance is determined by comparing the total area of severity of specific vegetation communities with the area in Fehmarnbelt inhabited by the community. The results for the significance evaluation are listed in Table 7-16.

244 ha of the eelgrass community are affected by sedimentation: 1 ha by high and 243 ha medium severity of impairment. The affected area is located outside Fehmarnbelt, where no eelgrass community occurs. Therefore the impacted area is only compared to assessment area. 244 ha correspond to and 2% of the eelgrass community in the assessment area.

2 ha of the eelgrass/algae community are affected by medium severity of impairment. As only 25 ha of this community occur in the Fehmarnbelt area this corresponds to 8% of this community in Fehmarnbelt but only to 0.08% in the assessment area.

Nearly all of the impaired area for flowering plant communities (eelgrass, eelgrass/algae) has a medium severity of impairment. The maximal deposited sediment thickness for the tunnel has been predicted to be 8 cm and medium level of impairment for flowering plants corresponds to sediment thickness between 5–10 cm for minimum 10 days. As mentioned before, quantitative studies of mortality due to sedimentation in eelgrass populations are scares. A single study exists, and it suggest up to 50% mortality when plants are 25% buried with sediment for 25 days (Mills and Fonseca 2003). Eelgrass in this area is app. 50 cm high and a burial of 5-8 cm correspond to app 10-16% of the plant height. Accordingly it cannot be excluded that such sedimentation thickness may cause some shoot mortality of smaller shoots and may affect the eelgrass growth rate. The likeness of severe impacts are however limited and regrowth of eelgrass can however balance shoot mortality and reduced biomass within the next growth seasons. The duration of the impact is therefore limited to the Construction phase+ (= recovered no later than two years after end of construction). Considering that only a small area is impacted (2% of eelgrass in the assessment area, 2.3% of eelgrass in Rødsand) and that recovery is expected within two years after end of construction, the impact on the flowering plant communities due to sedimentation is assessed to be insignificant.

33 ha of the *Fucus* community are affected by minor severity of impairment. This corresponds to 6 % of the community in the assessment area.

Overall 208 ha of the *Furcellaria* community are affected by sedimentation: 1 ha by high, 16 ha by medium and 191 ha by minor severity of impairment. All of the affected area occurs in the near zone or in the local zone. 207 ha correspond to 9% of the *Furcellaria* community in Fehmarnbelt and 5% in the assessment area.

51 ha of the *Phycodrys/Delesseria* community is affected by minor severity of impairment. This corresponds to 7% of the *Phycodrys/Delesseria* community in Fehmarnbelt and to 2% in the assessment area.

34 ha of the *Saccharina* community is affected by minor severity of impairment. This corresponds to 4% of the *Saccharina* community in Fehmarnbelt and to 3% in the assessment area.

Nearly all of the impaired area for macroalgal communities (*Fucus*, *Furcellaria*, *Phycodrys/Delesseria* and *Saccharina*) has a minor severity of impairment. This level of impairment for macroalgae corresponds to sediment thickness between 0.2–1 cm. Such sedimentation thickness will not cause increased mortality and only a slight reduction in growth/biomass. Only the recruitment success will be reduced as hard substrates will be covered, reducing the possible settlement area for propagules. The viability of the communities is therefore not impaired. All macroalgae can balance the temporary failure of recruitment success within the next reproduction periods. The duration of the impact is limited to the Construction phase+ (= recovered within two years after end of construction). The impact on the macroalgal communities due to sedimentation is insignificant in terms of duration and severity level.

Table 7-16 Severity of impairment (in % of area) for impairment per community caused by sedimentation for the tunnel alternative. Basis for the calculation is the total area of severity per community.

	Eelgrass		**Eelgrass/algae**		***Fucus***	
	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area
Very high						
High						
Medium		2	8	0.08		
Minor						6
Total		2	8	0.08		6

	Furcellaria		***Phycodrys/Delesseria***		***Saccharina***	
	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area
Very high						
High	0.04	0.03				
Medium	0.68	0.41				
Minor	8	5	7	2	4	3
Total	9	5	7	2	4	3

7.3 Footprint

7.3.1 Magnitude of pressure

Several structures of the tunnel alternative will cause footprints, which can be classified into the two relevant types.

Structure-related footprints

Reclamation areas and work harbour inside these: The work harbours will be partly integrated in the reclamation areas. The integrated part will not be assessed separately. The duration is the lifetime of the project and therefore permanent (= Operation phase C).

Elevated protection reef: The seabed is locally raised to incorporate the protection layer of the tunnel over a distance of approximately 250 m from the proposed coastline. The duration is the lifetime of the project and therefore permanent (= Operation phase C).

Construction-related footprints

Access channel: As the depth range at Fehmarn is naturally sufficient, only an access channel to the work harbour at Lolland is needed. The channel has to be dredged down to 12 m water depth and will not be backfilled after construction. The width varies between 100 and 170 m. A deepening of the seabed of nearly 6 m depth is partly necessary (near reclamation area). The seabed (level) will re-establish naturally after construction. The time scale for the re-establishment varies along the access channel due to varying depth and width and is calculated to a maximum of 30 years for the deepest trench sections (FEHY 2013b).

Tunnel trench, outside NATURA 2000 area Fehmarnbelt DE 1332-301: After lowering the tunnel elements into the dredged trench and covering of elements with a stony protection layer, a trench of ~ 0.7 m depth and max. 200 m width will be left open. The seabed will re-establish naturally after construction. The time scale for the re-establishment of the seabed depends on the location along the alignment. Due to higher sediment transport rates, the recovery time of the seabed level is lower (< 10 years) in shallow areas than in deeper areas (up to 22 years, FEHY 2013b).

Tunnel trench, inside NATURA 2000 area Fehmarnbelt DE1332-301: The re-establishment of the seabed is accelerated by covering the protection layer of the tunnel with sediments comparable of the former seabed. The time scale for the re-establishment of the seabed is calculated to take less than 8 years (FEHY 2013b). No vegetation communities occur in this area. Therefore the duration is irrelevant for benthic vegetation.

Work harbour outside reclamation areas: The working harbours are partly located outside of those reclamation areas. After construction those parts (e.g. harbour basin, quays and pilings) will be dismantled/removed and backfilled, if necessary. The re-establishment of the seabed will take less than 5 years (FEHY 2013b).

Table 7-17 lists the overall footprint area and the footprint area for the different footprint types, tunnel structures and geographical zones and Figure 7-15 illustrates the different footprint types.

Table 7-17 *Footprint area (in ha) with respect to type, tunnel structure and geographical zone. As all footprints are located near zone. Irrelevant zones are left out in the table.*

Type	**Structure**	**Footprint area (ha)**			
		Total	DK national + EEZ	DE national	DE EEZ
Structure-related	Reclamation areas	343	329	14	
	Elevated protection reef	13	7	6	
Construction-related	Access channel	32	32		
	Tunnel trench	125	77	48	
	Tunnel trench, within Natura2000	56			56
	Working harbours	15	7	8	
Total		**584**	**452**	**76**	**56**

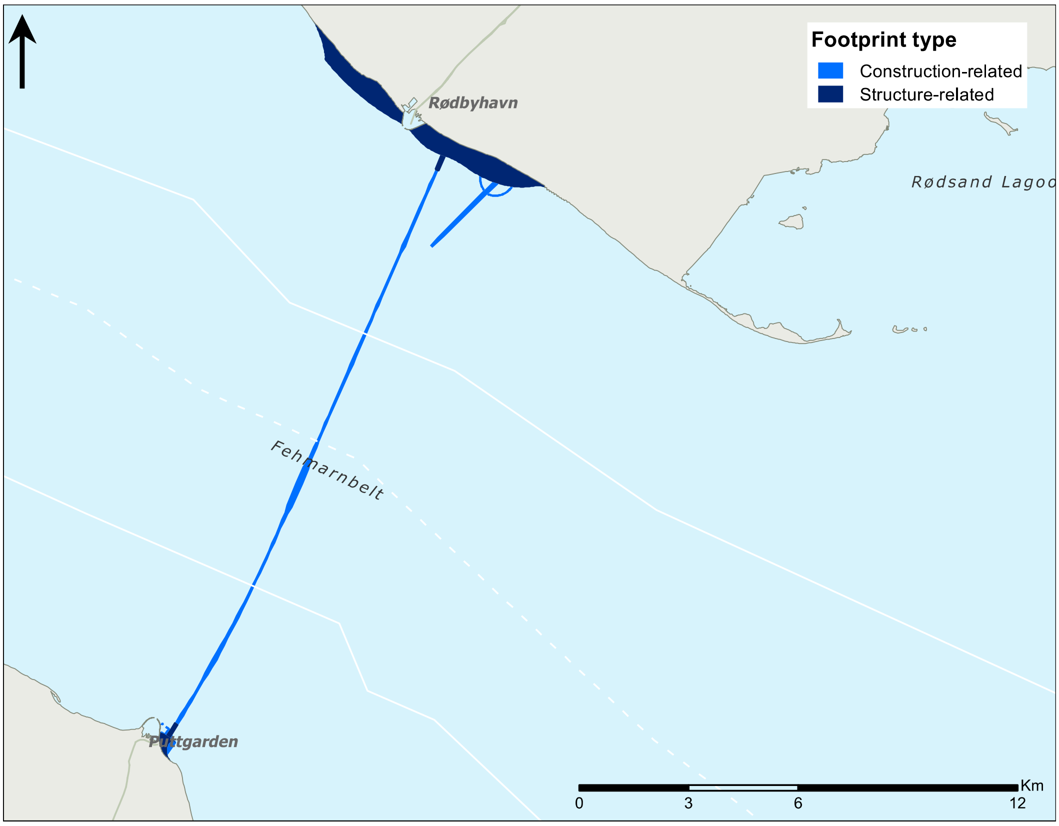


Figure 7-15 Location of the different footprint types for the tunnel alternative.

According to the general methodology, the magnitude of pressure is very high regardless of the type and structure of the footprint. Overall, the tunnel footprints take up 584 ha. Structure-related, permanent footprints occupy most of the area (356 ha), whereas construction-related footprints take up only 228 ha. Reclamation areas (structure-related footprints) and the tunnel trench (construction-related footprints) occupy the largest area.

In Danish waters footprints cover a respective larger area (452 ha) compared to Germany and most of those footprints are structure-related with no possibility of recovery.

In German national waters footprints occupy 76 ha; and 56 ha in German EEZ waters. Most of the footprints in the German area (56 of national + 56 ha of EEZ waters) belong to construction-related footprints with a possibility of recovery. The aspect recoverability is discussed within the significance chapter.

7.3.2 *Severity of loss*

The severity of loss was estimated by intersecting the footprint area (corresponds to very high magnitude of pressure) with importance, following the matrix showed in chapter 3.8.1. The results are presented in Figure 7-16 and Table 7-18 and Table 7-19.

Overall tunnel footprints affect 298 ha of benthic flora; 218 ha are affected by structure-related footprints and 80 ha by construction-related footprints. Nearly all of the lost area occurs in DK national and EEZ waters (298 ha). In German waters 0.22 ha are lost: 0.22 ha in DE national and none in DE EEZ waters.

No very high severity of loss occurs due to footprints.

High severity of loss (18 ha) appears exclusively along the Lolland coastline, where dense stands of the *Furcellaria* community occur (> 50% cover). The main part is lost due to structure-related footprints (14 ha).

Medium severity of loss occurs mostly due to footprints by structure-related footprints (147 out of 190 ha). Medium severity of loss appears exclusively along the Lolland coastline, where the *Furcellaria* community occurs with coverage between 10 and 50%.

For minor severity of loss 30 ha are covered by structure-related and 60 ha by construction-related footprints. Minor severity of loss appears along the Lolland coastline (90 ha) and only to a small extent along the Fehmarn coastline (0.22 ha). At the Fehmarn coastline the filamentous algae community and at the Lolland coastline the filamentous algae community as well as single vegetation stands (coverage 1–10%) are affected by a minor severity of loss.

Table 7-18 Severity of loss (in ha) caused by footprints for the tunnel alternative. Areas are divided into structure-related footprints (s) and construction-related footprints (c). As all footprints are located near zone. Irrelevant zones are left out in the table.

	Footprint Type	**Total**	**DK national + EEZ**	**DE national**	**DE EEZ**
Very high	S				
	C				
High	S	14	14		
	C	4	4		
Medium	s	174	174		
	c	16	16		
Minor	s	30	30	0.22	
	c	60	60		
Total	s	218	218		
	c	80	80	0.22	
		298	298	0.22	

Table 7-19 Severity of loss (in ha) per community caused by footprints for the tunnel alternative. Areas are divided into structure-related footprints (s) and construction-related footprints (c). As all footprints are located near zone. Irrelevant zones are left out in the table.

	Footprint type	**Filamentous algae**				***Furcellaria***				**Vegetation stands (1–10 %)**			
		Total	DK	DE nat.	DE EEZ	Total	DK	DE nat.	DE EEZ	Total	DK	DE nat.	DE EEZ
Very high	s												
	c												
High	s					14	14						
	c					4	4						
Medium	s					174	174						
	c					16	16						
Minor	s									30	30		
	c	15	15	0.22						45	45		
Total	s					188	188			30	30		
	C	15	15	0.22		20	20			45	45		
		15	15	0.22		208	208			75	75		

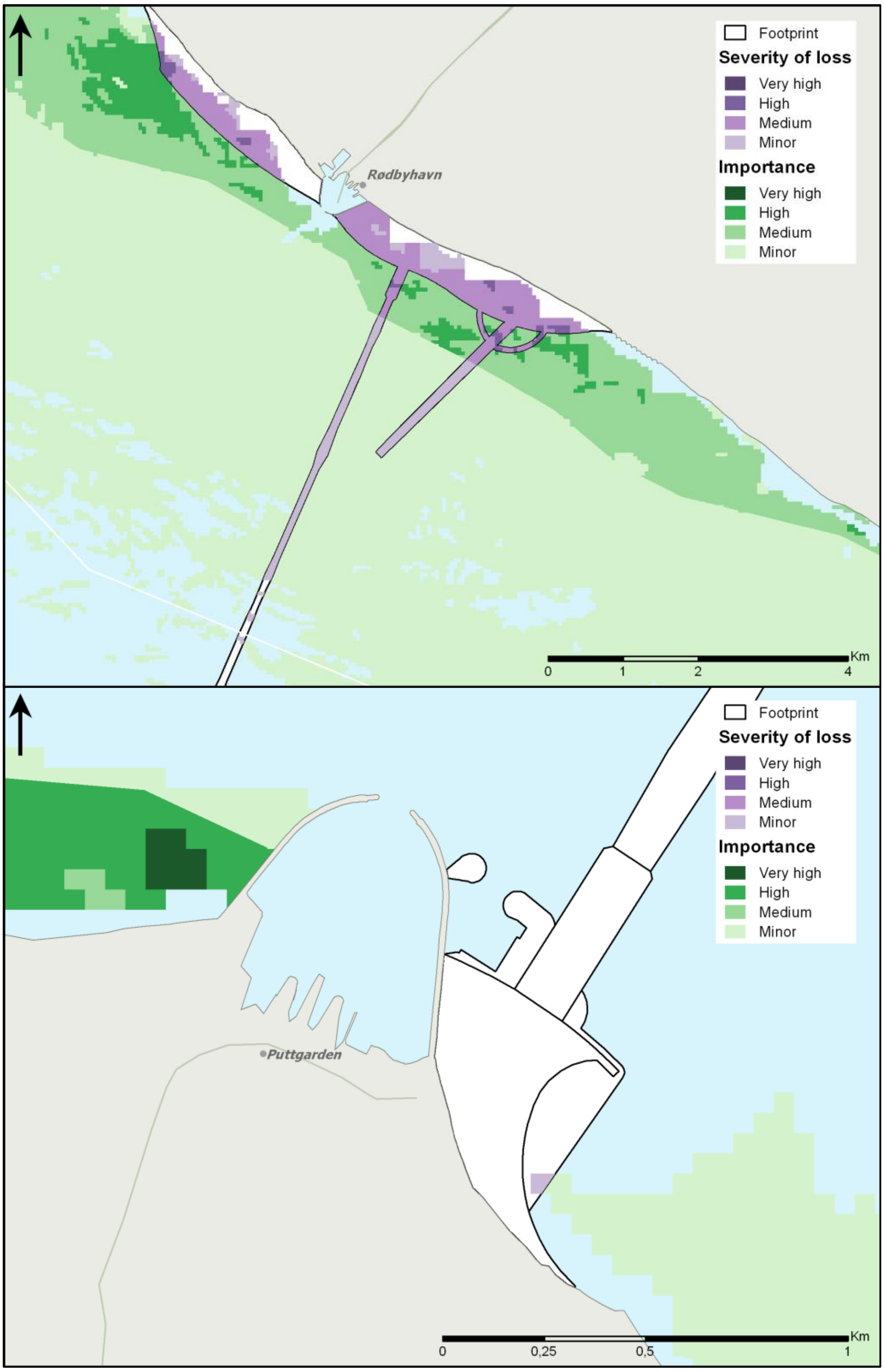


Figure 7-16 Spatial distribution of severity of loss caused by footprints for the tunnel alternative along the Lolland coastline (above) and along the Fehmarn coastline (below). Please note that severity of loss only occur in the coastal areas. In the deeper

parts of Fehmarnbelt no severity of loss has been assessed as vegetation is missing. The severity is in this figure overlaying the importance levels.

7.3.3 *Significance*

Significance is determined by comparing the loss of specific vegetation communities (Table 7-19) with the inhabited area in Fehmarnbelt or the assessment area and the possibility and duration of the recovery from the impact. The results for the significance evaluation are listed in Table 7-20.

The loss of filamentous algae community (15 ha) or single vegetation stands (1–10% coverage, 75 ha) is assessed as minor severity of loss as both communities have a low ecological value and are not protected by any international or national guideline or legislation (and therefore is of minor importance). The 15 ha of filamentous algae correspond to less than 1% (0.98%) of filamentous algae in Fehmarnbelt and 0.21% in the assessment area. The 75 ha of single vegetation stands correspond to less than 1% (0.86%) of single stands in Fehmarnbelt and 0.06 % in the assessment area.

The impact due to footprints is therefore insignificant for filamentous algae and single vegetation stands in terms of area loss on a local and regional scale.

Within most of the impacted area (208 ha) the *Furcellaria* community occurs in different coverage degrees (>50 % coverage, 10–50 % coverage), which is reflected in the severity level: 18 ha with high severity of loss and 190 ha with medium severity of loss. The 208 ha correspond to 9 % of the *Furcellaria* community area in Fehmarnbelt and to 5% in the assessment area.

Based on the predicted biomasses (Figure 6.5 in the baseline report), the loss correspond to 6 % of the total algal biomass and 8.8 % of the Furcellaria-community biomass in Fehmarnbelt.

The loss is mainly caused by structure-related footprints (188 ha), for which the impact is permanent and therefore not reversible. Those 188 ha of lost *Furcellaria* corresponds 8% in Fehmarnbelt and to 5% in the assessment area; the areas are lost permanently.

Furcellaria is not protected by Danish legislation, while it is protected in German waters (§30 BNatSchG). However, the loss occurs exclusively in Danish waters.

The *Furcellaria* community is a valuable part of benthic flora (high to medium importance). The area loss will not threaten the existence of the community in the Fehmarnbelt but is assessed to be significant for the functioning of the local ecosystem of Fehmarnbelt, as perennial coastal macrophytes are important as habitat structuring elements contribution to the coastal primary production, O_2 production and creating habitats for associated flora and fauna. However, the loss will not threaten the existence or function of community in the Baltic Sea. The *Furcellaria* community is common in the whole Baltic Sea area and is dominant or occurring frequently from Skagerrak to Bothnian Sea (Nielsen et al 1995). *Furcellaria* is red-listed in the HELCOM area (HELCOM 2007).

The construction-related part of *Furcellaria* loss (20 ha) is caused by the access channel to the Lolland working harbour and to a very low degree by the tunnel trench and the working harbour itself. The duration of the seabed establishment for the access channel is calculated to a maximum of 30 years for the deepest trench sections near to the reclamation areas, where the *Furcellaria* community occurs (FEHY 2013b). The recovery time for *Furcellaria* is high (5–10 years). The duration for the impact for the access channel is therefore longer than 30 years (Operation phase C).

For the tunnel trench and the working harbour the duration was calculated to 1–10 years (tunnel trench, Section A) and < 5 years (working harbour), respectively (FEHY 2013b). With a recovery time for *Furcellaria* between 5 and 10 years, the duration of those impacts varies between 5 as minimum and 15 years as maximum (Construction phase+, Operation phase A–B).

The estimated recovery times may be longer if the seabed recovery is not resulting in areas with suitable hard substrate for macroalgal colonisation.

The impact on the *Furcellaria* community is therefore significant on a local scale as the percentage of footprint area, which has no permanent duration, is too small and also the temporary part of the impact has partly a long recovery duration.

Table 7-20 Severity of impairment (in %) for loss per community caused by footprint for the tunnel alternative Basis for the calculation is the total area of severity per community.

	Filamentous algae		***Furcellaria***		**Vegetation stands (1–10 % cover)**	
	Fehmarnbelt	Assessment area	Fehmarnbelt	Assessment area	Fehmarnbelt	Assessment area
Very high						
High			0.76	0.46		
Medium			8	5		
Minor	0.97	0.21			0.86	0.06
Total	0.97	0.21	9	5	0.86	0.06

7.4 *Solid substrate*

7.4.1 *Magnitude of pressure*

At the shorelines new solid substrate will be created by new shorelines around the reclamation areas and the protection reef, which covers the tunnel elements close the shoreline that are not fully submersed in the sediment.

The surfaces of these structures provide new substrate for macroalgae species requiring solid substrate for colonisation. The potential new area and biomass of new algal communities depend on the depth extension and the position (vertical or horizontal) of the new structures.

The tunnel elements will be immersed in a dredged trench, and covered by a protection layer of rocks. In the tunnel trench a natural refill by sedimentation will take place. These areas are included as additional solid substrate. The natural refilling is expected to take up to 30 years and during refilling the majority of the sediment will deposit on the slopes and gradually narrow the channel (FEHY 2013b). Theoretically, the gradual narrowing means that the rocks are available for colonisation of macroalgae in a period. However, some deposition on the stones at the bottom must be expected and even a thin layer may reduce settlement of spores.

Altogether, in the depth interval from 0 – 20 m an area of 584,102 m^2 in Danish waters and 222,190 m^2 solid substrate are added to the area. Below 20 m no substantial algae growth is expected.

Table 7-21 Area (ha) of new solid substrate added by the planned tunnel to Fehmarnbelt in the depth interval 0 – 20 m

Total area	Near zone	Denmark National+ EEZ	Germany national	Germany EEZ
80	80	58	22	0

7.4.2 *Degree of impairment*

Possible impacts to the benthic flora are:

- Introduction of hard bottom macroalgal communities if hard substrate was not present in the area before. This is not relevant for Fehmarnbelt as the baseline study show that macroalgal communities already are characteristic for the area (FEMA 2013a).
- Increased risk of an introduction of non-indigenous species. Newly introduced solid substrates can be used by non-indigenous species if free substrate is limiting their dispersal. The species composition found on new structures of the Øresund and Great Belt Fixed links are comparable to the communities of the surrounding hard bottom communities and not dominated by non-indigenous species. Therefore the risk seems to be limited.

New structures will increase the area of hard bottom macroalgal communities. Macroalgae from the surrounding hard substrates can use the additional solid substrate for settlement and increase their area of distribution (no impact but a positive effect).

Monitoring from other new structures like Øresund and Øland bridge (Qvarfordt & Kautsky 2006, Øresundsbroen 2005) as well as investigations from artificial reefs (Kraufelin et al. 2007) showed that new solid substrates are often dominated by species with a low ecological value like filamentous algae. Those opportunistic species are comparable to the primary colonizers on land. Comparison between artificial reefs of different composition showed that reefs built out of concrete inhabit fewer algae species and lower algae biomasses (Ambrose 1994).

Based on the calculated additional solid substrate and the relationship between depth and macroalgae biomass (FEMA 2013) the additional algae biomass was estimated (Table 7-22).

Table 7-22 Estimated biomass of benthic macroalgae (kg DW) on new solid substrate in the depth layer between 0 and 20m assuming similar distribution of biomass as under baseline conditions.

Total area	**Near zone**	**Denmark National+ EEZ**	**Germany national**	**Germany EEZ**
102,896	102,896	75021	27875	0

7.4.3 *Severity and significance of impairment*

If the new solid substrate is colonised with macroalgae with the same biomasses as found in the baseline study on natural rocks the new area constitute 10% of the area and 7% of the biomass of the existing communities in the near zone (Table 7-23). This is a positive impact.

Assuming that the same communities will be established this will to some degree counterbalance the loss from footprints.

On the larger scales (e.g. local), the potential new communities will not significantly change to the functioning of the ecosystem as they only make up 1.5% or less of the existing area and biomass.

Table 7-23 Percentages new solid substrate in relation to existing areas and biomass of macroalgae in the different zones (1-10% vegetation cover not included)

	Total area	**Near zone**	**Local zone**	**Denmark National+ EEZ**	**Germany national**	**Germany EEZ**
Area	0.4%	10%	1.5%	0.7%	0.2%	0%
Biomass	0.6%	7%	1%	0.8%	0.3%	0%

7.5 Coastal morphology

7.5.1 *Magnitude of pressure and severity of loss*

Several structures of the tunnel alternative can have influence on the near bed current system or can cause a “barrier” effect on the sedimentation transport system along the coastline and change the morphology of the seabed and/or coastline. In section 4.6 effects on the seabed morphology have already been assessed as negligible, as no or only insignificant changes to the near bed current system are detectable (FEHY 2013b).

Results are illustrated in Figure 7-18 and listed in Table 7-24 and Table 7-25.

Lolland coast

East of the reclamation area no or only negligible changes are expected. West of the reclamation are sand accumulation (accretion) is expected. Within a time span of more than 30 years new land will be formed broadening the natural existing beach (FEHY 2013d). This means that 31 ha of marine environment will be lost permanently. Only a limited part of this area (8 ha) are colonised by benthic flora.

Eight ha of benthic flora are affected by loss: 0.23 ha with high severity of loss, 6 ha with medium severity of loss and 2 ha with minor severity of loss. Most of the lost area is restricted to near zone (7 ha), only 1 ha occurs in the local zone. Overall 6 ha of the *Furcellaria* community and 2 ha of single vegetation stands are affected by loss.

Figure 7-17 Location of sand accumulation west of the reclamation area at Lolland and predicted time span for accretion (Figure from FEHY 2013d).

Fehmarn coast

Along the Fehmarn coastline only insignificant changes to the sand transportation system are expected and thus, no changes of coastal morphology are detectable (FEHY 2013d). The impacts on benthic flora due to changed coastal morphology for the tunnel alternative are negligible in German waters.

Table 7-24 Severity of loss (area loss in ha) caused by changed coastal morphology for the tunnel alternative. Geographical zones without any changes (DE waters) are left out in the table.

	Total	**Near zone**	**Local zone**	**DK national + EEZ**
Very high	0			
High	0.15	0.15		0.15
Medium	6	5	1	6
Minor	2	2		2
Total	8	7	1	8

Table 7-25 *Severity of loss (area loss in ha) per community caused by changed coastal morphology for the tunnel alternative. Geographical zones without any changes (DE waters) are left out in the table.*

	Furcellaria				**Vegetation stands (1–10 %)**			
	Total	Near zone	Local zone	DK	Total	Near zone	Local zone	DK
Very high	0							
High	0.15	0.15						
Medium	6	5	1	6				
Minor					2	2		2
Total	6	5	1	6	2	2	0	2

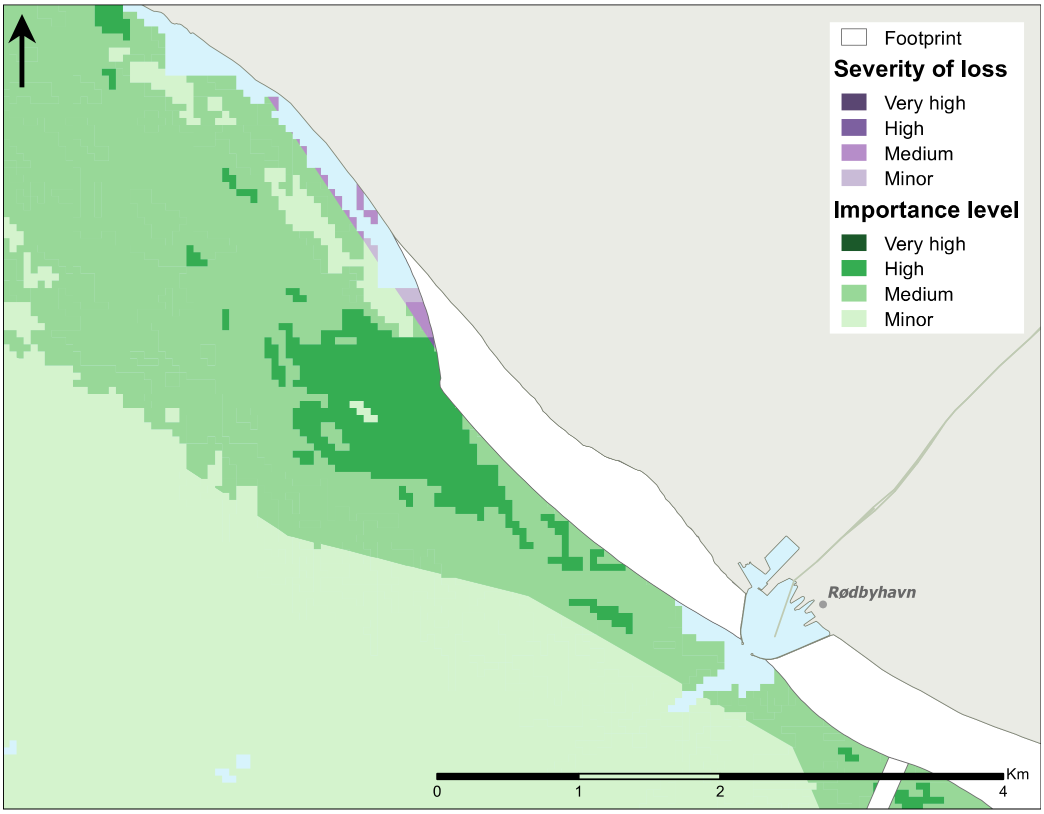


Figure 7-18 *Severity of loss caused by changes of coastal morphology for the tunnel alternative along the Lolland coastline.*

7.5.2 *Significance*

Results for the significance evaluation are listed in Table 7-26.

6 ha of *Furcellaria* community and 2 ha of single vegetation stands comprises < 1 % of the *Furcellaria* community and the single vegetation stands in Fehmarnbelt (= local zone) and also in near zone.

The impact due to changes in coastal morphology is insignificant for *Furcellaria* and single vegetation stands in terms of area loss.

Table 7-26 *Severity of impairment (in %) for loss per community caused by coastal morphology for the tunnel alternative. Basis for the calculation is the total area of severity per community.*

	Furcellaria		**Vegetation stands (1–10 %)**	
	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area
Very high				
High	0.01	< 0.01		
Medium	0.16	0.12		
Minor			0.03	< 0.01
Total	0.17	0.12	0.03	< 0.01

7.6 Aggregation of impacts

The potential pressures identified to possibly impact benthic flora due to activities during the construction and operation phases and due to new structures are listed in Table 7-27. Most pressures have a very low magnitude and could be screened out as having negligible impacts on the benthic vegetation.

Table 7-27 *Pressures potentially causing an impact on benthic flora in the construction, structure and operation phases of the project and their relevance in the impact assessment.*

Phase	Pressure	Duration	Range	Relevance for benthic flora
Construction	Suspended sediment	Construction phase+	Outside local zone	Relevant
	Sedimentation	Construction phase+	Outside local zone	Relevant
	Toxic substances	Construction phase+	Near zone	Negligible
	Nutrients	Construction phase+	Near zone	Negligible
	Construction vessels and imported material	Construction phase+	Near zone and transport zones	Negligible
Structure	Footprint	Operation phase C	Near zone	Relevant
	Solid substrate	Operation phase C	Near zone	Relevant
	Seabed and coastal morphology	Operation phase C	Outside local zone	Relevant
	Hydrographical regime (salinity, temperature) and Water quality (nutrients, Secchi depth)	Operation phase C	Outside local zone	Negligible
Operation	Drainage	Operation phase C	Near zone	Negligible

Relevant pressures and the area they impact are compared and shortly discussed community by community. The total area of loss/impairment for each grade of severity, and the significance are taken into account (Table 7-28).

Table 7-28 The lost/impaired areas (in ha) for the different pressures are listed per community; divided into severity levels. Significant impacts are marked with (s). For suspended sediment the worst impact year is shown.

	Suspended sediment		Sedimentation	Footprint	Seabed/coastal morphology
	2015	2019			
Eelgrass					
Very high					
High	96		1		
Medium	1925		243		
Minor	6315	352			
Total	8336	352	244		
Eelgrass/algae					
Very high					
High					
Medium			2		
Minor	891	1			
Total	891	1	2		
Filamentous algae					
Very high					
High					
Medium					
Minor	1679	3		15	
Total	1679	3		15	
Fucus					
Very high					
High					
Medium					
Minor			33		
Total	0	0	33		
Furcellaria					
Very high					
High	20		1	18 (s)	0.23
Medium	727		16	190 (s)	6
Minor	2126		191		
Total	2873	0	208	208 (s)	6
Phycodrys/Delesseria					
Very high					
High					

	Suspended sediment 2015	Suspended sediment 2019	Sedimentation	Footprint	Seabed/ coastal morphology
Medium					
Minor	487	65	51		
Total	487	65			
Saccharina					
Very high					
High					
Medium					
Minor	118	49	34		
Total	118	49			
Tasselweed/dwarf eelgrass					
Very high					
High					
Medium	22				
Minor	135				
Total	157	0			
Vegetation stands (1–10 % cover)					
Very high					
High					
Medium					
Minor				75	2
Total				75	2

The tunnel alternative impacts all of the vegetation communities and the single vegetation stands. Most of the impacts are of minor severity. Impacted areas are large especially for the pressures suspended sediment and sedimentation and the spatial range of the impacts exceeds the local zone for those two pressures.

The *Furcellaria* community is impacted on higher severity levels. Temporary high reductions in biomass are predicted, but recovery are predicted within two years after the construction and therefore considered to be insignificant. The permanent loss of the community in the reclamation area is regarded as significant.

The Eelgrass community is impacted on a medium severity level. But those impacts refer to impairment and not to loss and are not regarded as significant.

All other communities are affected in much smaller areas compared to the former listed ones.

Assessed separately the pressures will not cause significant impacts, but the cumulative impact of more pressures could potentially result in a more severe impact. The impacts from the pressures cannot be added, as they are not directly comparable. For example, the impact from suspended sediment is related to a certain reduction in biomass for each year and for sedimentation the impact assessment is of more qualitative nature and described for the whole construction period. However, the potential cumulative impact on the vegetation can be tentatively assessed by estimating the areas that are exposed to more than one pressure.

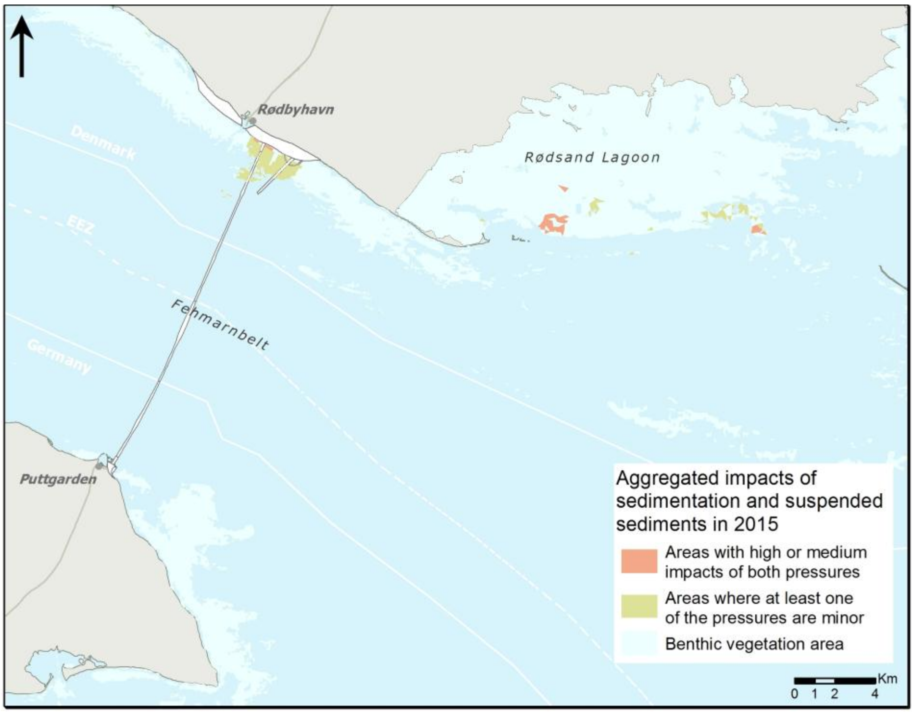
For eelgrass the total area where aggregated impacts are predicted to occur is 221 ha, corresponding to 2% of the eelgrass population in Rødsand Lagoon, see Figure 7-19. The area with medium or high degree of impairment for sedimentation and suspended sediment (2015) correspond to approximately 1% (106 ha) of the eelgrass community in Rødsand. In these areas, the impact is expected to be higher than predicted for the individual pressures with larger reductions in biomass and increased mortality. In other overlap areas at least one of the pressure only cause minor degree of impairment. High sedimentation and minor suspended sediment occur in 5 ha, and medium sedimentation and minor suspended sediment in 109 ha. Minor degree of impairment for suspended sediment reduces biomass with 10-25% and consequencely could cause a higher impact than sedimentation alone.

For macroalgae the total area where cumulative effects could occur is 289 ha, corresponding to 1.8% of the macroalgae area in the assessment area, see Figure 7-19. The area that are estimated to be exposed to combinations of medium and high degrees of sedimentation and suspended sediment (2015) correspond to approximately 0.1% (10 ha) of the macroalgal area in the Fehmarnbelt area. In these areas, the impact is expected to be higher than predicted for the individual pressures with larger reductions in biomass and increased mortality. In other overlap areas at least one of the pressure only cause minor degree of impairment. High suspended sediment and minor sedimentation occur in 60 ha, medium suspended sediment and minor sedimentation in 138 ha, and minor suspended sediment and minor sedimentation in 83 ha. In these areas, the impact of suspended sediment is dominating and the additional effect of sedimentation is small.

For later years, the area with overlapping impairment from suspended sediment and sedimentation is smaller.

As lost vegetation cannot be any further impacted, cumulative impairments are not relevant for the impact loss.

In summary, the cumulative effects of sedimentation and suspended sediment can cause an increase in the degree of impairment in areas corresponding to app. 2% of the eelgrass population in Rødsand Lagoon and of the macroalgal population in the assessment area. Since the areas affected are small these aggregated impacts are considered negligible.



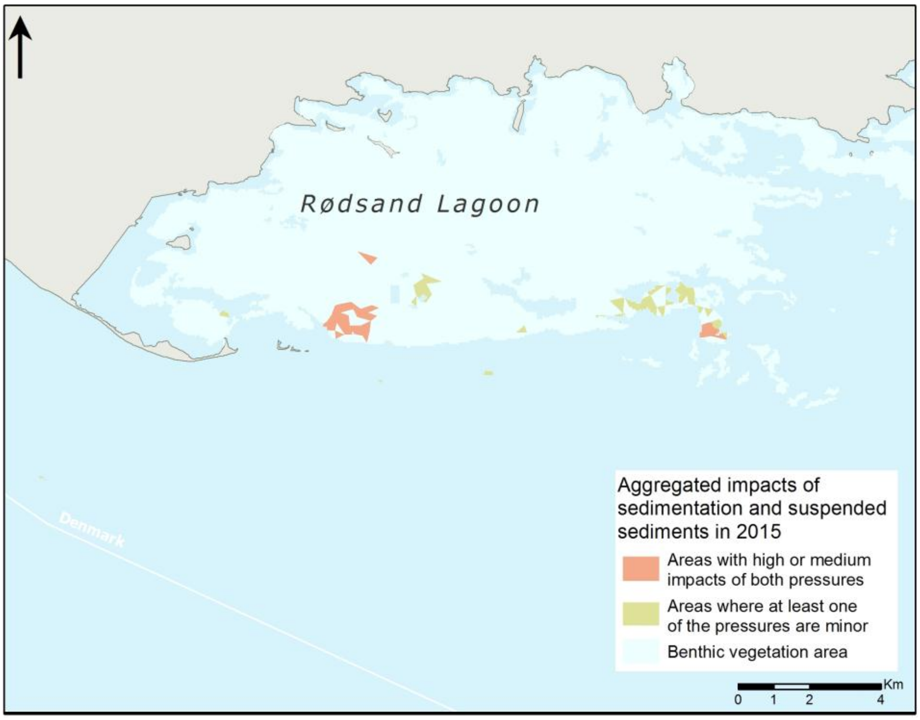


Figure 7-19 Areas where aggregated effects of suspended sediment and sedimentation can be expected in the whole area (upper) and in Rødsand Lagoon (lower).DOI = degree of impairment.

7.7 Cumulative impacts

There are no cumulative impacts for benthic flora.

7.8 Transboundary impacts

No transboundary impacts on benthic flora are predicted for the tunnel alternative.

7.9 Mitigation and compensation measures

This chapter of the report is prepared in co-operation with Femern A/S.

Mitigation can reduce the magnitude of pressure and subsequent loss and impairment of the environmental factors. Mitigation measures have to be pressure-specific and may differ between sub-components (communities). Only mitigation of significant impacts is included.

Compensation is a legal requirement, if protected habitats/species are lost or impaired significantly. As none of the pressures will affect protected benthic vegetation by significant loss or impairment, compensation of benthic flora is not necessary for the tunnel alternative.

Footprint
The footprint of the tunnel alternative causes significant habitat loss. The reclamation area along the Lolland coastline causes a significant loss of the *Furcellaria* community.

The project has already included optimisation of the impact of the footprint through the comparison of alignments and along the Fehmarn coastline, the chosen shape and area of footprints exclude the loss of vegetation nearly completely. The present footprints fulfil technical requirements of the project and further mitigation is not possible.

Lost habitats can be compensated by moving the hard substrate presently situated in the planned reclamation area to nearby areas with low cover of hard substrate in shallow water.

7.10 Decommissioning

Decommissioning of the tunnel alternative is foreseen to take place in 2140, when the Fixed Link has been in operation for the design lifetime of 120 years.

With regard to the marine part, the overall plan is that the main elements of the tunnel will be decommissioned as follows:

The tunnel elements will remain under the seabed. The tunnel tubes are flooded with water and the tunnel tubes will be sealed. There will be no impact on the marine environment and hence the benthic flora.

The reclamation areas will remain in place and not be decommissioned. There will therefore not be an impact on the marine environment nor the benthic flora.

The two elements of the tunnel, which are in contact with the marine area, will not impact the marine area due to decommissioning of the tunnel alternative.

8 ASSESSMENT OF IMPACTS OF MAIN BRIDGE ALTERNATIVE

8.1 Suspended sediment

8.1.1 *Magnitude of pressure*

Average reduction in available light at the bottom during the growth season (1/3 – 1/9) in the coastal areas is relatively small (up to 2-5%) in the first year of the construction of the bridge. In the deep areas west of the alignment the average reduction is 5-10%.

The reduction in light in the near coast areas is highest in the second year of the construction phase. Between 2-10% reduction in light during the growth season is predicted along the coast of Lolland and in Rødsand Lagoon. The same patterns of reduction in light just in smaller areas are predicted for the third year (Figure 8-1).

The maximum reduction in light along the Fehmarn coast is 2-5%.

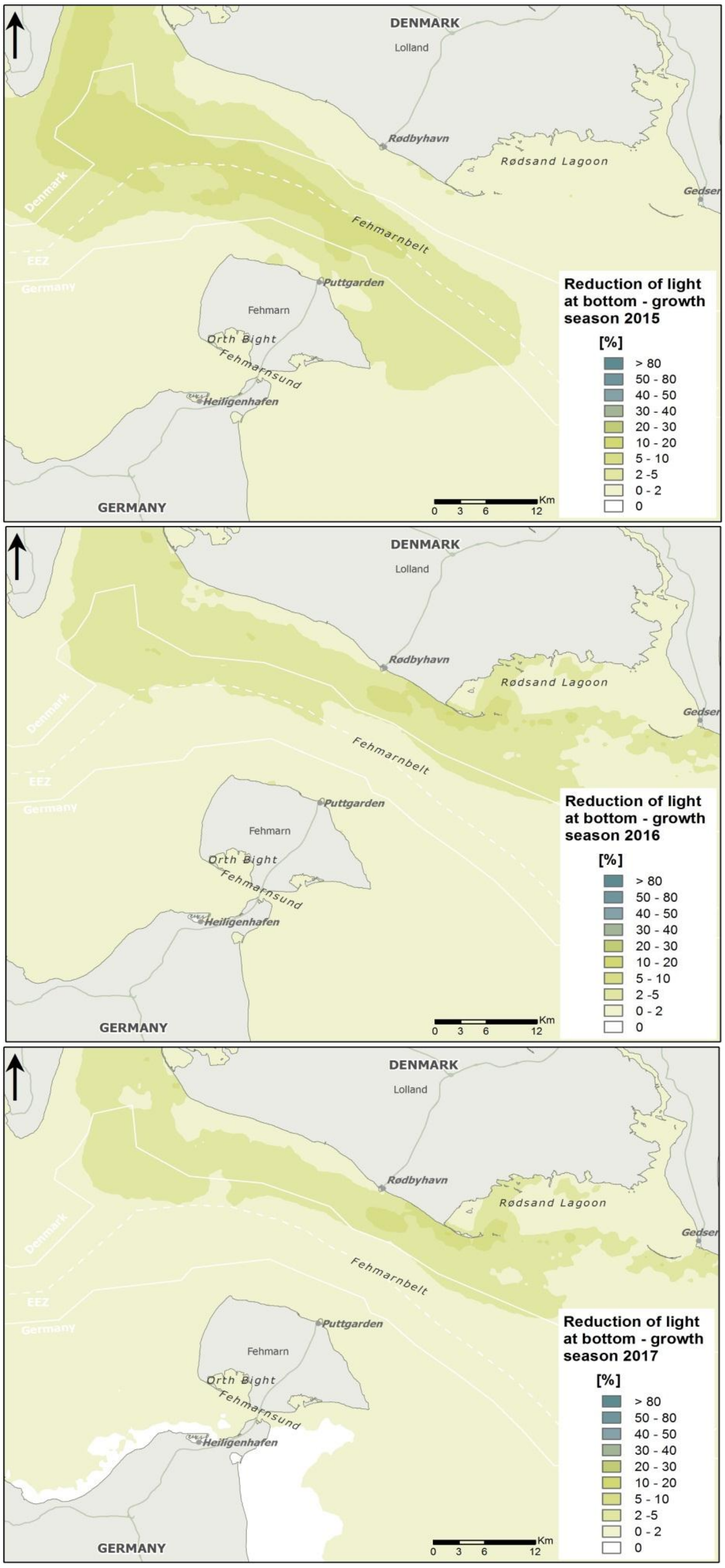


Figure 8-1 Reduced light availability during the growth season in the three years of bridge construction: 2015 (upper), 2016 (middle) and 2017 (lower). The reduction is calculated as cumulative light in the growth season relative to the reference conditions with no sediment spill.

8.1.2 *Severity of loss*

No loss (of function) is predicted due to suspended sediment.

8.1.3 *Degree of impairment*

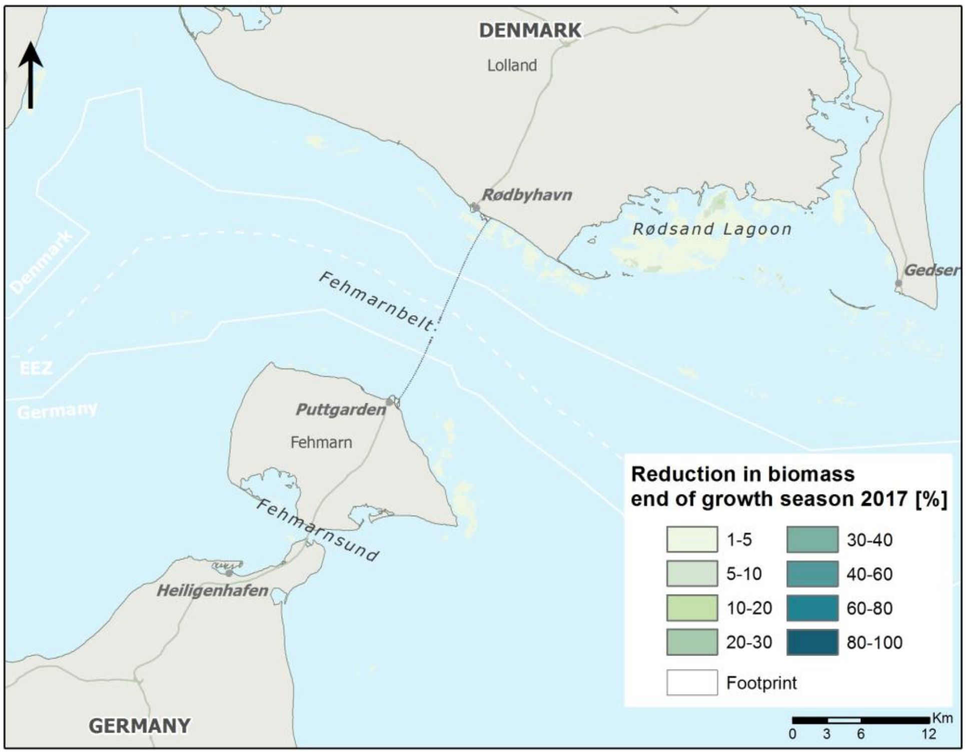
Very small reductions in biomass of benthic flora are predicted as consequences of increased concentrations of suspended sediment for the bridge alternative.

In the first and third year of the bridge construction, no biomass reduction is expected for macroalgae. The second year light reductions are predicted along the coast of Lolland (Figure 8-1) resulting in small reductions in benthic flora biomasses. The biomass of filamentous species community is reduced 0.25 ha by between 10-20%, equivalent to a minor degree of impairment.

No biomass reduction of eelgrass is expected in the first year (2015) of the bridge construction. The second year (2016) 12 ha and the third year (2017) 32 ha eelgrass is impacted with minor degree of impairment (Table 8-1, Figure 8-2)

Table 8-1 Degree of impairment (areas in ha) caused by suspended sediments for the tunnel alternative. Geographical zones without any impacts (transboundary) are left out in the table.

	Total	Near zone	Local zone	DK national + EEZ	DE national	DE EEZ
2015						
Very high	0					
High	0					
Medium	0					
Minor	0					
Total	**0**	**0**	**0**	**0**	**0**	**0**
2016						
Very high	0					
High	0					
Medium	0					
Minor	0			12		
Total	**0**	**0**	**0**	**12**	**0**	**0**
2017						
Very high	0					
High	0					
Medium	0					
Minor	0			32		
Total	**0**	**0**	**0**	**32**	**0**	**0**



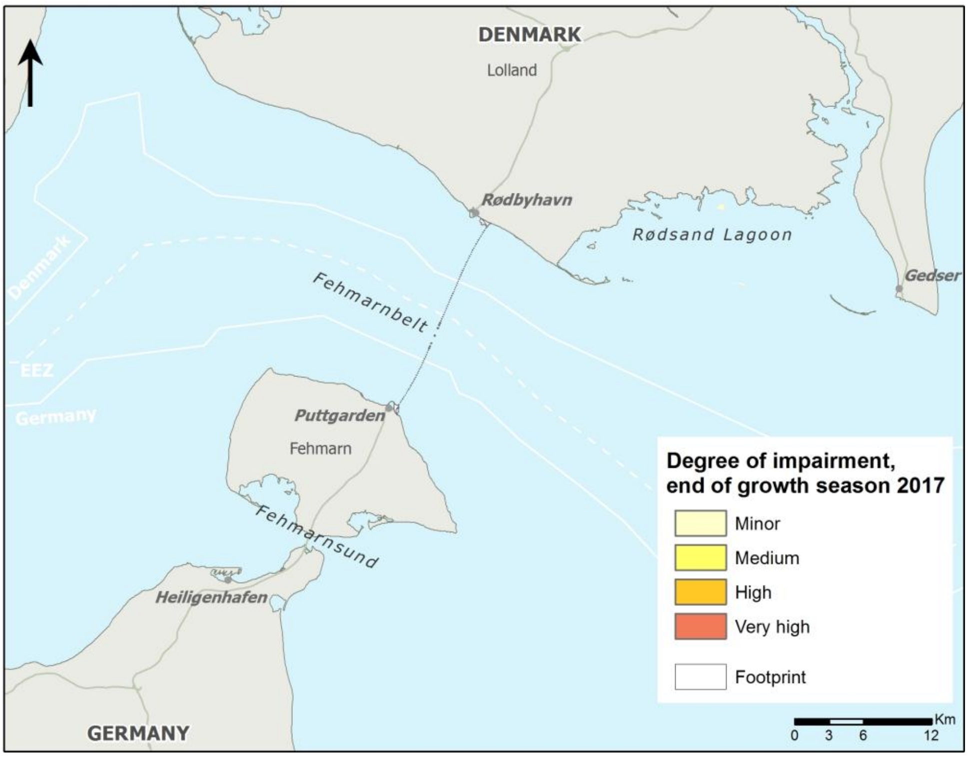


Figure 8-2 Reduction in benthic flora biomass and degree of impairment at end of the growth season in the second third year of the bridge construction (the same illustrations for 2015 and 2016 are shown in Appendix C).

8.1.4 *Severity of loss*

As no very high magnitude of pressure is predicted for suspended sediment, no loss of function and therefore no severity of loss occur due to sedimentation.

8.1.5 *Severity of impairment*

Macroalgae were not impacted to any degree of severity as a consequence of increased concentrations of suspended sediment for the bridge alternative.

Eelgrass is not impacted to any degree of severity in the first year of the bridge construction. In the second year 12 ha and the third year 32 ha eelgrass is impacted to minor degree of severity.

8.1.6 *Significance*

The impact is only of minor severity and impacting less than 0.5% of eelgrass in the assessment area and is therefore considered to be non-significant.

8.2 *Sedimentation*

8.2.1 *Magnitude of pressure*

Dredging and backfilling activities during the construction of the bridge alternative cause sediment spill and subsequent deposition of sediment on the seabed (see Chapter 4.1).

The simulation of accumulation of spilled sediment on the seabed (FEHY 2013c) showed that with the given dredging/backfilling plan the sediment layers with a persistence of ≥ 10 days reached a maximum of 3 cm in the assessment area (Figure 4-3); and only at the alignment area around the pylons of the main bridge and at the Lolland coastline near the reclamation peninsulas.

The sedimentation was transformed into magnitude of pressure levels, as defined for soft and hard bottom communities (see chapter 4.2, Table 8-3 and Table 8-4). It illustrates the spatial range and Table 8-2 lists the areas (ha), for the different levels of magnitude of pressure.

Table 8-2 Magnitude of pressure (areas in ha) caused by sedimentation for the bridge alternative. Geographical zones without any sedimentation (transboundary) are left out in the table.

	Total	**Near zone**	**Local zone**	**DK national + EEZ**	**DE national**	**DE EEZ**
Very high						
High						
Medium	12	11	1	12		
Minor	71	20	51	22	49	
Total	83	31	52	34	49	

Table 8-3 Magnitude of pressure levels for macroalgal communities.

Magnitude of pressure	Thickness of sediment layer (persistent ≥ 10 days)
Very high	> 10.0 cm
High	> 5.0 – 10.0 cm
Medium	> 1.0 – 5.0 cm
Minor	> 0.2 – 1.0 cm

Table 8-4 Magnitude of pressure levels for flowering plant communities.

Magnitude of pressure	Thickness of sediment layer (persistent ≥ 10 days)
Very high	> 20.0 cm
High	> 10.0 – 20.0 cm
Medium	> 5.0 – 10.0 cm
Minor	> 1.0 – 5.0 cm

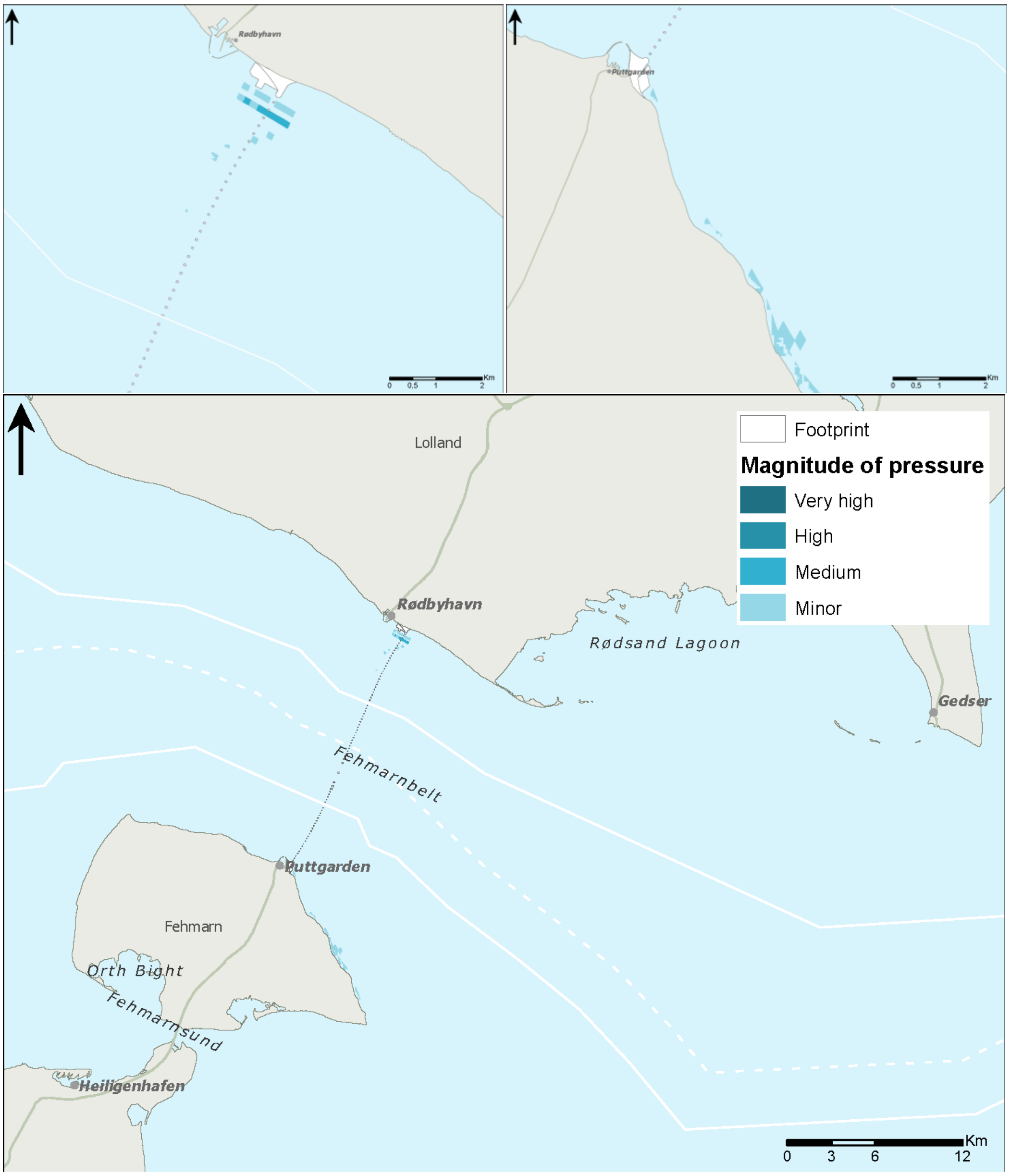


Figure 8-3 *Magnitude of pressure caused by sedimentation for the bridge alternative in detailed zones (above, left: Lolland coastline, right: Fehmarn coastline) and as overview (below).*

Sedimentation occurs at 901 ha of the assessment area, but only at 83 ha sedimentation exceeds the threshold value defined for benthic flora. 31 ha of the sedimentation is predicted for near zone, 52 ha for local zone and outside of the local zone no vegetation communities are affected by sedimentation.

More German areas than Danish areas are affected. In Danish waters 34 ha are affected by sedimentation and in German national waters 49 ha.

No very high and no high magnitude of pressure occurs due to sedimentation as no sedimentation layers > 10 cm/5–10 cm (for macroalgae) or > 20 cm/10–20 cm (for flowering plants) occur, which are the thresholds for very high and high magnitude of pressure.

12 ha are affected by medium magnitude of pressure: 11 ha in the near zone and 1 ha in the local zone. Medium magnitude of pressure occurs only in Danish waters. Medium magnitude of pressure corresponds to a deposited sediment height of 1–5 cm for macroalgae and 5–10 cm for flowering plants.

86% of the overall affected area is opposed to minor magnitude of pressure (83 ha). 31 ha occur in the near zone and 52 ha in the local zone. In Danish waters 22 ha of seabed are affected and 49 ha in German national waters. Minor magnitude of pressure corresponds to a deposited sediment height of 0.2–1 cm for macroalgae and 1–5 cm for flowering plants.

8.2.2 *Severity of loss*

As no very high magnitude of pressure is predicted for sedimentation, no loss of function and therefore no severity of loss occur due to sedimentation.

8.2.3 *Degree of impairment*

The degree of impairment for sedimentation is illustrated in

Figure 8-4 and listed in Table 8-5 and Table 8-6.

Overall 83 ha of benthic flora are affected by degree of impairment caused by sedimentation. 31 ha of impairment are predicted for near zone, 52 ha for local zone and no degree of impairment occurs outside of the local zone.

In German national waters there are only small areas with benthic vegetation In the areas affected by sedimentation thus the impacted area are small (49 ha) compared to the are affected by sedimentation. In Danish waters 34 ha are impaired.

No very high and no high degree of impairment occurs due to sedimentation.

At 12 ha the degree of impairment is medium. Medium degree of impairment appears exclusively along the Lolland coastline. The *Furcellaria* community is affected by medium degree of impairment: 11 ha in the near zone and 1 ha in the local zone.

At 71 ha a minor degree of impairment occurs. Minor degree of impairment appears in Danish waters (22 ha) and in German national waters (49 ha). Minor degree of impairment occurs, if minor magnitude of pressure affects communities with medium or minor sensitivity or if medium magnitude of pressure affects communities with minor sensitivity. Those combinations are the most probable ones as the minor magnitude area is the biggest one and many communities have medium or minor sensitivity towards sedimentation. Several communities are therefore affected by a minor degree of impairment.

The filamentous algae community is impaired on 15 ha by minor degree of impairment. The affected area occurs in near zone (7 ha) and local zone (8 ha). The impairment occurs mostly in Danish waters (5 ha) and in German national waters (10 ha).

The *Fucus* community is affected by minor degree of impairment on 1 ha. All of the impaired area is located in German national waters and all in the local zone.

The *Furcellaria* community is affected on 46 ha by minor degree of impairment. 17 ha of the impaired area occur in Danish waters, 29 ha in German national waters. 14 ha occur in the near zone and 32 ha in the local zone.

The *Phycodrys/Delesseria* community is affected on 9 ha with minor degree of impairment. The impaired area occurs exclusively in German national waters and all in the local zone.

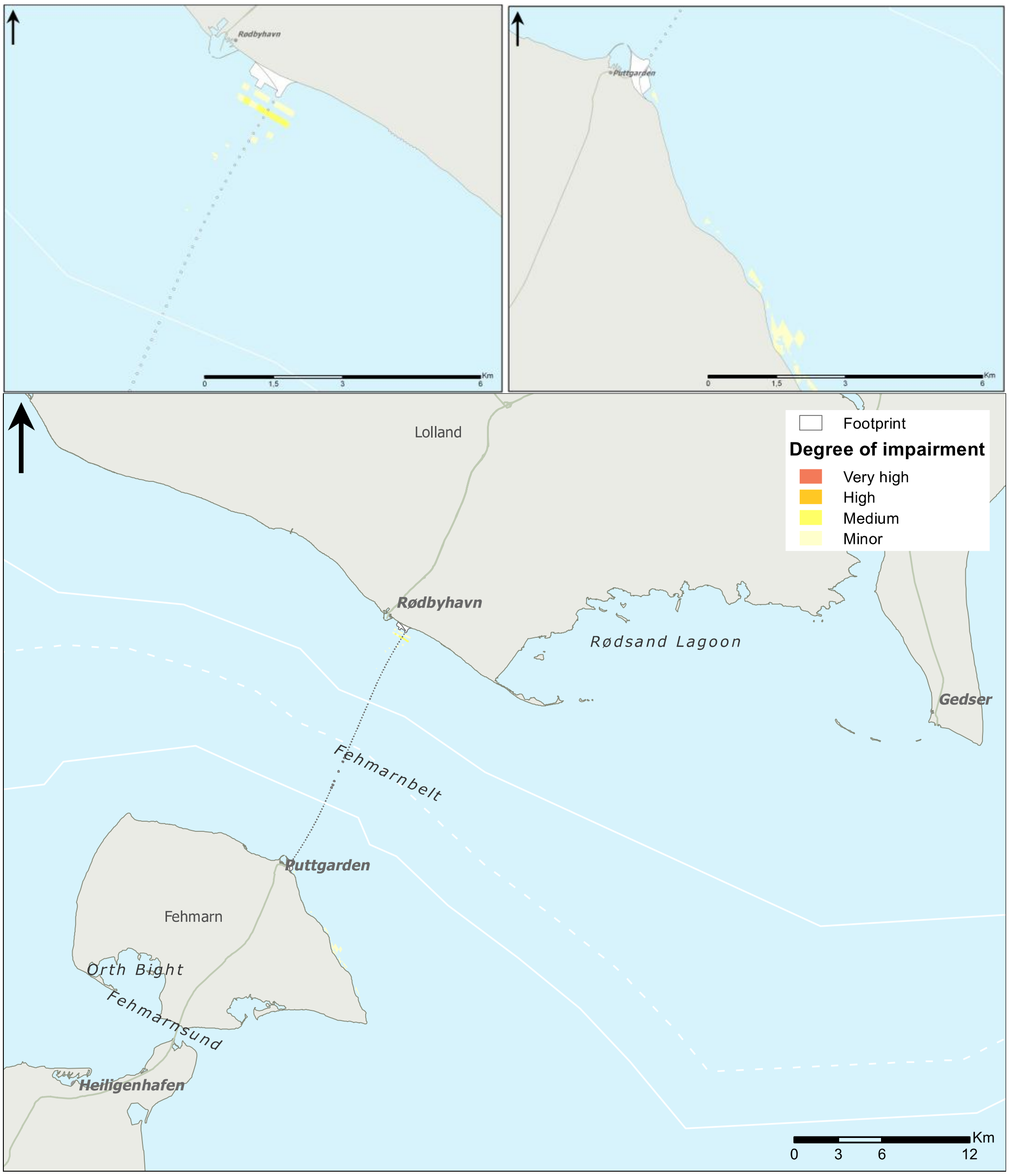


Figure 8-4 Degree of impairment caused by sedimentation for the bridge alternative for detailed zones (above, left: Lolland coastline, right: Fehmarn coastline) and as overview (below).

Table 8-5 Degree of impairment (areas in ha) caused by sedimentation for the bridge alternative. Geographical zones without any sedimentation (transboundary) are left out in the table.

	Total	**Near zone**	**Local zone**	**DK national + EEZ**	**DE national**	**DE EEZ**
Very high						
High						
Medium	12	11	1	12		
Minor	71	20	51	22	49	
Total	83	31	52	34	49	

Table 8-6 Degree of impairment (area loss in ha) per sub-component (community) caused by sedimentation for the bridge alternative. Geographical zones without any sedimentation (transboundary) are left out in the table.

	Filamentous algae						***Fucus***						**Furcellaria**					
	Total	Near zone	Local zone	DK	DE nat.	DE EEZ	Total	Near zone	Local zone	DK	DE nat.	DE EEZ	Total	Near zone	Local zone	DK	DE nat.	DE EEZ
Very high																		
High																		
Medium													12	11	1	12		
Minor	15	7	8	5	10		1		1		1		46	14	32	17	29	
Total	15	7	8	5	10		1		1		1		58	25	33	29	29	

	Phycodrys/Delesseria					
	Total	Near zone	Local zone	DK	DE nat.	DE EEZ
Very high						
High						
Medium						
Minor	9		9		9	
Total	9		9		9	

8.2.4 *Severity of impairment*

The severity of impairment results is illustrated in Figure 8-5 and listed in Table 8-7 and

Table 8-8.

Overall 68 ha of benthic flora are affected by severity of impairment caused by sedimentation. 25 ha of impairment are predicted for near zone, 43 ha for local zone and none outside of the local zone.

Compared to the results of degree of impairment only areas inhabited by the filamentous community has negligible severity of impairment, as filamentous algae were affected by minor degree of impairment and have a minor importance.

For all other communities no changes in area could be assessed compared to the degree of impairment results. This is due to the fact that most of the communities were impaired by minor degree of impairment and if this is intersected with importance the resulting severity of impairment remains minor for the importance classes very high to medium. Only for minor importance communities, the result is negligible severity of impairment as mentioned before.

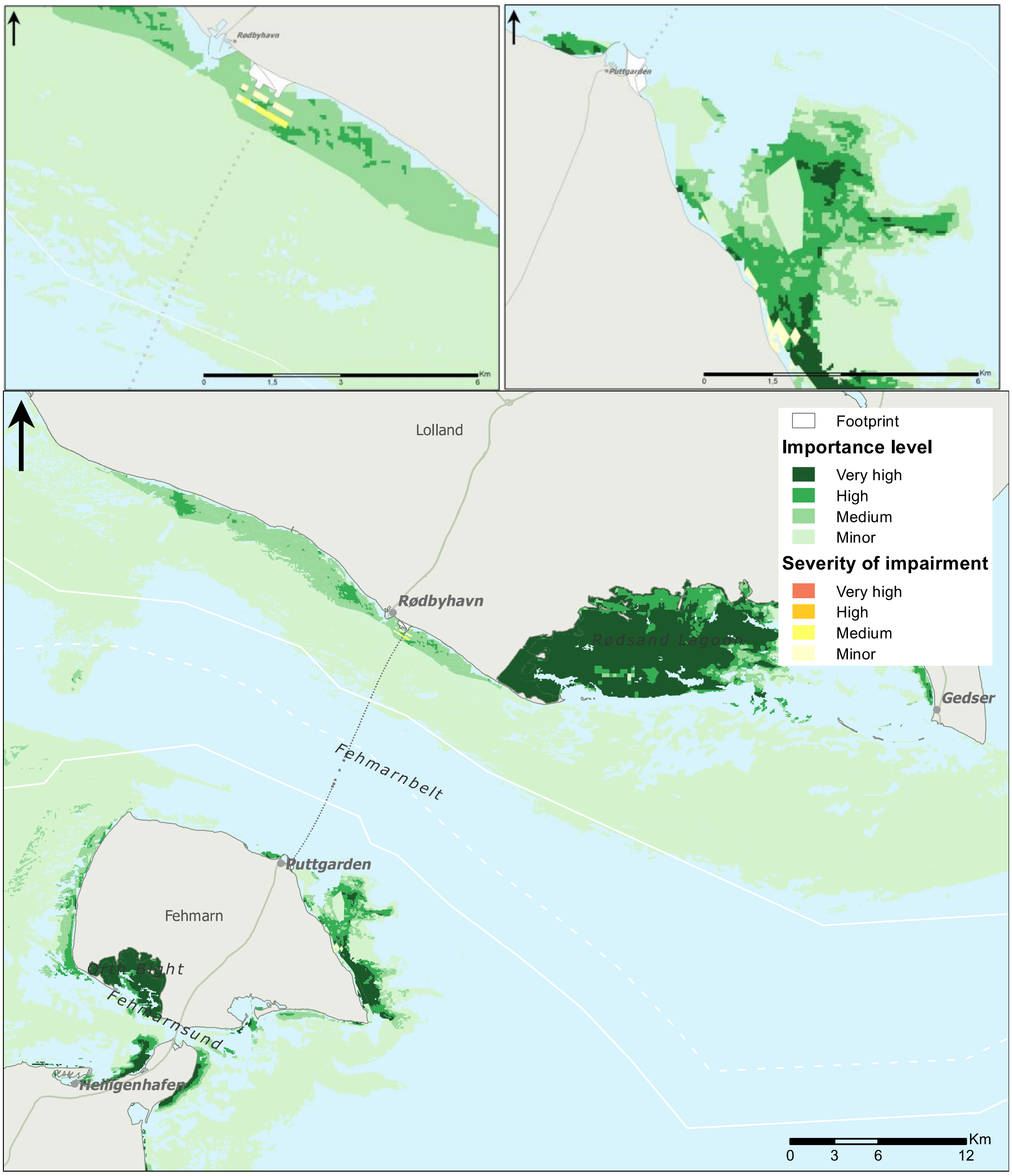


Figure 8-5 Severity of impairment caused by sedimentation for the bridge alternative for detailed zones (above, left: Lolland coastline, right: Fehmarn coastline) and as overview (below). The severity is in this figure overlaying the importance levels.

Table 8-7 Severity of impairment (areas in ha) caused by sedimentation for the bridge alternative. Geographical zones without any sedimentation (transboundary) are left out in the table.

	Total	Near zone	Local zone	DK national + EEZ	DE national	DE EEZ
Very high						
High						
Medium	12	11	1	12		
Minor	56	14	42	17	39	
Total	68	25	43	29	39	

Table 8-8 Severity of impairment (area loss in ha) per sub-component (community) caused by sedimentation for the bridge alternative. Geographical zones without any sedimentation (transboundary) are left out in the table.

	Fucus						***Furcellaria***						***Phycodrys/Delesseria***					
	Total	Near zone	Local zone	DK	DE nat.	DE EEZ	Total	Near zone	Local zone	DK	DE nat.	DE EEZ	Total	Near zone	Local zone	DK	DE nat.	DE EEZ
Very high																		
High																		
Medium							12	11	1	12								
Minor	1		1		1		46	14	32	17	29		9		9		9	
Total	1		1		1		58	25	33	29	29		9		9		9	

8.2.5 *Significance*

Significance is determined by comparing the impairment for specific vegetation communities with the inhabited area in Fehmarnbelt and the assessment area and the possibility and duration of the recovery from the impact. The results for the significance evaluation are listed in Table 8-98-10.

One ha of the *Fucus* community is affected by minor severity of impairment. This corresponds to 1% of the *Fucus* community in Fehmarnbelt and to 0.17% in the assessment area.

Overall 58 ha of the *Furcellaria* community are affected by sedimentation: 12 ha by medium and 46 ha by minor severity of impairment. 58 ha correspond to 2 % of the *Furcellaria* community in Fehmarnbelt and 1% in the assessment area.

Nine ha of the *Phycodrys/Delesseria* community is affected by minor severity of impairment. This corresponds to 1% of the *Phycodrys/Delesseria* community in Fehmarnbelt and to 0.23% in the assessment area.

Nearly all of the impaired macroalgae area (*Fucus*, *Furcellaria*, and *Phycodrys/Delesseria*) has a minor severity of impairment. The maximal deposited sediment height for the bridge has been predicted to 3 cm only and minor severity of impairment for macroalgae corresponds to sediment heights between 0.2–1 cm. Those sedimentation heights will not cause increased mortality and only a slight reduction in growth/biomass. Only the recruitment success will be reducedreduced, as hard substrates will be covered, reducing the possible settlement area for propagules. The viability of the communities is therefore not impaired. All macroalgae can balance the temporary failure of recruitment success within the next reproduction periods. The duration of the impact is limited to the Construction phase+ (= recovered within two years after end of construction). The impact on the macroalgae communities due to sedimentation is insignificant in terms of duration, severity level and partly area loss on a regional scale.

Table 8-98-10 Severity of impairment (in % of area) per community caused by sedimentation for the bridge alternative. Basis for the calculation is the total area of severity per community.

	Fucus		***Furcellaria***		***Phycodrys/Delesseria***	
	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area
Very high						
High						
Medium			0.51	0.30		
Minor	1	0.17	2	1	1	0.23
Total	1	0.17	2	1	1	0.23

8.3 *Footprint*

8.3.1 *Magnitude of pressure*

Several structures of the bridge alternative will cause footprints, which can be classified into the several types and time scales for re-establishment.

Structure-related footprints
Reclamation peninsulas: They are necessary for the connection of the approach bridges to each coastline and will reach out to water depths of 5–6 m. No re-establishment is possible. The duration is classified as the life span of the design, i.e. as permanent (= Operation phase C).

Piers and pylons (of main and approach bridges): Soil improvements or scour protection around those structures are included in the footprint area. No re-establishment is possible. The duration is classified as permanent (= Operation phase C).

Construction-related footprints
Work harbours and access channels: The work harbours are partly included in the reclamation peninsulas. This part is assessed within those footprints, but some parts are located outside of the reclamation peninsulas. After construction those parts (e.g. harbour basin, quays and pilings) will be dismantled/removed and backfilled, if necessary. The re-establishment of the seabed will take less than 5 years.

Table 8-11 lists the overall footprint area and the footprint area for the different footprint types, bridge structures and geographical zones and Figure 8-6 illustrates the location of the different footprint types.

Table 8-11 Footprint area with respect to type, bridge structure and geographical zone. As all footprints are near zone, irrelevant zones are left out in the table.

Type	**Structure**	**Footprint area [ha]**			
		Total	DK national + EEZ	DE national	DE EEZ
Structure-related	Reclamation peninsulas	36	16	20	
	Piers and pylons	20	7	4	9
Construction-related	Working harbours and access channels	24	15	9	
Total		**80**	**38**	**33**	**9**

The magnitude of pressure is very high regardless of the type and structure of the footprint. Overall the bridge footprints take up 80 ha. Structure-related, permanent footprints occupy 56 ha and construction-related footprints take up 24 ha. Reclamation peninsulas (structure-related footprints) and the working harbours (construction-related footprints) occupy the largest area.

In Danish waters footprints cover 38 ha. Most of those footprints are structure-related with no possibility of recovery.

Most of the footprints in the German area (24 of national + 9 ha of EEZ waters) belong to structure-related footprints with no possibility of recovery. The aspect recoverability will be discussed in the significance chapter.

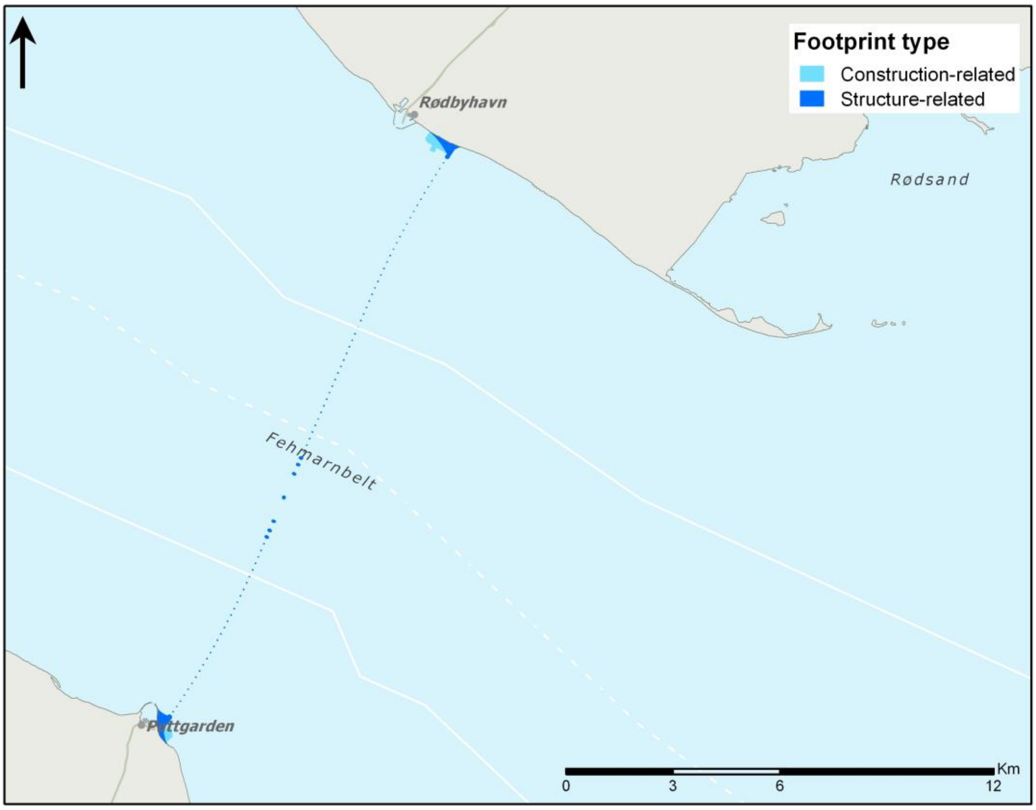


Figure 8-6 Location of the different footprint types for the bridge alternative.

8.3.2 *Severity of loss*

After intersecting the footprint area (corresponds to very high magnitude of pressure) with importance, the severity of loss was defined following the matrix showed in chapter 3.8.1. Results are illustrated in Figure 8-7 and listed in Table 8-12 and Table 8-13. The results are divided within the table in structure- and construction-related footprints to simplify the significance discussion.

Overall bridge footprints affect 24 ha of benthic flora; 14 ha are affected by structure-related footprints and 10 ha by construction-related footprints. Nearly all of the lost area occurs in Danish waters (26 ha). In German waters 1 ha are lost: 1 ha in DE national and none in DE EEZ waters.

No very high severity of loss occurs due to footprints.

At 0.05 ha, the loss of benthic flora has a high severity. High severity of loss appears exclusively along the Lolland coastline, where dense stands of the *Furcellaria* community occur (> 50% cover). The loss occurs due to structure-related footprints.

At 8 ha, a medium severity of loss occurs due to footprints mostly by construction-related footprints (6 ha). 2 ha are affected by structure-related footprints. Medium severity of loss appears exclusively along the Lolland coastline, where the *Furcellaria* community occurs with coverage between 10 and 50%.

At 17 ha a minor severity of loss occurs due to footprints. 13 ha are covered by structure-related and 4 ha by construction-related footprints. Minor severity of loss appears along the Lolland coastline (16 ha) and only to a small extent along the Fehmarn coastline (1 ha). At the Fehmarn coastline the filamentous algae community and at the Lolland coastline the filamentous algae community as well as single vegetation stands (coverage 1–10%) are affected by a minor severity of loss.

Table 8-12 Severity of loss (area loss) caused by footprint for the bridge alternative divided into structure-related footprints (s) and construction-related footprints (c). As all footprints are located near zone, irrelevant zones are left out in the table.

	Footprint type	**Total**	**DK national + EEZ**	**DE national**	**DE EEZ**
Very high	s				
	c				
High	s	0.05	0.05		
	c				
Medium	s	2	2		
	c	6	6		
Minor	s	13	13		
	c	4	3	1	
Total	s	15	15		
	c	10	9	1	
		25	24	1	

Table 8-13 Severity of loss (area loss in ha) per sub-component (community) caused by footprints for the bridge alternative. Areas are divided into structure-related footprints (s) and construction-related footprints (c). As all footprints are located near zone, irrelevant zones are left out in the table.

	Footprint type	**Filamentous algae**				***Furcellaria***				**Vegetation stands (1–10 %)**			
		Total	DK	DE nat.	DE EEZ	Total	DK	DE nat.	DE EEZ	Total	DK	DE nat.	DE EEZ
Very high	s												
	c												
High	s					0,05	0,05						
	c												
Medium	s					2	2						
	c					6	6						
Minor	s	1	1							12	12		
	c	1		1						3	3		
Total	s	1	1			2	2			12	12		
	c	1		1		6	6			3	3		
		2	1	1		8	8			15	15		

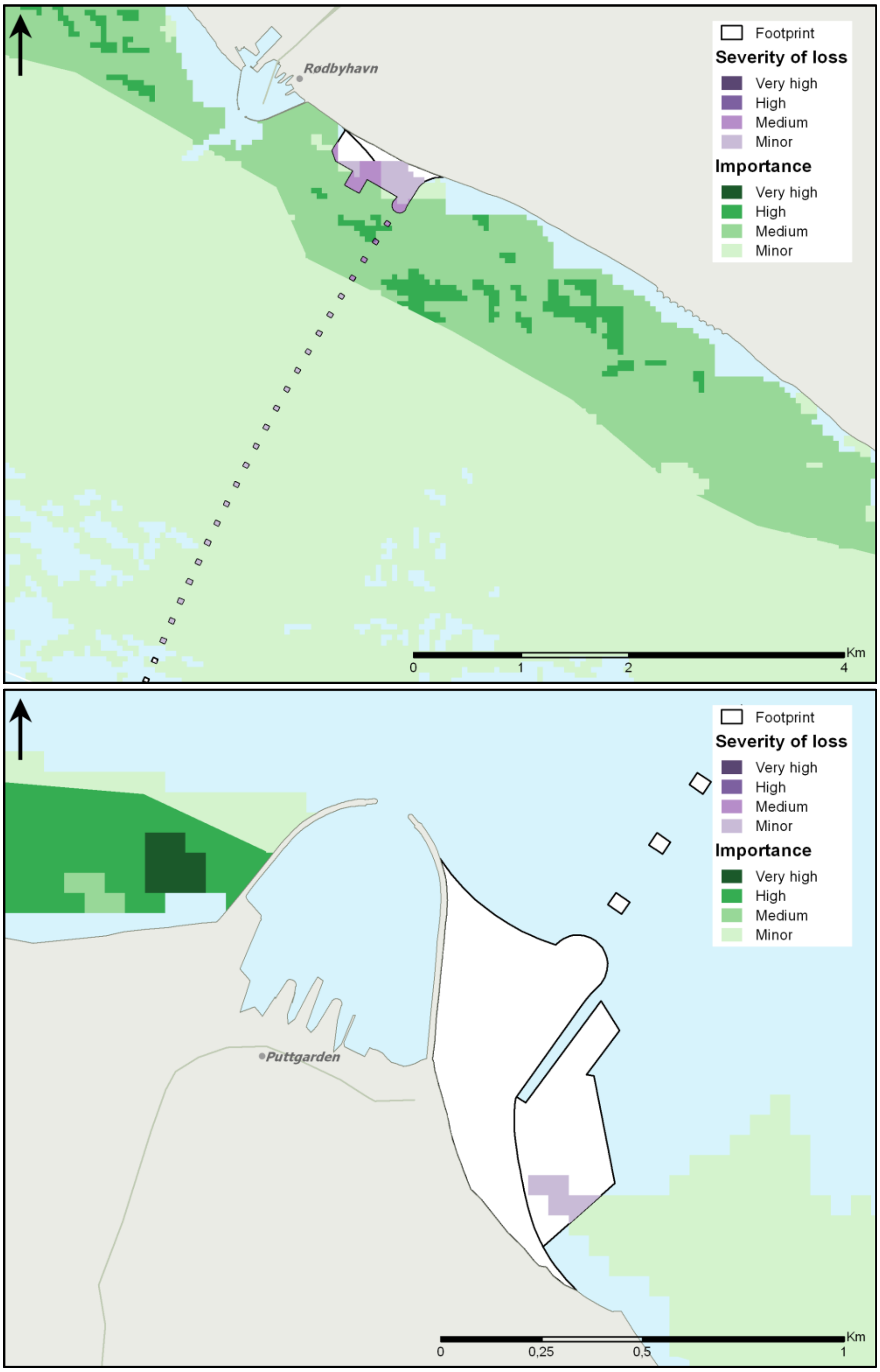


Figure 8-7 Severity of loss caused by footprint for the bridge alternative along the Lolland coastline (above) and along the Fehmarn coastline (below). Please note that only the near zone area differs between the alternatives. The severity is in this figure

overlaying the importance levels. In geographical zones outside of those detailed maps (e.g. deeper Fehmarnbelt) no severity of loss has been assessed as vegetation is missing.

8.3.3 *Significance*

Significance is determined by comparing the loss for specific vegetation communities (Table 8-13) with the inhabited area in the local zone (= Fehmarnbelt area) and the possibility and duration of the recovery from the impact. The results for the significance evaluation are listed in Table 8-14.

At 19 ha of the affected area, the filamentous algae community (2 ha) or single vegetation stands (1–10% coverage, 15 ha) occur. Both have a low ecological value (and therefore a minor importance). The impact is regarded as minor severity of loss. Both forms are not protected by any international or national guideline or legislation. 2 ha of filamentous algae correspond to 0.13 % of filamentous algae in Fehmarnbelt. 15 ha of single vegetation stands correspond to 0.17% of single stands in Fehmarnbelt.

The loss of filamentous algae and vegetation stands is partly caused by structure-related footprints (13 ha). The construction-related part is caused by the working harbour (4 ha). For the working harbour the re-establishment of the seabed was calculated to less than 5 years (FEHY 2013b). With a recovery time for filamentous algae of < 1 year, the duration for those impacts varies between 1 year as minimum and 6 years as maximum (Construction phase+). However, due to the small affected area duration is irrelevant.

The impact due to footprints is therefore insignificant for filamentous algae and single vegetation stands in terms of area loss on a local scale.

The *Furcellaria* community is impacted by loss in 8 ha. *Furcellaria* occurs in different coverage degrees (>50 % coverage, 10–50% coverage), which is reflected in the severity level: 0.05 ha with high severity of loss and 8 ha with medium severity of loss. The total, 8 ha, corresponds to 0.38% of *Furcellaria* in Fehmarnbelt.

The loss is to a small degree caused by structure-related irreversible footprints (2 ha). The construction-related part is caused by the working harbour (6 ha). The duration of the seabed establishment for the working harbours is calculated to less than 5 years (FEHY 2013b). The recovery time for *Furcellaria* is 5–10 years. The duration of the impact varies therefore between 5 years as minimum and 15 years as maximum (Construction phase+, Operation phase A). However, due to the small affected area duration is irrelevant. The impact on the *Furcellaria* community due to footprints is therefore insignificant in terms of area loss

Table 8-14 *Severity of loss (in % of area) per community caused by footprint for the tunnel alternative. Basis for the calculation is the total area of severity per community.*

	Filamentous algae		***Furcellaria***		**Vegetation stands (1–10 % cover)**	
	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area	Fehmarn-belt	Assessment area
Very high						
High			<0.01	<0.01		
Medium			0.34	0.20		
Minor	0.13	0.01			0.17	0.01
Total	0.13	0.01	0.34	0.20	0.17	0.01

8.4 *Solid substrate*

8.4.1 *Magnitude of pressure*

The bridge alternative comprises altogether 81 pylons and piers and two artificial peninsulas on both sides of the bridge. The surfaces of these structures that are situated in the photic zone is potential new substrate for macroalgae species requiring solid substrate for colonisation.

Area and depth distribution of new structures
The position of pylons and piers in different territorial zones are summarised in Table 8-15, and all pylons are listed, and in which area they are planned to be built.

Table 8-15 *Number and locations of bridge structures in Fehmarnbelt.*

	Total area	**Near zone**	**Denmark National +EEZ**	**Germany National**	**Germany EEZ**
Peninsula Fehmarn	1	1		1	
type IV F	7	7		7	
type III F	9	9		9	
type II F	12	12		12	5
center pylon	1	1			1
outer pylon	2	2			2
anchor pier	2	2			2
transition pier	2	2			2
type II L	18	18	16		4
type III L	11	11	11		
type IV L	17	17	17		
Peninsula Lolland	1	1	1		

8.4.2 *Severity of loss*

No areas are lost due to new solid substrate.

8.4.3 *Degree of impairment*

The areas of additional solid substrate are shown in Table 8-16. The additional hard substrates are separated for vertical structures (piers and pylons) and horizontal structures (scour protection), as well as for the different areas in Fehmarnbelt.

Table 8-16 Additional solid substrates (ha) at water depths less than 20m

	Total area	Near zone	Local zone	Denmark national	Germany national	Germany EEZ
Total area <20 m	25	25		11	7	7
Pylons and piers < 20 m	18	18		7	4	7
Scour protection < 20 m	7	7		4	3	0

Potential new communities

The new solid substrate will be colonised by species from nearby communities. Since the algae will experience the same conditions of light, nutrients and exposure at the coast, the new communities should eventually after some years of succession resemble the communities on hard substrate in the surroundings. This is likely for communities that establish on scour protection that are horizontal and consist of stones. The communities that establish on vertical structures such as piers and pylons may however differ since they experience other light conditions and exposure.

A comparable new marine structure in the vicinity of the planned fixed link is the Nysted wind farm a few kilometres east of the planned fixed link. The foundations in Nysted Offshore Wind Farm constructed from October 2002 to June 2003. Post-construction surveys of the fouling community on shafts and stones are carried out in 2003, 2004 and 2005. In the 2004-05 surveys communities on the stone reef Schönheiders Pulle were included to provide data on a natural hard bottom community close to the wind farm.

The three years of monitoring at the Nysted Offshore Wind Farm showed an almost complete disappearance of macroalgae on the shafts at the turbines. The biomass of macroalgae on stones was highest in the foundation chambers in 2003 and 2004 but has continued to increase on the scour protection stones.

The algal communities in 2003 and 2005 were dominated by red algae resembling the communities observed during the Fehmarnbelt fixed link baseline study (FEMA 2013a). The biomass was 1.5 to 5 times higher on horizontal structures (stones) than on vertical structures (shafts). Also the biomasses found at nearby stone reef Schönheiders Pulle was higher than found on stones or shafts, suggesting that vertical structures or the artificial substrate is not as optimal for growth of algae as natural stones.

Studies on pillars and pylons of the Øresund bridge and the Øland bridge supports the observations from Nysted wind farm (Qvarfordt & Kautsky 2006, Øresundsbroen 2005). Several years after construction of Øresund bridge and restoration of the Øland bridge, the epibenthic communities on piers and pylons were in both cases dominated by *Mytilus*. The algae assemble on the bridge piers primarily consisted of filamentous alga species and a low frequency of occurrence of perennial species. At boulders near the Øland bridge several perennial species were growing and algal biomass were higher than on bridge piers and pylons (Qvarfordt & Kautsky 2006).

Comparison between artificial reefs of different composition also showed that reefs built out of concrete inhabit fewer algae species and lower algae biomasses (Ambrose 1994).

Based on the calculated area of additional solid substrate and the relationship between biomass and depth obtained for baseline macroalgal data the additional algae biomass was estimated (Table 8-17). However, taking into consideration the observations described above for other bridges these biomasses are probably unrealistically high.

Table 8-17 Biomass of benthic flora (kg DW) on new solid substrate assuming similar distribution of biomass as under baseline conditions. Based on the function describing macroalgae biomass reduction as a function of depth for the Fehmarnbelt area (FEMA 2013a).

	Total area	**Near zone**	**Local zone**	**Denmark national**	**Germany national**	**Germany EEZ**
Pylons and piers < 20 m	30374	30374		10405	5401	14568
Scour protection < 20 m	13203	13203		6547	6659	0
Total area <20 m	43,580	43,580		16,952	12060	14568

8.4.4 *Significance of impairment*

If the new solid substrate is colonised by macroalgae with the same biomasses as found in the baseline study on natural rocks the new solid substrate contribute with 11% additional area and 16% more biomass in the near zone.

The German EEZ zone is in the deep part of Fehmarnbelt. The area and abundance of hard substrate are restricted and due to limited light availability, in deep water macroalgal biomasses are low. The additional new solid substrate in the photic zone is therefore potentially contributing with a high biomass compared to the existing.

As described above these estimates of biomass are overestimating the effect of increased biomass on pylons and piers.

On the larger scales (e.g. local) the potential new communities will not contribute significantly to the functioning of the ecosystem as they only make up 1% or less of the existing area and biomass. The additional new substrate is not considered to cause any significant changes to the function of the ecosystem in Fehmarnbelt.

Table 8-18 *Relative contribution of area of new macroalgal communities in relation to areas of existing macroalgal communities in the different zones.*

	Total area	**Near zone**	**Local zone**	**Denmark national**	**Germany national**	**Germany EEZ**
Pylons and piers < 20 m	0.1%	8.2%	0.3%	0.1%	0.04%	5.2%
Scour protection < 20 m	0.04%	3.2%	0.1%	0.05%	0.03%	0%
Total area <20 m	0.1%	11.4%	0.5%	0.1%	0.1%	5.2%

Table 8-19 *Relative contribution macroalgal biomass estimated at new solid structures in relation to biomasses of existing communities in the different zones.*

	Total area	**Near zone**	**Local zone**	**Denmark national**	**Germany national**	**Germany EEZ**
Pylons and piers < 20 m	0.2%	11%	0.4%	0.1%	0.1%	30%
Scour protection < 20 m	0.1%	5%	0.2%	0.1%	0.1%	0%
Total biomass <20 m	0.2%	16%	0.6%	0.2%	0.1%	30%

8.5 Seabed morphology

8.5.1 *Magnitude of pressure*

Several structures of the bridge alternative can have influence on the near bed current system or can cause a “barrier” effect on the sedimentation transport system. In section 4.6 effects on the coastal morphology have already been assessed as negligible, as no or only insignificant changes to the coastline are detectable (FEHY 2013d).

Seabed morphology

The barrier or blocking effect of the piers and pylons cause an increase of current speed between the structures and decrease leeward of the piers and pylons. Changes in the current speed of > 25% have been predicted within an area of four diameters around the piers and pylons and a total change of the seabed morphology was assessed for this area (FEHY 2013b). Overall 128 ha of seabed are affected by this change in seabed morphology but most of the area occurs in deep water and is therefore lacking vegetation communities.

Additionally to the direct vicinity of the structures, a change in near bottom currents on a larger scale is predicted. Impacts have been assessed to occur only on active bed forms but will not change the seabed morphology significantly outside of those active bed forms (FEHY 2013b). As no vegetation occurs in these areas with active bed forms, there will be no seabed-mediated impacts on benthic flora.

8.5.2 *Severity of loss*

Overall, only 3 ha of benthic flora will be lost, all in the vicinity of piers in the near zone and all in Danish waters (Figure 8-8). The loss affects only single vegetation stands and is therefore of minor severity.

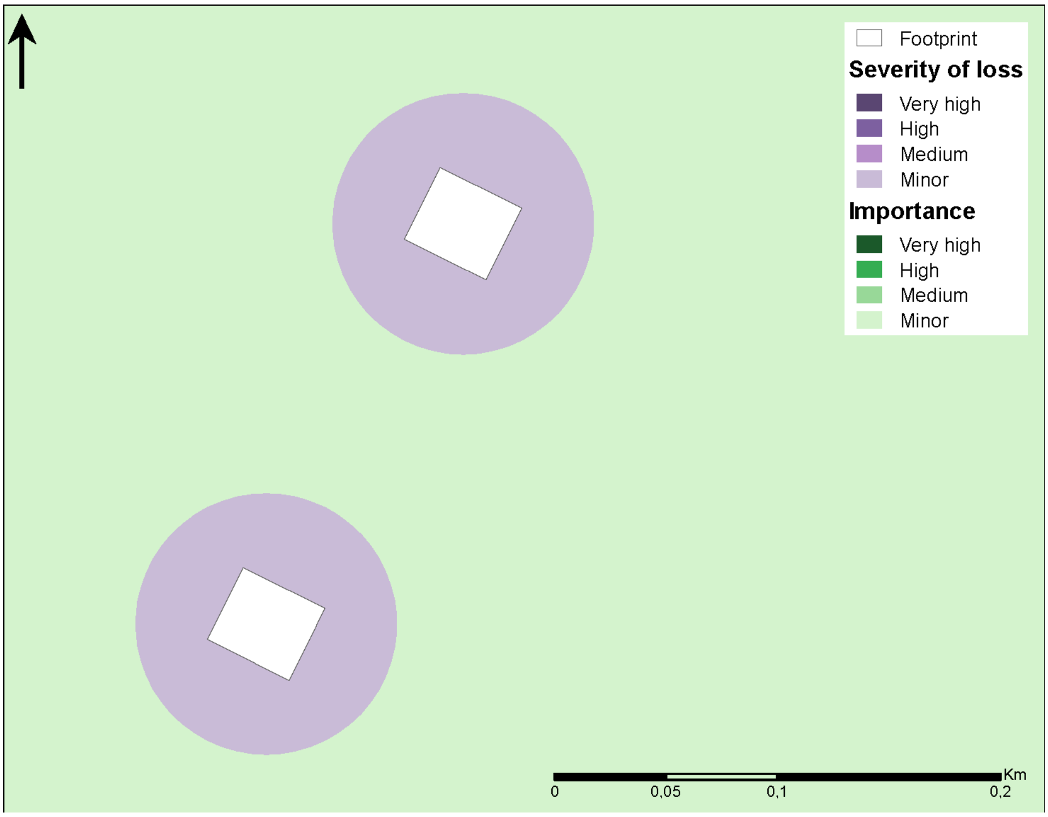


Figure 8-8 Severity of loss caused by changes in seabed morphology in the vicinity of piers on the Danish side.

8.5.3 *Significance*

The loss comprises less than 1% of the specific vegetation sub-components in the Fehmarnbelt and is therefore insignificant in Danish waters in terms of area and biomass loss.

8.6 *Aggregation of impacts*

The assessment results for the relevant pressures are compared and briefly discussed community by community. The overall severity area of loss/impairment, the different levels of severity and the significance are taken into account (Table 8-20).

Table 8-20 The lost/impaired areas (in ha) for the different pressures are listed community by community and divided into severity levels. Significant impacts are marked with (s). For suspended sediment the worst impact year is shown. Only communities with loss are shown.

	Suspended sediment	**Sedimentation**	**Footprint**	**Sea-bed/coastal morphology**
Eelgrass				
Very high				
High				
Medium				
Minor	32			
Total				
Filamentous algae				
Very high				
High				
Medium				
Minor			2	
Total			2	
Fucus				
Very high				
High				
Medium				
Minor		1		
Total		1		
Furcellaria				
Very high				
High			0.05	
Medium		12	8	
Minor		46		
Total		58	8	
Phycodrys/Delesseria				
Very high				
High				
Medium				
Minor		9		
Total		9		
Vegetation stands (1–10 % cover)				
Very high				
High				
Medium				
Minor			15	3
Total			15	3

The bridge alternative impacts only few vegetation communities and most of the impacts are assessed as being of minor severity. In addition, the impacted areas are small. The spatial range of the impacts only exceeds the local zone for the small impact of suspended sediment on eelgrass.

Only the *Furcellaria* community is impacted at higher severity, but all affected areas are small and none of the impacts is significant.

Assessed separately the pressures will not cause significant impacts, but the cumulative impact of more pressures could potentially cause a more severe impact. The impacts from the pressures cannot be added, as they are not directly comparable. For example, the impact from suspended sediment is related to a certain reduction in biomass for each year and for sedimentation the impact assessment is of more qualitative nature and described once for the whole construction period. However, the potential cumulative impact on the vegetation can be indicated by estimating the areas that are exposed to more than one pressure. For the bridge alternative, no areas of impacts from suspended sediment and sedimentation are overlapping. Loss of vegetation will not contribute to a cumulative effect as the vegetation cannot be any further impacted. Thus, cumulative effects are not expected for the bridge solution.

8.7 Cumulative impacts

There are no cumulative impacts for the benthic flora.

8.8 Transboundary impacts

No transboundary impacts on benthic flora are predicted for the bridge alternative.

8.9 Mitigation and compensation measures

This chapter of the report is prepared in co-operation with Femern A/S.

Mitigation can reduce the magnitude of pressure and subsequent loss and impairment of the environmental factors. Mitigation measures have to be pressure-specific and may differ between sub-components (communities). Only mitigation of significant impacts is included. There are no significant impacts from the bridge solution and thus no impact to mitigate.

Compensation is a legal requirement, if protected habitats/species are lost or impaired significantly. As none of the pressures will affect protected benthic vegetation by significant loss or impairment, compensation of benthic flora is not necessary for the bridge alternative.

8.10 Decommissioning

Decommissioning of the bridge alternative is foreseen to take place in 2140, when the Fixed Link has been in operation for the design lifetime of 120 years.

There is an overall plan for all main elements of the bridge. At sea all parts of the construction will be removed, leaving only the pile inclusions, which are located under the seabed. This section describes the decommissioning which is in relation to the marine area and hence the benthic flora.

Dismantling of the bridge superstructure will happen at sea and structures will then be transported to the shore.

All elements of pylons and piers will be cut in-situ into manageable sizes and then transported to shore.

The pylon caissons will be removed by in-situ demolition of the plinth, de-ballasting and de-floating of the caissons. Caissons are transported ashore. The pier caissons are removed by removal of internal ballast material, removal of scour protection and backfill material around the caissons and then transported to shore.

Ship collision structures are removed by a reversed construction.

During the decommissioning of the bridge, flora communities associated with the bridge structures will be lost. Macroalgae will probably colonise the hard substrate structures of the bridge, which function as an artificial reef. Based on observations from other bridges in the region it is expected that mussels (*Mytilus*) will dominate the vertical surfaces and macroalgal biomass should be low.

Reversed construction, in-situ demolition and cutting procedures can have a minor near zone effect on the benthic flora in the working areas. The impact is regarded as negligible.

9 COMPARISON OF BRIDGE AND TUNNEL MAIN ALTERNATIVES

The assessment results are compared and shortly discussed pressure by pressure. The overall severity area of loss/impairment, the different levels of severity and the significance are taken into account (Table 9-1).

The alternatives are classified pressure-specifically in terms of preferable alternative (Table 9-2). Three classes are used for the classification:

- ++: preferred alternative (the alternatives differ in terms of significance)
- +: slightly preferred alternative (the alternatives differ in terms of overall affected area and severity levels, respectively)
- 0: no difference between alternatives

Table 9-1 The lost/impaired areas for both alternative are listed pressure by pressure and divided into severity levels. Significant impacts are marked with (s). For suspended sediment, the worst impact year is shown.

		Tunnel	Bridge
Suspended sediment			
Severity of loss		No loss occurs	
Severity of impairments	Very high		
	High	115	
	Medium	2689	
	Minor	11751	32
	Total	14555	32
Sedimentation			
Severity of loss		No loss occurs	
Severity of impairments	Very high		
	High	1	
	Medium	262	12
	Minor	309	56
	Total	572	68
Footprint			
Severity of loss	Very high		
	High	18	1
	Medium	190 (s)	8
	Minor	90	19
	Total	298	28
Seabed and coastal morphology			
Severity of loss	Very high		
	High	0.15	
	Medium	6	
	Minor	2	3
	Total	8	3

Suspended sediment
No loss of benthic flora area is predictable; neither for the tunnel nor for the bridge alternative. The overall impaired area for the tunnel alternative is by a factor of 1000 larger. Only for the tunnel alternative high severity of impairment was assessed. The area affected by medium severity of impairment is relatively larger. All of the occurring communities of Fehmarnbelt are affected by suspended sediment from the tunnel alternative (eight communities) compared to the bridge alternative (two communities). The impairments for the bridge are mainly restricted to small area in Rødsand Lagoon. For the tunnel impairments in- and outside the local zone have been assessed. All of the impairments have been assessed as insignificant.

The bridge is the preferred alternative for suspended sediment, because the intensity and area impacted is much smaller than for the tunnel.

Sedimentation
No loss of area is predictable; neither for the tunnel nor for the bridge alternative. The overall impaired area for the tunnel alternative is by a factor of eight larger than for the bridge. Only for the tunnel alternative high severity of impairment was assessed, but in a small area. The area affected by medium severity of impairment is relatively larger. Six different communities are affected by sedimentation from the tunnel alternative compared to 3 communities from the bridge alternative. The impairments for the bridge are restricted to the near and local zone, whereas for the tunnel also impairments outside the local zone have been predicted. Only the tunnel alternative causes impairments in Rødsand Lagoon. All of the impairments have been assessed as insignificant.

Although the impairments for the tunnel have been assessed as insignificant, the bridge is the slightly preferred alternative for sedimentation, because of the much smaller impairment area and the subsequent reduced number of affected vegetation communities.

Footprint
The overall lost area for the tunnel alternative is a factor 10 larger compared to the bridge alternative. Especially the lost area with high severity is much larger for the tunnel. The *Furcellaria* community is affected to a significant degree in terms of area loss on local and regional scale. The duration of the impact is permanent.

The bridge is the preferred alternative for footprint, because of the much smaller lost area and the insignificant impacts.

Solid substrate
The area and biomasses of new benthic flora communities predicted for the tunnel and bridge solutions are not in any of the cases causing a significant contribution to the benthic flora of Fehmarnbelt.

There is no preferred alternative for new solid substrate.

Seabed and coastal morphology
The lost area for tunnel and bridge alternative for seabed and coastal morphology are similar and very low. No significant impact could be assessed for any of the alternatives.

There is no preferred alternative for seabed and coastal morphology.

Table 9-2 Results for the comparison between alternatives (++ preferred, + slightly preferred, 0 no difference).

	Tunnel	**Bridge**
Suspended sediments		+
Sedimentation		+
Footprint		++
Solid substrate	0	0
Seabed and coastal morphology	0	0
Total		++

For benthic flora the bridge alternative is the preferred alternative.

10 CLIMATE CHANGE

Several climate change scenarios up to the years 2080–2100 have been evaluated for the Fehmarnbelt area (FEHY 2009). Climate change will influence different abiotic parameters, but not all of them have influence on benthic flora.

Air temperature, sea ice and annual precipitation
Climate change scenarios predict an increase in air temperature of 1–4° C. Summers will become drier in all of the evaluated scenarios and longer summers are also indicate. The trend towards warmer and wetter winters reduces the number of days with air temperatures below 0 °C. Therefore, the probability for sea ice in the Western Baltic, the overall ice-covered area and the number of days with sea ice are expected to decrease in Fehmarnbelt.

Global warming will also increase the annual precipitation with a clear higher signal during winter and a less obvious signal during summer. Although the annual precipitation will increase, this will not result in an increase the frequency of precipitation events but the single precipitation events will be heavier.

Wind intensity and direction
The extreme wind speed will increase by 3 m s^{-1} or 10% and a slight increase of intense wind events could be demonstrated. Additionally, an increase of westerly winds is expected within the investigation area.

Sea level rise
A rise in the sea level of 10–15 cm/century is predicted in the region, however an increase in wind intensity may further intensify the sea level rise to 30 cm/century. Taken the unpredictability of the development of the Greenland and Arctic ice shelf into account a sea level rise up to 1 m within the investigation area is plausible.

Climate changes and benthic flora
The climate changes described above may have a direct influence on the benthic flora communities. Warmer winter temperatures, absent or rare ice cover as well as prolonged summer periods in general favour growth of algae, also opportunistic macroalgae. The algae can start their growing earlier in the year and built up higher biomasses with higher mean temperatures. If the seasonal growth period is prolonged they can build up more generations per year. If nutrients are available in sufficient amount this may especially favour opportunistic annual species. The perennial vegetation loses the advantage of withstanding unsuitable seasonal periods (winter phases) by building up resources. The shift to opportunistic life cycles, already favoured by eutrophication, could be intensified.

Higher temperatures may favour the spreading and establishment of species from neighbouring, warmer marine areas like the Mediterranean and disadvantage native species from the boreal-temperate climatic range. However, this effect is currently concentrated more to the North Sea as the brackish environment hinders most of the vegetation species to migrate to the Baltic Sea. Similar is valid for the spreading of freshwater species, which can seldom survive in brackish waters with salinities higher than 3 psu.

Increased wind intensity and a shift to more westerly winds increase the coastal erosion and sediment transportation processes. The area with sediment instability may increase. Opportunistic filamentous macroalgae may replace perennial macroalgae communities typical for the upper littoral zone (e. g. *Fucus*), which are sensitive to sediment instability and the upper distribution depth of soft bottom communities like eelgrass may be shifted to deeper waters with more sediment stability. The growth area, suitable for perennial communities, can thus be reduced.

A rise in seawater level can generally enlarge the area suitable for vegetation growth. Although the "new marine" settling ground will be exposed to very instable abiotic factors favouring the settlement and growth of opportunistic algae.

Indirectly, benthic vegetation may be influenced by climate changes through changes in the hydrographical regime, as an enhanced mixing between in- and outflowing water masses of the Baltic was suggested. This would result in an effect on small and medium inflow events by lowering the salinity of the inflowing water (FEHY 2013a).

The impacts of the tunnel alternative and the bridge alternative on changes in hydrographical regime, seabed morphology and coastal morphology have been evaluated to be within the frame of the proposed climate changes for the Fehmarnbelt area (FEHY 2013a, b, d). The impacts of the fixed link will not intensify the effects of climate changes (FEHY 2013a, b, d). Therefore, the consequences for the benthic flora are negligible.

11 PROTECTED SPECIES

The legal framework encompassing the protection of habitats and species is set by different national and international legislations:

- Natura 2000 with legal basis in the Wild Birds Directive 79/409/EC and the Habitats Directive 92/43/EEC (last amended by 06/105/ EC): Any significant disturbance of protected species and habitat in a Natura 2000 area must prior to the project adoption be identified. Project related impacts to Natura 2000 areas are assessed within are separate report (cross reference) and therefore not evaluated here.
- Annex IV species: According to the Habitats Directive Art. 12 plans or projects cannot be approved, if the plan or project will disturb breeding and resting places for species listed in Annex IV of the directive. No marine macrophyte species are listed in Annex IV; therefore this legislation is not relevant for the marine benthic flora.
- Danish Nature conservation act (Naturbeskyttelsesloven): § 3 protects fresh meadow, common (in Danish: "overdrev"), salt marsh and shore swamp, moors, lakes and ponds, watercourses, marshlands, and fens etc.; it is only protecting biotopes on land and is therefore not relevant for the marine benthic flora.
- German Nature conservation act (Bundesnaturschutzgesetz, *BNatSchG*): § 15, section 1 requires the project proponent to omit avoidable adverse effects of intervention in nature and landscape. The term "nature and landscape" covers "all nature" and includes also the marine environment.

Therefore only the German Nature conservation act (Bundesnaturschutzgesetz, *BNatSchG*) is relevant for marine benthic flora in terms of protected habitats and species. In §30 the following marine macrophyte biotopes are listed: seagrass beds and other macrophytes stocks. No exact definition for "other macrophytes stocks" is given, but normally this refers to important perennial and dense macrophyte stocks and not to opportunistic annual macroalgae stands.

For both alternatives, no significant loss or impairments of seagrass beds or perennial macrophyte stocks within German waters have been assessed.

12 CONSEQUENCES IN TERMS OF WFD AND MSFD

The European Water Framework Directive (WFD) aims at establishing a good ecological status for European surface waters. For all water bodies, which are not reaching the good ecological status until 2015, member states have to take measures within their water action plans to achieve the good ecological status. Generally, a degradation of the ecological status of all surface waters has to be avoided.

Several WFD water bodies are located within the assessment area and the assessments have demonstrated impacts for some of them.

Table 12-1 Project-related impacts on WFD water bodies and indicators.

Alternative	Pressure		Water body	Impacts
Tunnel	Footprint	DK	Femerbælt, Aabne del (open part of) Femerbælt OW3a	Loss of *Furcellaria*, filamentous algae and single vegetation stands – no impact on WFD indicator
		DE	Fehmarnbelt	Loss of filamentous algae – no impact on WFD indicators
	Sedimentation	DK	Femerbælt, Aabne del Femerbælt OW3a, Rødsand, M2 Femerbælt 12sm	Impairment of eelgrass and *Furcellaria* – no impact on the WFD indicator depth limit of eelgrass
		DE	Fehmarnbelt	Impairment of eelgrass/algae, *Fucus*, *Furcellaria, Phycodrys/Delesseria* and *Saccharina* – impact on at least four WFD indicators
	Suspended sediment	DK	Femerbælt, Aabne del Femerbælt OW3a, Rødsand, M2 Femerbælt 12sm, Aabne STB Syd	Impairment of eelgrass, *Furcellaria* and *Phycodrys/Delesseria* – – no impact on WFD indicator
		DE	Fehmarnbelt, Fehmarnsund, Orther Bucht	Impairment of eelgrass, eelgrass/algae, *Furcellaria* and *Phycodrys/Delesseria* – impact on at least four WFD indicators
Bridge	Footprint	DK	Femernbælt, Aabne del Femerbælt OW3a	Loss of *Furcellaria*, filamentous algae and single vegetation stands – no impact on WFD indicator
		DE	Fehmarnbelt	Loss of filamentous algae – no impact on WFD indicators
	Sedimentation	DK	Femernbælt, Aabne del Femerbælt OW3a	Impairment of *Furcellaria* – no impact on WFD indicator
		DE	Fehmarnbelt	Impairment of *Fucus*, *Furcellaria* and *Phycodrys/Delesseria* – impact on at least three WFD indicators
	Suspended sediments	DK	Rødsand, M2	Impairment of eelgrass – no impact on WFD indicator
		DE	-	No impacts

Along the Danish coast, impacts are predicted in five different water bodies for the tunnel and in three different water bodies for the bridge. However, none of the areas is currently classified. Basis for the WFD classification in Denmark is solely the eelgrass depth limit. As none of the project related pressures for tunnel or bridge show permanent impacts on the light conditions and thus the eelgrass depth limit (maximum depth limit as well as depth limit of main abundance) in Rødsand Lagoon, no impacts on the basis for assessing the WFD ecological status are expected.

Along the German coast, impacts are predicted in three different water bodies for the tunnel and in two different water bodies for the bridge. Mainly the water body Fehmarnbelt is opposed to several pressures, whereas the water bodies Fehmarnsund and Orth Bight are impacted only by suspended sediment and to a minor degree. According to the national WFD monitoring of Germany, the ecological status of Fehmarnbelt is good (0.6) at the good-moderate boundary (Fürhaupter et al. 2008).

In Germany seven indicators are used to assess the ecological status:

1. depth limit eelgrass
2. percentage opportunist in eelgrass
3. depth limit *Fucus* spp., dominance of *Fucus*
4. percentage of opportunist in red algae
5. species reduction in red algae, *Furcellaria* biomass.

The pressure footprint has no impact on those seven indicators.

Due to sedimentation the eelgrass/algae, *Fucus*, *Furcellaria* and *Phycodrys/Delesseria, Saccharina* community (tunnel alternative) and the *Furcellaria* and *Phycodrys/Delesseria* community (bridge alternative) of Fehmarnbelt show minor impairments. Minor impairments can be slight growth/biomass reductions and/or reduction in recruitment. Dominant and/or biomass of the key-species in the communities are included in the German WFD indicators (bullet point 3 to 5 in the above list). Therefore, the predicted minor impairments may result in a minor reduced ecological value of the Fehmarnbelt water body. The water body ranges are at the boundary between good and moderate ecological status. Therefore, minor impairments can result in a downgrade of the water body to a moderate ecological status.

Due to suspended sediment the eelgrass, eelgrass/algae, *Furcellaria* and *Phycodrys/Delesseria* community (tunnel alternative) show minor impairments. For the bridge alternative no impacts have been predicted. Minor impairments are slight biomass reductions. Biomass of the key-species in the communities are included in the German WFD indicators (bullet points 1., 2., 4. and 5. in the above list). Therefore, the predicted minor impairments may result in a minor reduced ecological value of the Fehmarnbelt water body. The water body ranges are at the boundary between good and moderate ecological status. Therefore, minor impairments can result in a downgrade of the water body to a moderate ecological status.

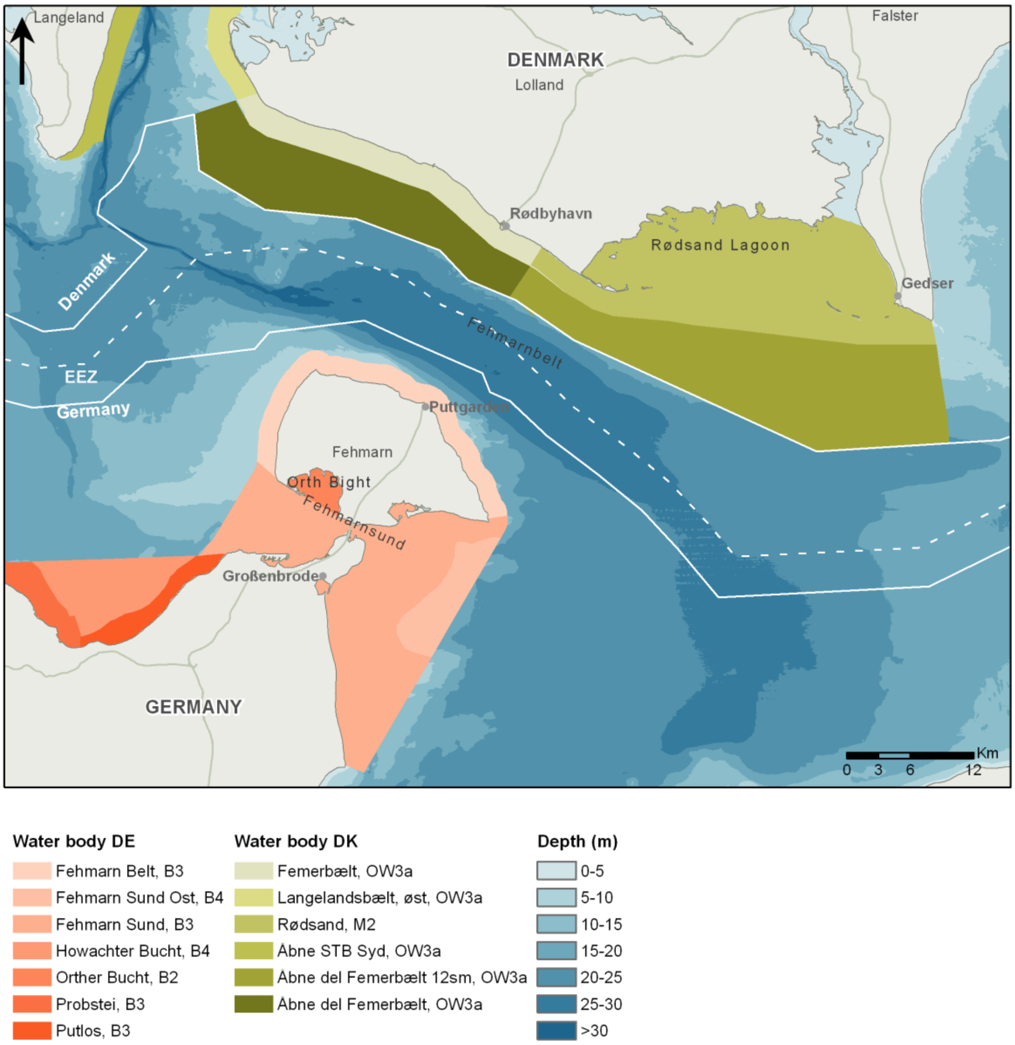


Figure 12-1 WFD water bodies located within the investigation area.

The Marine Strategy Framework Directive (MSFD) is based on the WFD and aims in extending its objectives into the offshore waters including the EEZ. It uses an ecosystem approach with an integrative approach and focuses therefore mainly on the environmental status of habitats instead of single quality components like the WFD. Several descriptors with specific indicators are used to assess the environmental status. As assessment systems are still under development, the impact of the fixed link in relation to the MSFD is currently not assessable.

13 KNOWLEDGE GAPS

The baseline investigations for benthic flora conducted in 2009–2010 provided the basis for the environmental impact assessment. They delivered a comprehensive documentation of the distribution, composition and abundance (coverage) of benthic flora and communities of the Fehmarnbelt. No gaps in terms of occurrence and status of vegetation could be identified for the assessment area.

Starting from those input data the effects of the different pressures on benthic flora and their sub-components are predicted. The knowledge and data basis of the effects varied between pressures and/or flora communities and is therefore described pressure-specific in the following sections.

13.1 Suspended sediments

The modelling of reduced biomass due to suspended sediment rely primarily on the modelled sediment spill, knowledge about the specific light attenuation of sediment with different particle sizes and knowledge about the sensitivity of species or communities to reduced light availability. In general knowledge based on literature supplemented with laboratory experiments have provided comprehensive knowledge about all three aspects.

13.2 Sedimentation

There exist many literature references, which deal with impacts of sedimentation on vegetation. However, after thoroughly consideration they could seldom be used for this impact assessment due to a variety of reasons:

- Quantitative relationships between sedimentation and effects on vegetation are scarce. Only one reference documents quantitative data for increased mortality of eelgrass due to sedimentation.

- Described effects are often documented in general (e.g. "species composition is changing") but not on a community-specific or species-specific level.

- The Baltic Sea forms a special environment. Due to the reduced salinity some species are already at the edge of their distribution area. Each additional stressor has more severe effects, making it difficult or even impossible to adopt references from other marine areas.

- Simple ecological basic data like growth season, reproductive season or average plant height and biomass are missing even for frequent species.

- The influences of natural sedimentation and resuspension processes on vegetation are lacking and make it difficult to define thresholds for the magnitude of pressure.

13.3 *Construction vessels/imported material and solid substrate*

Both pressures increase the risk for the introduction of non-indigenous species. Effects on the benthic flora can be expected, if those newly introduced species have an invasive potential. Invasive potential means that the occurrence and species composition of the native vegetation are altered by the newly introduced species.

Although several vegetation species have been introduced to the Baltic and the assessment area during the last decades (e.g. *Dasya baillouviana, Gracilaria vermiculophylla*), none of them have shown an invasive potential until today.

It is nearly impossible to foresee, which species could be introduced and if they will have an invasive potential. There exists only scarce information, which specific features of the life and growth cycles of the introduced species and which ecosystem functions of the newly inhabited area, enables an "invasion".

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FEMA benthic flora model

Model description and calibration

Benthic vegetation sub-model

The ecological model consists of an advanced description of the benthic vegetation community, the benthic vegetation sub-model (FEMA1). This includes detailed descriptions of their growth and death processes, as well as modelling of dependencies for nutrients, temperature and light for three distinct groups of macroalgae and one representative for rooted vegetation (eelgrass), representing the dominating benthic vegetation communities in the Fehmarnbelt area. As some benthic communities, identified during the baseline survey, are limited to very few and small locations, they are not represented by independent model organisms

The four distinct groups of the benthic vegetation sub-model are:

- Filamentous macroalgae: Represented by *Ceramium sp*., organism modelled to represent the filamentous algae community

- Corticate foliose macroalgae: Represented by *Delesseria* sp., organism modelled to represent the *Phycodrys/Delesseria* and *Saccharina* community

- Corticate macroalgae: Represented by *Furcellaria* sp., organism modelled to represent the *Furcellaria*

- Eelgrass: Represented by *Zostera sp*., organism modelled to represent the eelgrass, eelgrass/algae and tasselweed/dwarf eelgrass community

The model is based on an existing well-proved ecological model. In this study, the functionality of the modelled benthic vegetation were modified to account for different controlling factors for their growth (light and nutrient availability) and death processes. It is noted that the interaction with the other components in the ecological model is an integral description of the model.

Model description

Benthic macrophytes (macroalgae and rooted vegetation) are associated with the bottom substrate. In their life stage macrophytes are not subject to hydrodynamic transport but they remain fixed at bottom in model grid cells. Loss of macrophyte occurs by sloughing of aged leaves (e.g. in *Zostera*) and by respiration (C and nutrients returned to inorganic pools).

The growth of the various benthic vegetation types in the model is dependent on light availability, temperature and nutrient availability. While macroalgae only take up nutrients from the water compartment, rooted macrophytes (e.g. *Zostera*) also take up nutrients from the upper sediment layer.

In addition, the growth of macroalgae and rooted vegetation are also affected negatively by low concentrations of dissolved oxygen. Furthermore, the growth of rooted macrophytes becomes reduced if oxygenated zone (i.e. the sulphide front) approaches the sediment-water interface. In specific, growth is reduced if the depth where nitrate is present in the sediment is less than 1 cm.

Sub-optimal conditions in any of these factors will result in growth rates below the maximum. The joint dependence of nutrients, temperature and light is defined by separate growth limiting factors, that range from 0 to 1, where a value of 1 means the factor does not limit growth (i.e. light is at optimum intensity, nutrients are available in excess, etc.). The limiting factors are then combined with a maximum growth rate at a reference temperature.

In contrast to phytoplankton and macroalgae description, nutrient composition of the rooted macrophytes and the microbenthic algae remains constant (fixed stoichiometric ratios) and growth and nutrient uptake rates are linearly dependent[1].

Effect of light on growth rate is described by saturation functions where light requirements differ between the four defined groups. Besides light, nutrient requirements, source of nutrients (water, sediment and water) and substrate are the main factors that differentiate the groups in the model. In Table App A1 the main characteristics of the four groups are listed.

Table.App A1 Overview of growth characteristics that define the functional benthic vegetation groups in the model. Half-saturation constants for uptake of nitrogen (Kn) and phosphorus (Kp) differs between sediment and water in rooted vegetation. I_k: Irradiance at light saturation.

Functional group	**Represented by**	**Max growth rate (d^{-1})**	**I_k (µmol photons m^{-2} s^{-1})**	**Kn / Kp g/m3**
Filamentous algal species	*Ceramium*	0.255	107	not relevant (growth relies on internal concentration)
Corticated, sheet formed algae	Delesseria	0.1516	93	not relevant (growth relies on internal concentration)
Corticated algae	*Furcellaria*	0.0694	116	not relevant (growth relies on internal concentration)
Flowering plants	*Zostera*	0.09	150	Sed: 0.05/0.01 Wat: 0.05/0.005

The fate of macrophyte production differs between groups. Overall, macrophytes can be grazed e.g. by swans, leaves can be shed as part of aging process and later decayed, such as in *Zostera*, and macroalgae tissue can die because of nutrient or light limitation. The dead plant material enters the detritus pool exposed for decomposition, sedimentation and advective transportation. The death rate of rooted vegetation is described as a function of water depth, bottom water oxygen saturation and the sulphide front in the

[1] ECO Lab macrophyte templates with partial uncoupling of nutrient uptake and growth are available but as this approach will add an additional 6 state variables to the model template with implications for simulation speed it was not applied.

sediment. The water depth is in this respect included to describe the physical stress on leaves due to waves.

A large number of dynamic models for rooted macrophytes, especially *Zostera* has been published in the literature, e.g. (Verhagen and Niehnuis 1983, Zimmerman et al. 1978, Bocci et al. 1997, Plus et al. 2003). DHI developed a dynamic eelgrass model in the early 1990's (Bach H.K. 1993) and based on advances published in the literature and numerous modelling studies of estuaries and coastal lagoons, the "eelgrass" model has been updated continuously. Besides information on max growth rate, light- and nutrient dependence, important characteristics of the rooted macrophyte model include:

- Only above-ground tissue (leaves) are modelled explicitly but rhizomes and roots are included functionally to mediate nutrient uptake from pore water in the upper sediment layer

- Uptake of nutrients take place from the sediment pore water through roots and from the water through leaves

- Accumulated nutrients are retained in the macrophyte patches by returning 90% of the old leaves (detritus) to the sediment locally for mineralization

In the FEMA1 sub-model, the growth of rooted macrophytes are restricted by requirements to light, sediment quality etc. Therefore, though macrophyte growth was initially allowed everywhere after a model warm-up period they could only sustain where sediment conditions (low H_2S in sediments, adequate nutrient conc. in pore water) and light conditions were appropriate. Still, in the model rooted macrophytes did growth outside the areas where they were found during the baseline mapping. For the impact assessment of sediment spill these areas were mapped out in the model output prior to estimate the impacts on area distribution of biomass.

Performance criteria for model calibration

The calibration and validation of the model followed international best practice using a number of system performance criteria. The main purpose was to ensure that controlling factors and processes for the model simulations are satisfactorily represented by the model.

The system performance criteria comprise:

1. Checking the calibrated model's ability to represent the general and observed horizontal biomass distribution patterns – by comparison of simulated and measured snapshots of the benthic vegetation biomass

2. Checking the calibrated model's ability to represent the general and observed vertical biomass distribution patterns – by comparison of simulated and measured transects of the benthic vegetation biomass

3. Checking the calibrated model's ability to represent the general and observed seasonal biomass distribution patterns – by comparison of simulated and measured time series of the benthic vegetation biomass

However, as a supporting instrument, also quantitative performance criteria are used. It should be noted, that, in the experience of the involved modellers, no internationally recognised standard exists for the performance of advance ecological modelling, and, as such, the model performance criteria should be viewed only as an indication of the performance. The performance of the benthic vegetation sub-model was evaluated using three different indices to quantify agreement between actual observations and model predictions of individual biomass:

(1) The regression coefficient R^2 expresses to what extent the model can explain variation in observations. In Table App A2, the target for the calibration of the benthic vegetation sub-model, based on a comparison of all pairs of measured and simulated biomasses using a regression analysis, is presented. Performance of pelagic biogeochemical models (addressing parameters in the water phase such as dissolved oxygen, nutrients and phytoplankton) are typically calibrated to median r^2 values ranging from 0.40 to 0.60. More complex models, in which also bacteria and zooplankton dynamics are included, are calibrated to lower performance for the higher trophic levels, with median r^2 values ranging from 0.06 to 0.24 (Arhonditsis and Brett 2004).

Table App A2 Quantitative performance criteria for model calibration

Parameter	**Coefficient of determination (r^2)**	**Reference**
Benthic vegetation biomass	0.25	Performance expected to comply with the upper bound of model performance for zooplankton dynamics (Arhonditsis and Brett 2004).

(2) The Nash Sutcliffe Model Efficiency (*ME*; Nash and Sutcliffe 1970) is a measure for the ratio of the model error to the variability of the data:

$$ME = 1 - \frac{\sum_1^N (O_i - P_i)^2}{\sum_1^N (O_i - \bar{O})^2}$$

where O_i is the observations, P_i the corresponding model estimate and $\bar{O}$ indicates the average of all observations, N is the total number of model data matches and i is the I^{th} comparison. Following Allen (2009) performance levels are categorised as levels > 0.65 are excellent, 0.65–0.5 is very good, 0.5–0.2 is good, and values < 0.2 are poor performance.

(3) The *Percentage Model Bias* (the sum of the model error normalized by the data) is given by:

$$P_{bias} = \frac{\sum_1^N (O_i - P_i)}{\sum_1^N O^i} * 100$$

and provides a measure of whether the model is systematically underestimating or overestimating the observations (symbols mean the same as in the previous formula). The closer the value is to zero the better the model.

Performance levels are categorised as follows $|P_{bias}|$ < 10 is excellent, 10–20 is very good, 20–40 is good and values > 40 are poor performance (Allen 2009).

Calibration results

The benthic vegetation sub-model has been subject to a comprehensive calibration exercise, during which model coefficients have been adjusted to obtain good accordance between simulated and measured biomasses.

Data collected for the baseline conditions (FEMA 2013a) constitute the basis for the calibration, including more than 200 observations in the 2009 summer period for

- biomass and spatial distribution of key macroalgal communities and/or species
- biomass and spatial distribution of flowering plants (angiosperms).

It should be noted that due to the chosen model resolution of the ecological model, constructed for simulation of 6 years of ecology including hydrodynamics in a multi-layer system, a grid spacing of approx. 500 – 2000m was applied in part of the habitat areas. Each model grid represents the average conditions within the actual grid area. This means that field observations for areas with detailed data coverage (up to 25m in some areas) must be averaged into a single value for comparison with the model output. Details on the field observations from summer 2009 for model comparison are shown in Table App A3.

Table App A3 Overview of data basis for model calibration, spatial distribution

Summer 2009	**Total number of observations**	**Total number of observations for model comparison after averaging of field data**
Fehmarn Belt	8	5
Staberhuk	82	18
Langeland	33	11
Lolland east	44	35
Rødsand Lagoon	41	17
Orth Bight	19	7
Total	*227*	*93*

The following sub-sections present the results of the calibration via comparisons of measured and modelled biomass distributions, horizontally in the study area for the geographical distribution, as well as vertically for the depth-related distribution, and seasonally for the temporal variability reproduced by the model. Also the overall performance by comparing all modelled and measured data statistically is presented. Finally, the degree of agreement with observations and the interpretation of the model results are discussed.

Biomass distribution (horizontal profiles)

Based on the horizontal biomass distribution measured in connection with the baseline investigations, averages of summer biomasses (2009 data) have been estimated and compared with simulated biomasses, with detailed comparisons of the macroalgal communities in the four sub-areas outlined in Figure App A1.

Both total biomass of all three modelled macroalgal groups and individual groups (representing the dominant vegetation communities), as determined by the baseline data, are presented in the following.

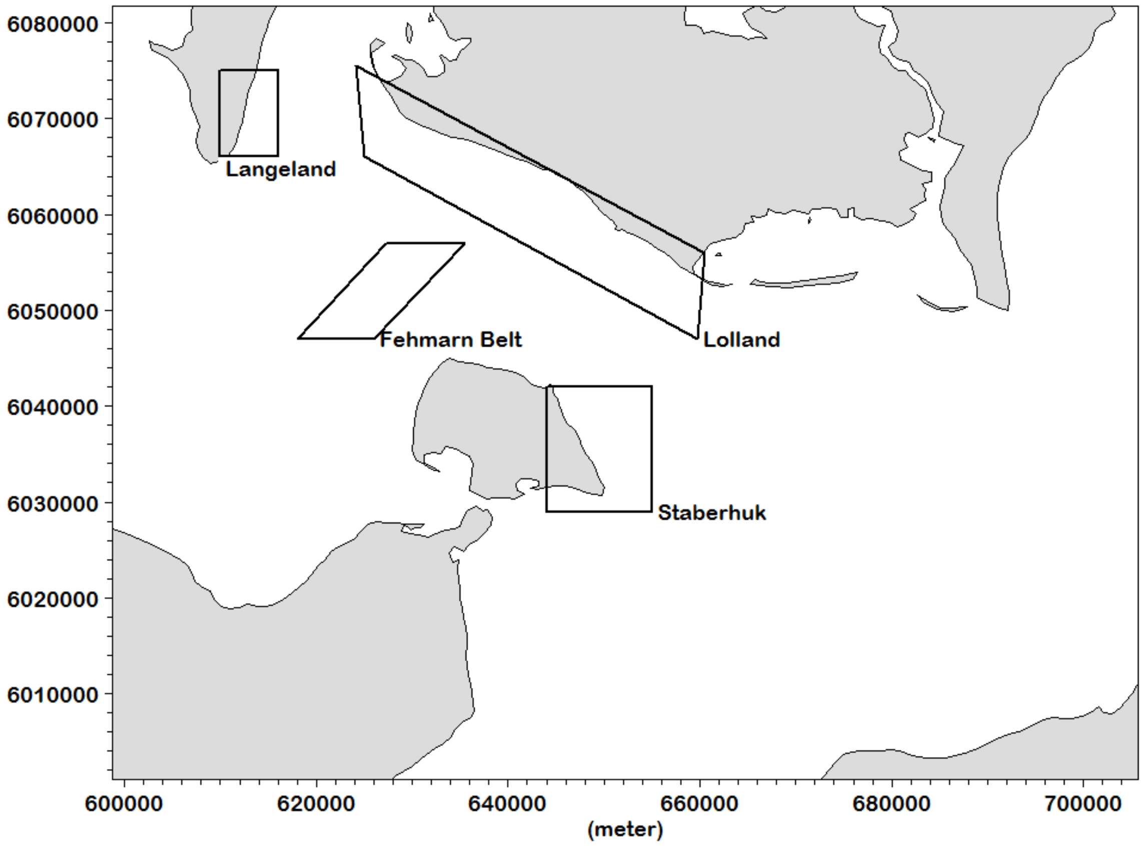


Figure App A1 Areas for comparison of modelled and measured data

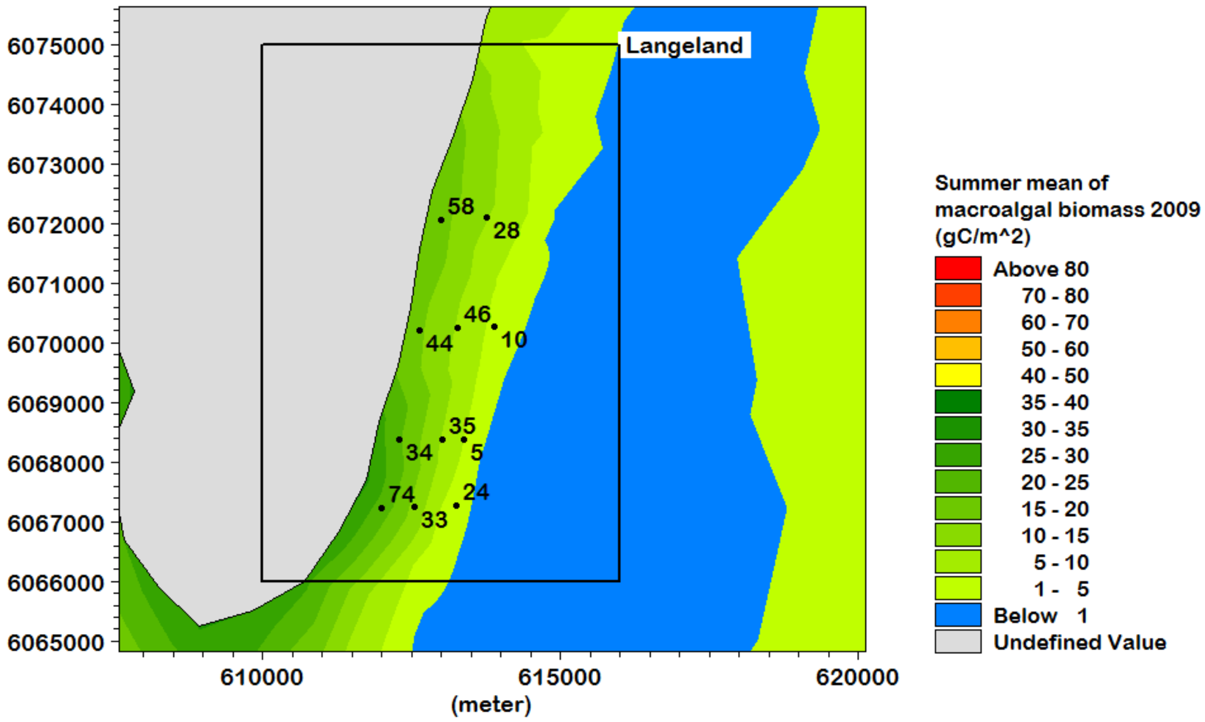


Figure App A2 Comparison of simulated and measured total macroalgal biomass, Langeland. The coloured zones present the modelling results according to the legend to the right. The figures are the estimated averages for the baseline stations located within the same areas.

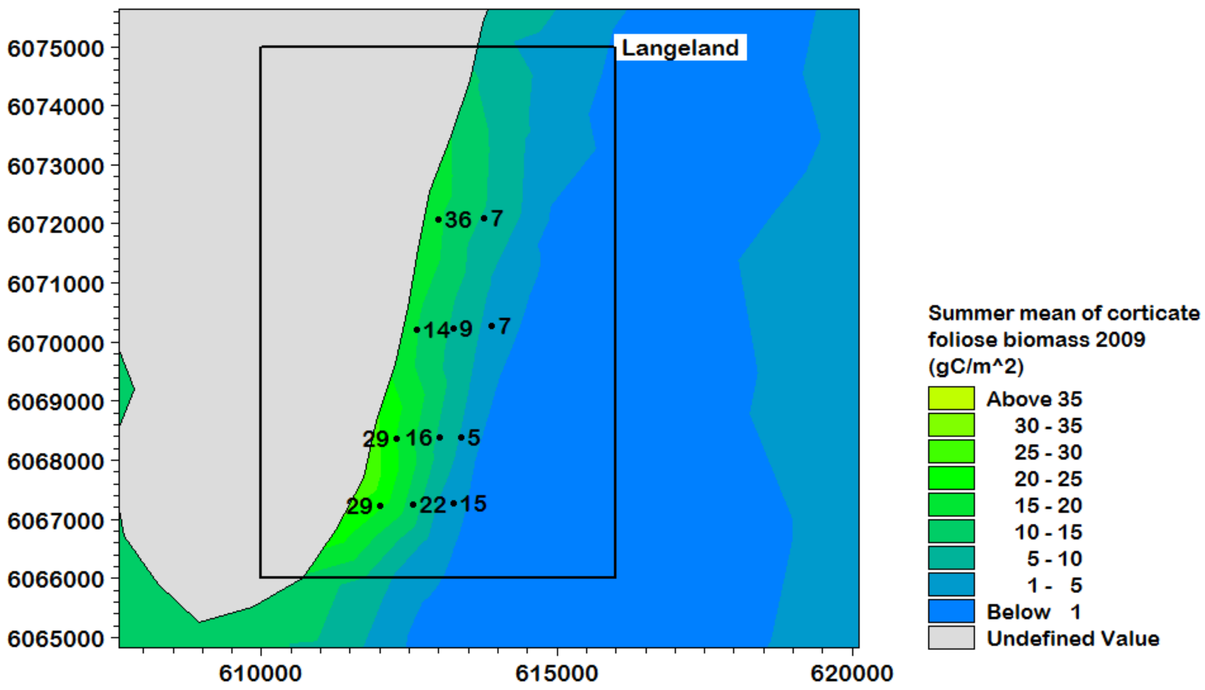


Figure App A3 Comparison of simulated and measured dominant macroalgal community, Langeland

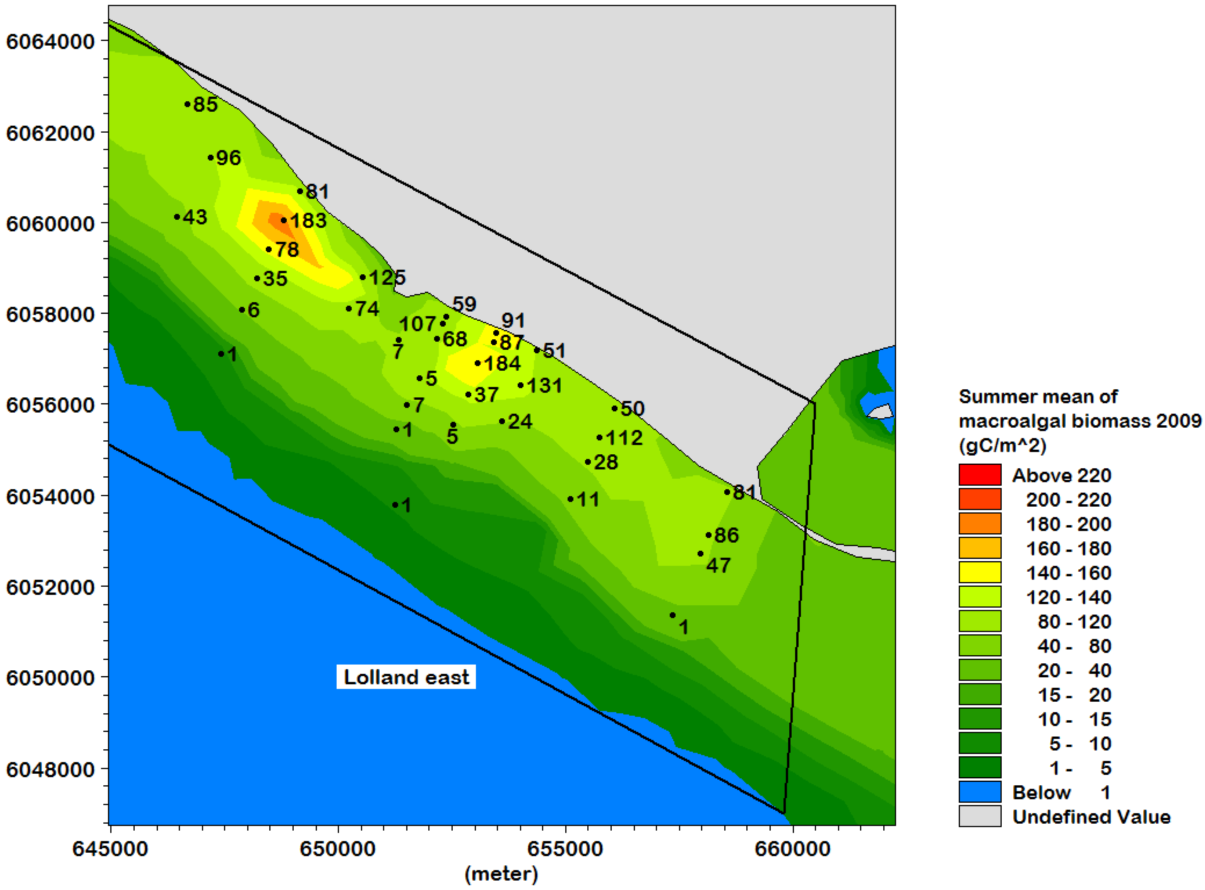


Figure App A4 Comparison of simulated and measured total macroalgal biomass, Lolland

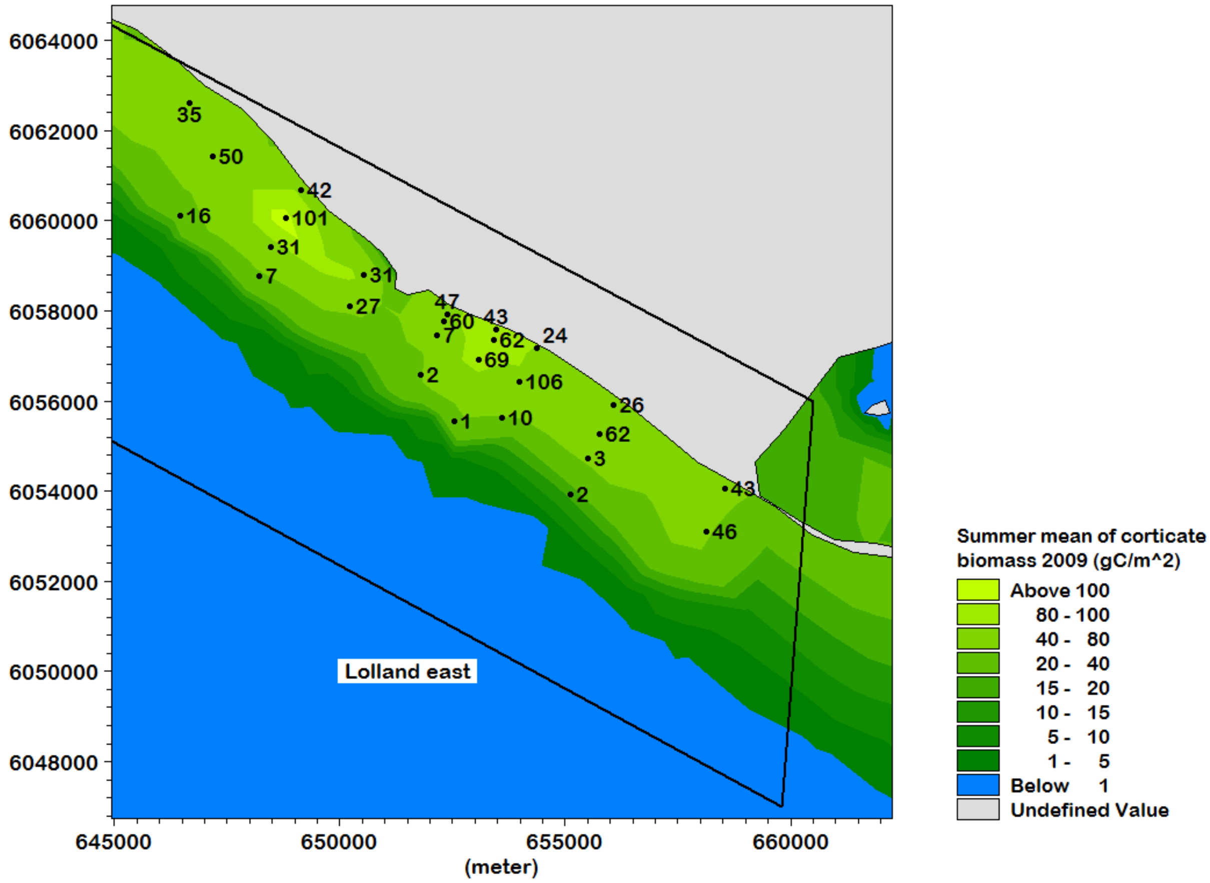


Figure App A5 Comparison of simulated and measured dominant macroalgal community, Lolland

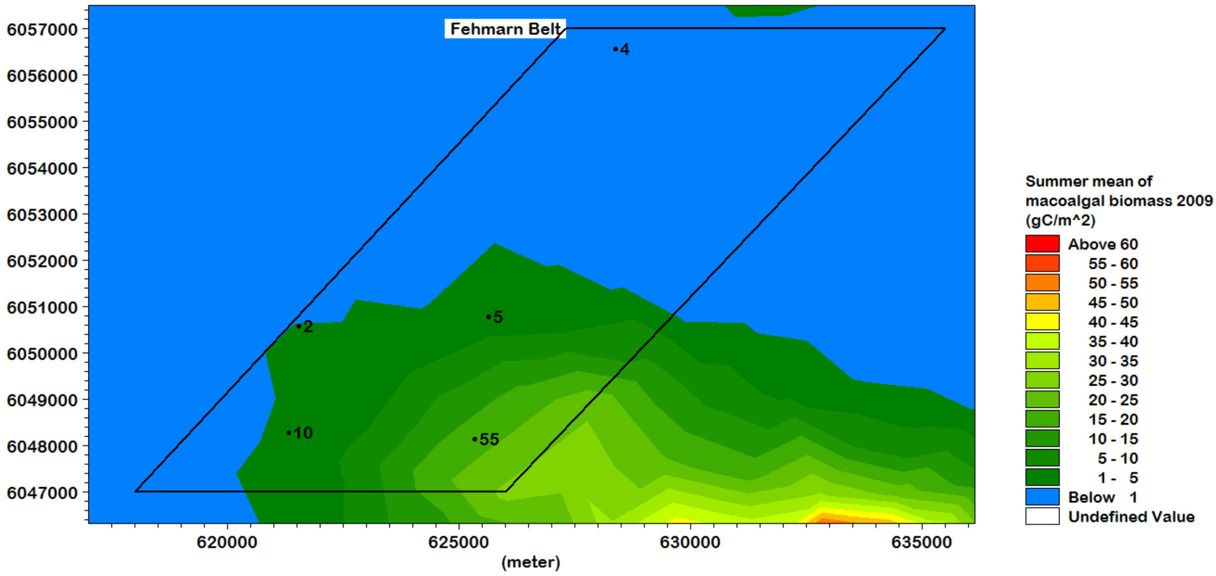


Figure App A6 Comparison of simulated and measured total macroalgal biomass, Fehmarn Belt

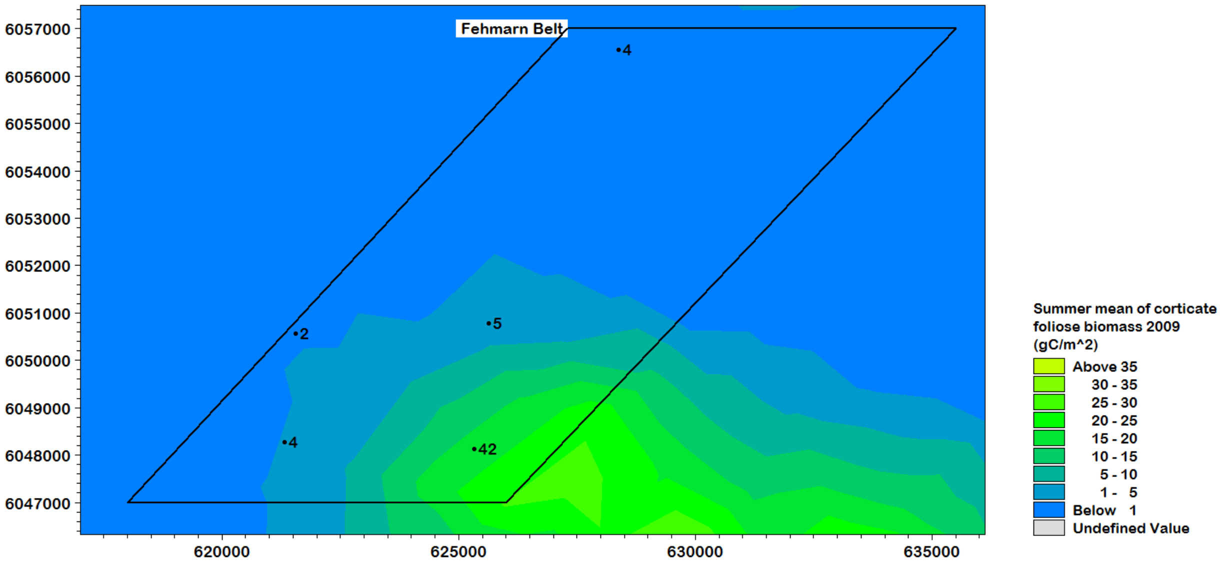


Figure App A7 Comparison of simulated and measured dominant macroalgal community, Fehmarn Belt

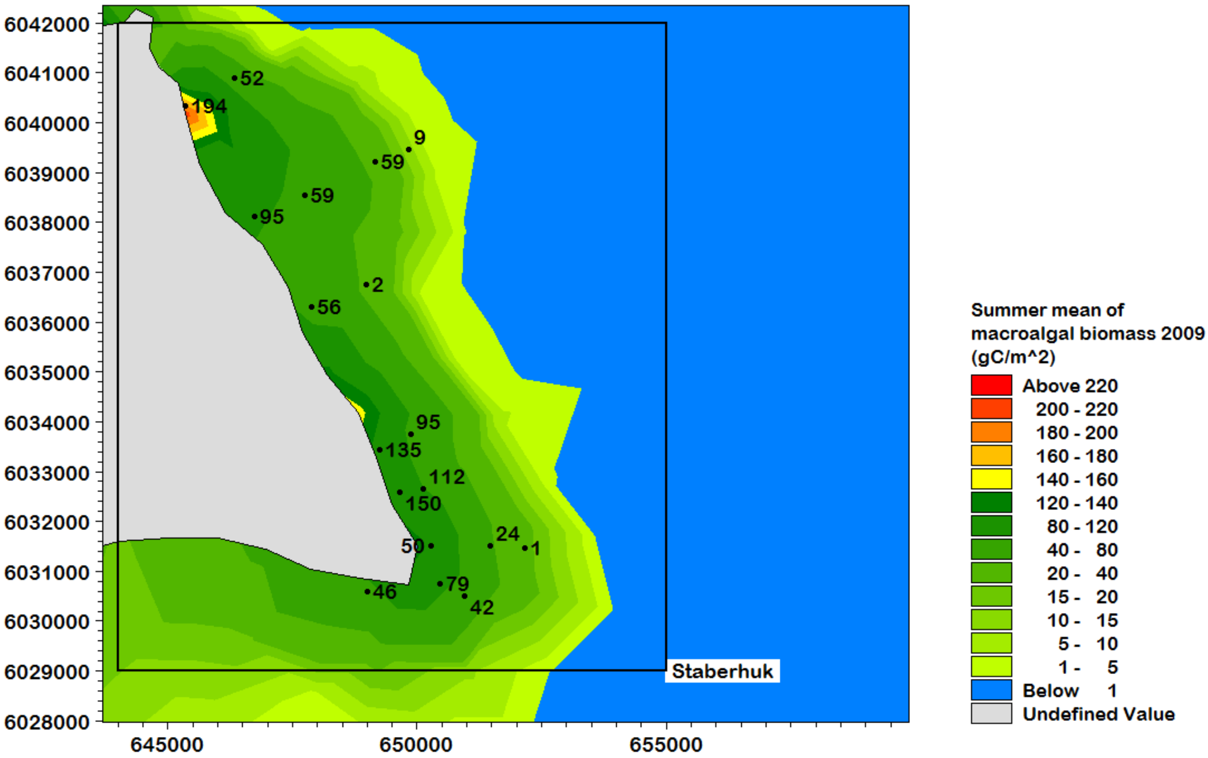


Figure App A8 Comparison of simulated and measured total macroalgal biomass, Staberhuk

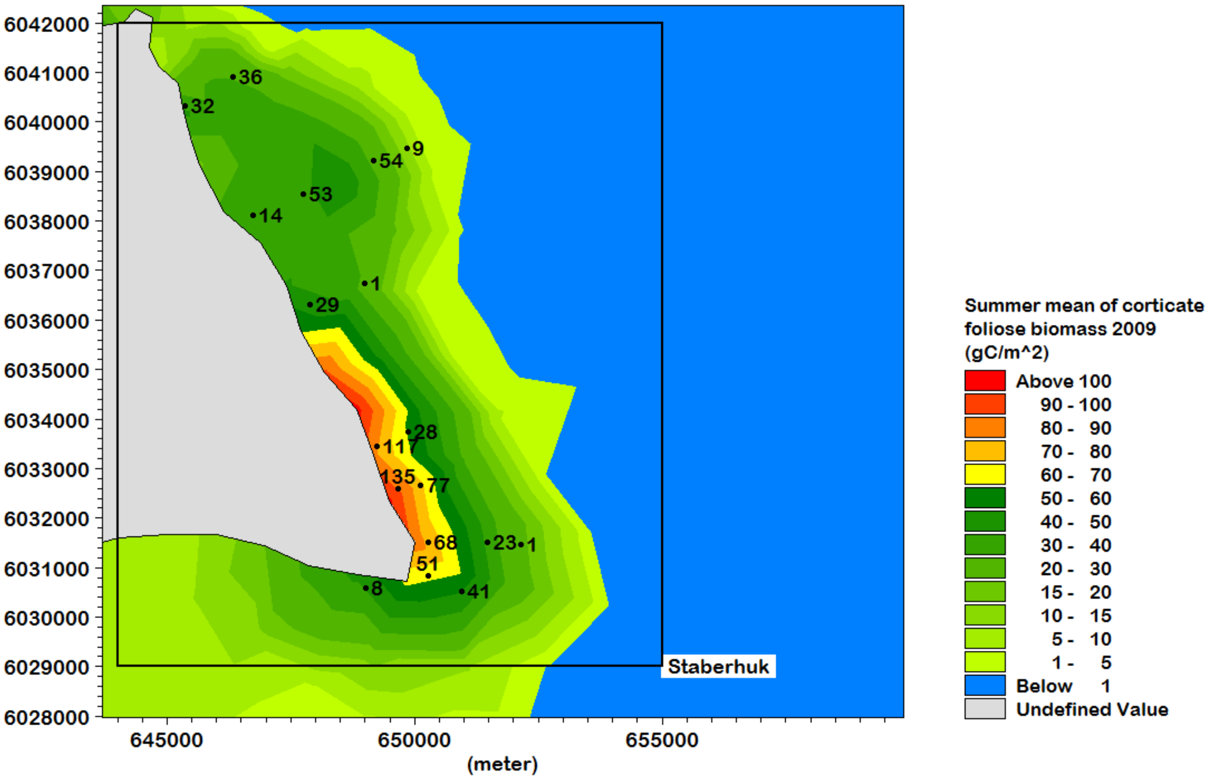


Figure App A9 Comparison of simulated and measured dominant macroalgal community, Staberhuk

Eelgrass communities were observed in two areas (Rødsand Lagoon and Orth Bight). The comparison of simulated and measured biomasses are presented in Figure App A10 and Figure App A11, respectively.

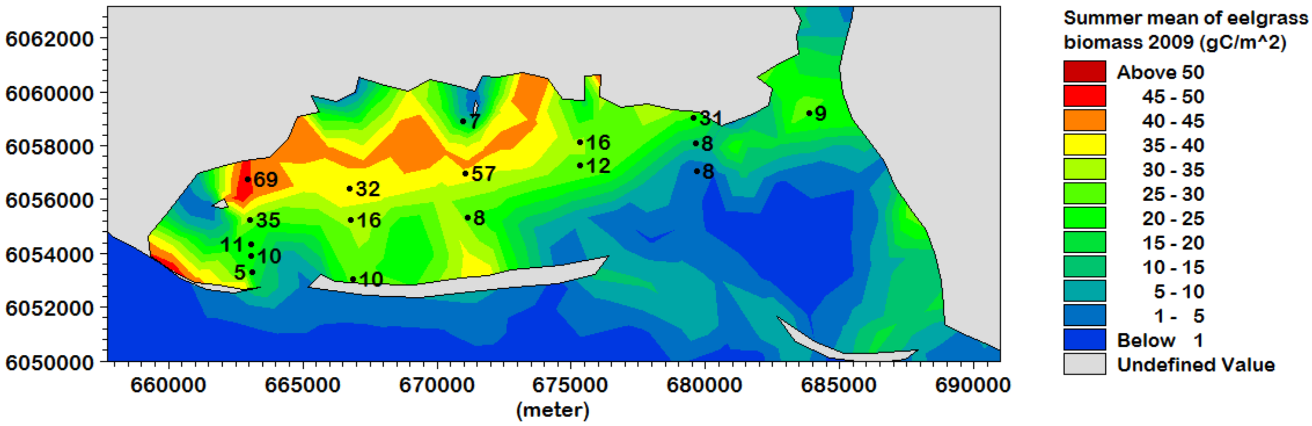


Figure App A10 Comparison of simulated and measured eelgrass biomass in Rødsand Lagoon

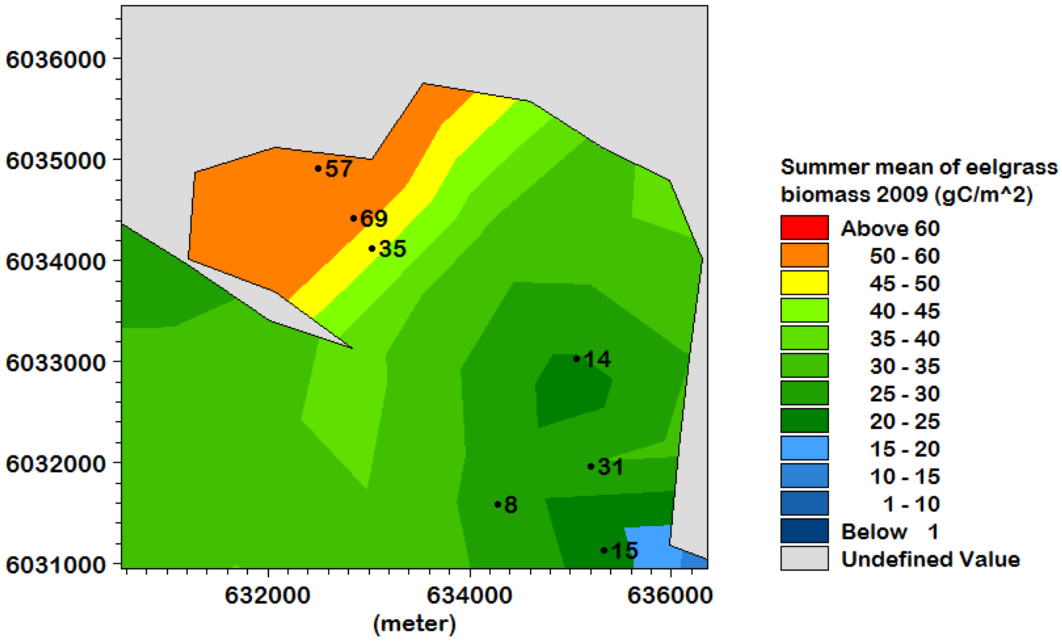


Figure App A11Comparison of simulated and measured eelgrass biomass in Orth Bight

Biomass distribution (vertical profiles)

In order to document the performance of the benthic vegetation sub-model with respect to the model's ability to reproduce the vertical biomass distribution with varying depth and light conditions, a comparison of field observations with the vertical distribution found in the model is made for the considered macroalgal communities.

The observed (blue bars) and modelled (red bars) depth distribution of macroalgal groups are presented in Figure App A12-A14. Summer measurements are used and Standard Deviation (SD) based on all observations is shown as whisker. The variability in biomass (SD) for a given depth range, as estimated by the model for the relevant macroalgal group, is shown for comparison.

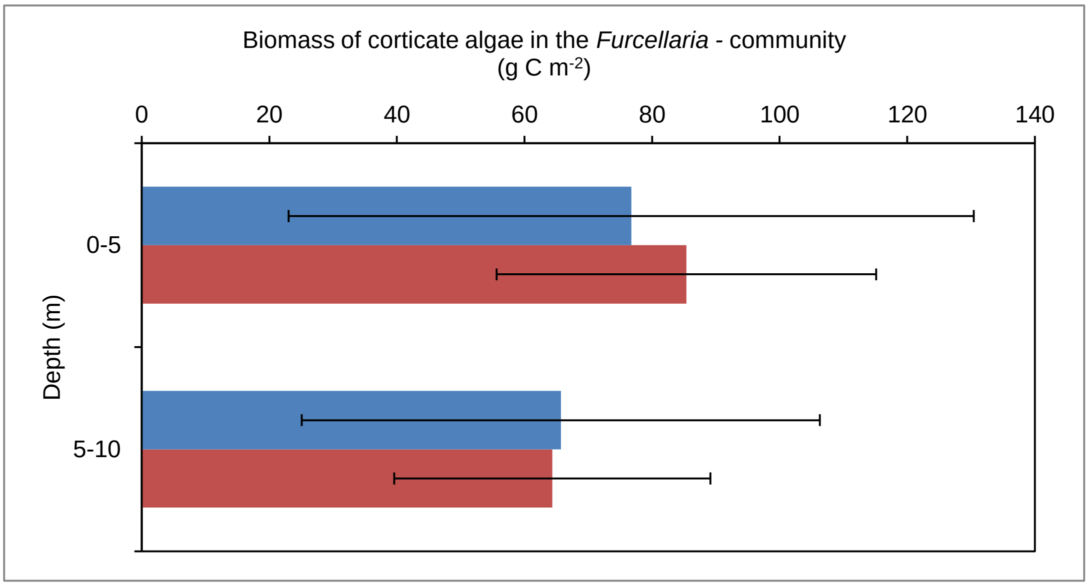


Figure App A12 Observed (blue bars) and modelled (red bars) depth distribution of macroalgae, corticated algae in the Furcellaria *community*

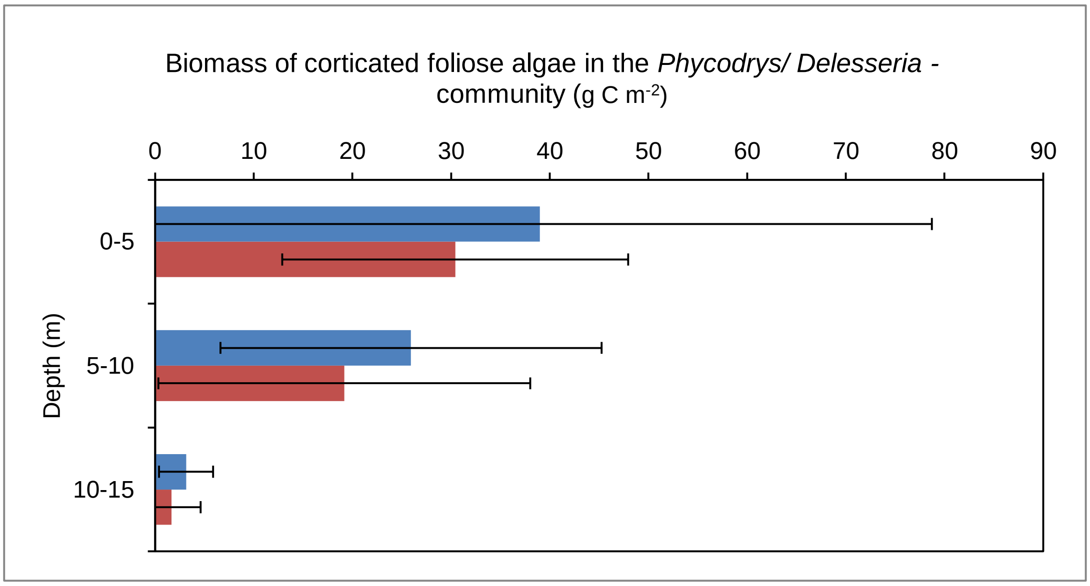


Figure App A13 Observed (blue bars) and modelled (red bars) depth distribution of macroalgae, corticated foliose algae in Phycodrys/Delesseria *community*

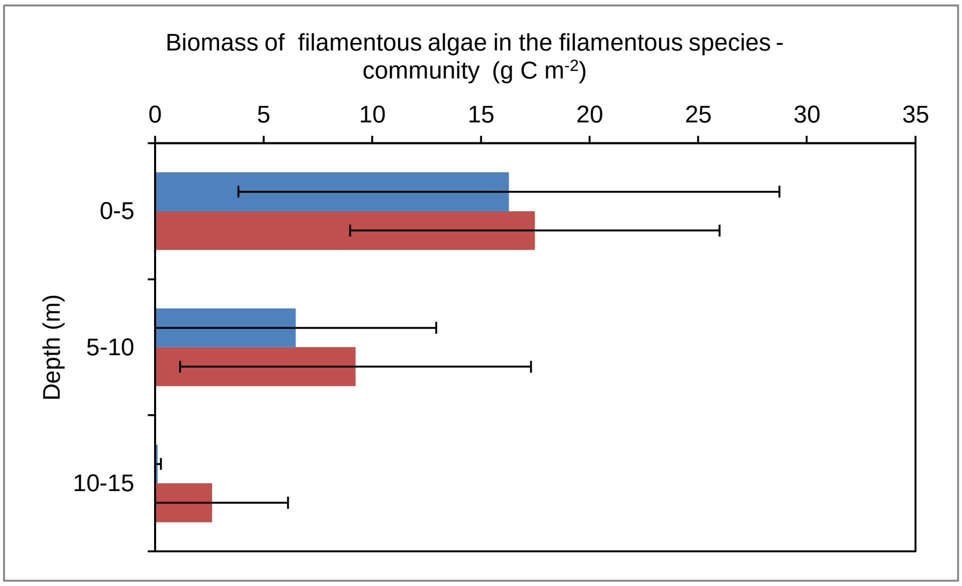


Figure App A14 Observed (blue bars) and modelled (red bars) depth distribution of macroalgae, filamentous algae in filamentous species community

Seasonal distribution

Seasonal spot samplings were carried out at a limited number of sites to support the calibration of the ecological model. The additional sampling were done in November 2009, March, April and May 2010 along the German coast, and in January, March, April and May 2010 along the Danish coast.

For comparison with modelled seasonal distribution, monitoring data from stations with additional sampling for seasonal variability have been compared with simulated biomasses for macroalgae and eelgrass, presented in Figure App A15.

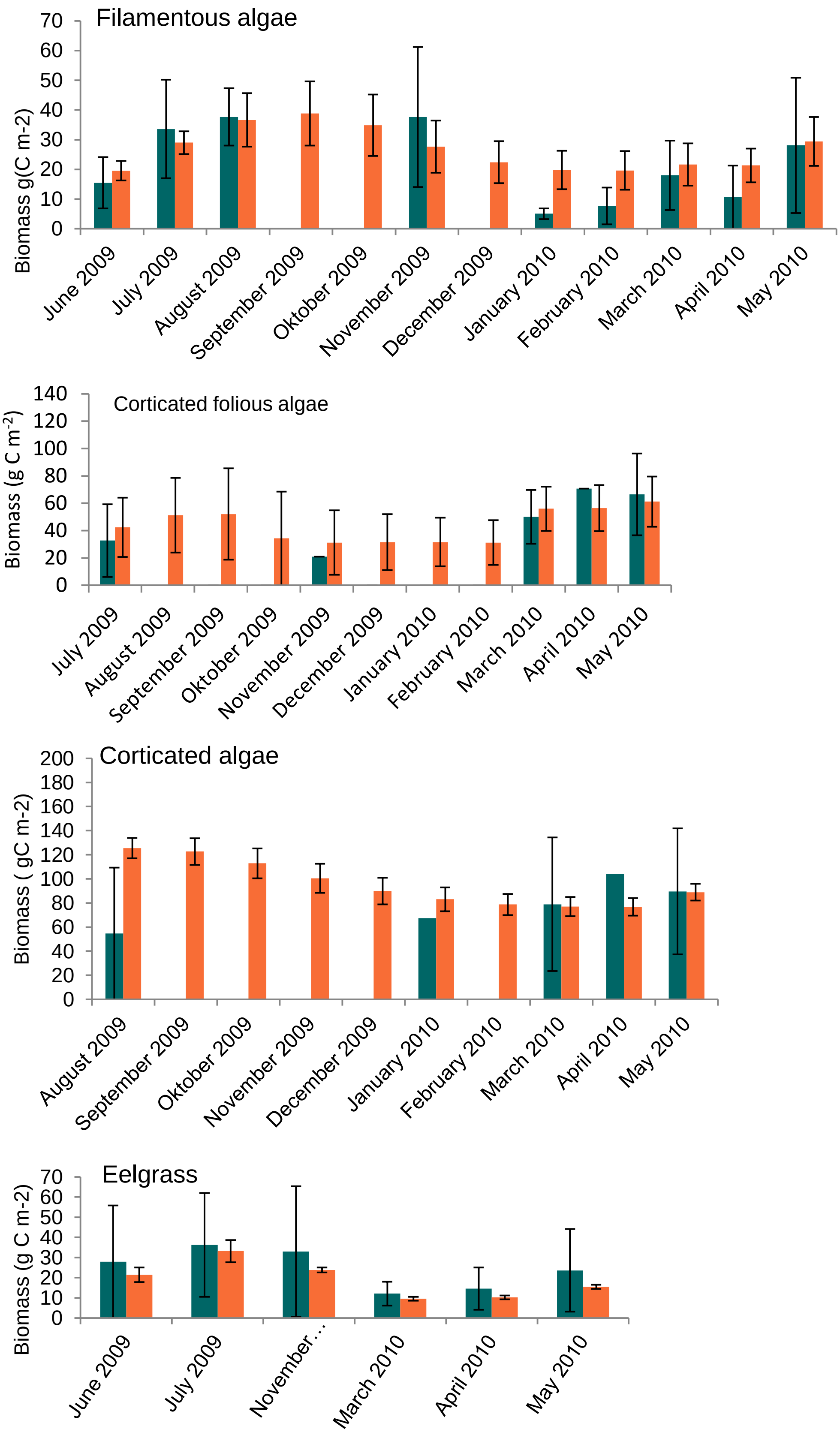


Figure App A15 Observed (blue bars) and modelled (red bars) seasonal variation in filamentous algae, corticated foliose algae, corticated algae and eelgrass

Comparison with performance criteria for model calibration

The model results are tested further in a regression model to assess the compliance with the suggested performance criteria proposed in Section 'Performance criteria for model calibration'. The comparison is based on all measured data for the considered benthic vegetation components. As such, no data filtering or removals of outliers have taken place. The comparisons are presented in Figure App A16 through Figure App A20.

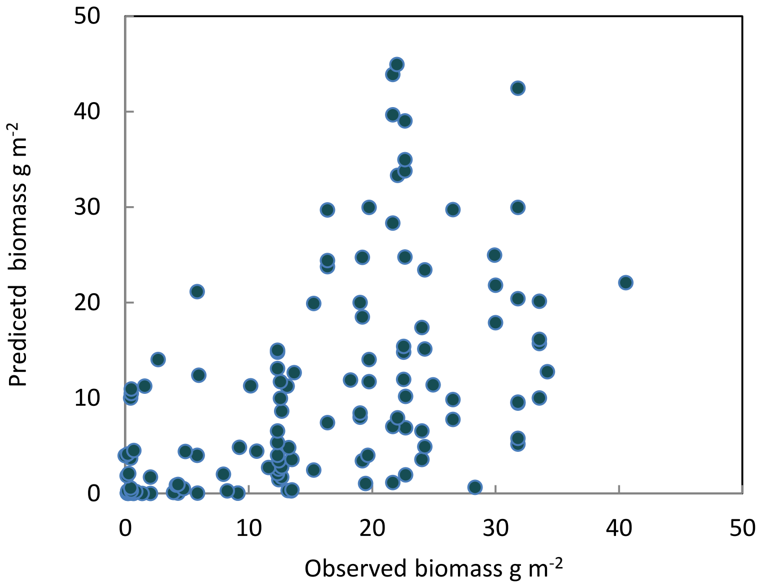


Figure App A16 Comparison of simulated and measured filamentous algae biomass

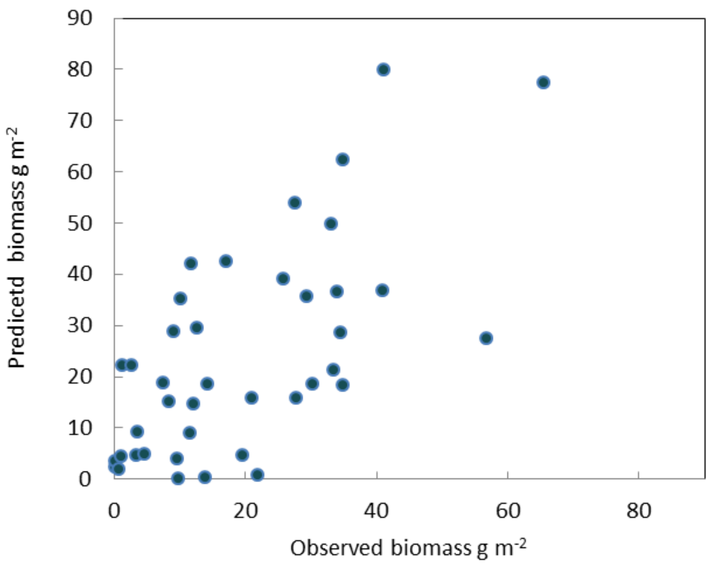


Figure App A17 Comparison of simulated and measured corticated foliose algae biomass.

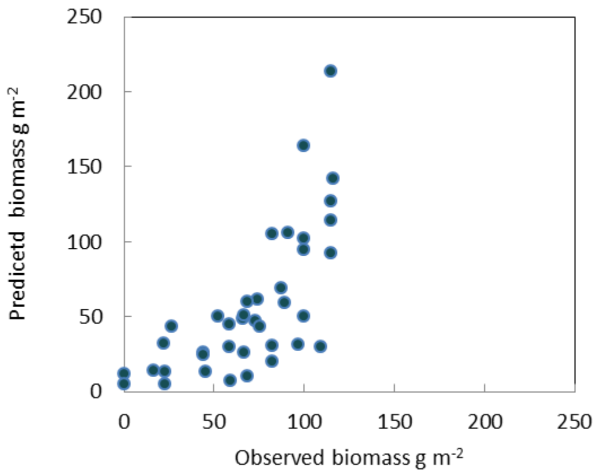


Figure App A18 Comparison of simulated and measured corticate algae biomass

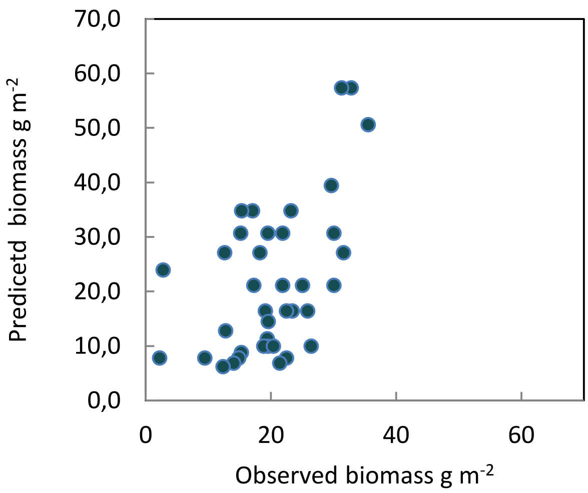
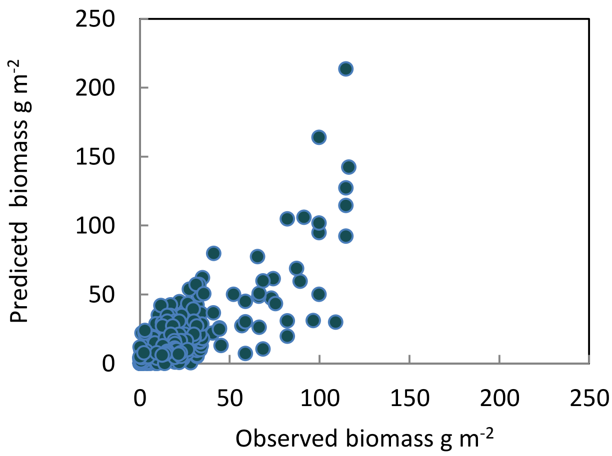


Figure App A19 Comparison of simulated and measured eelgrass biomass



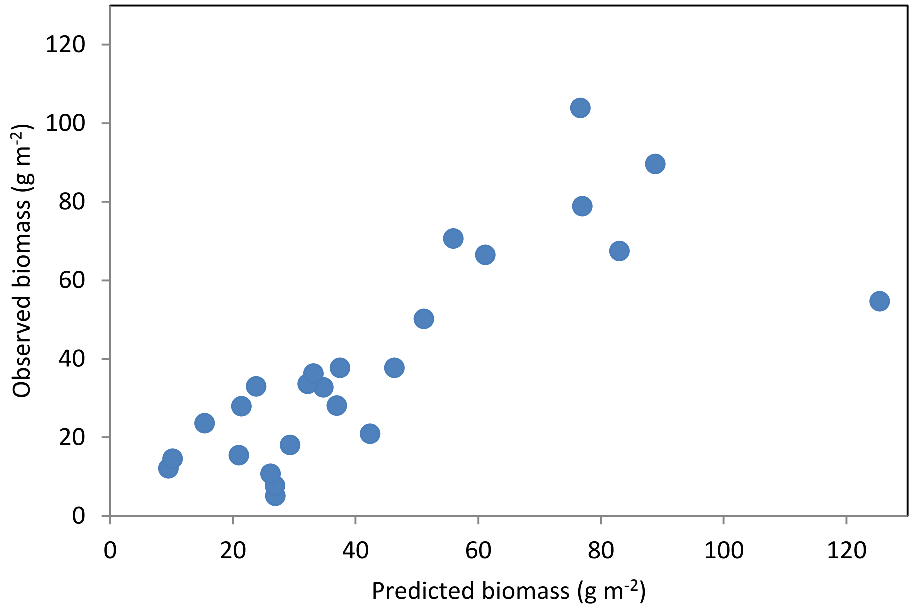
FigureApp A20 Comparison of simulated and measured overall biomass (macroalgae and eelgrass)

The performance measures for the linear regression analysis (r^2), the Nash Sutcliffe Model Efficiency (ME) and the Percentage Model Bias (Pbias) are shown in Table App A4. The ME and Pbias values indicate that the model is good to excellent. Only the Pbias value for filamentous species is >40 and thus indicate that the model has a tendency to overestimating the biomasses for this algae group.

Table App A4 Relationships between biomass values predicted by the model (P) and observed biomass values (O), regression coefficients (r^2), the Nash Sutcliffe Model Efficiency (ME) and the Percentage Model Bias (Pbias).

Benthic vegetation component	**Function**	**r^2**	**ME**	**Pbias**
Filamentous species	O=0.56*P+2.1	0.29	0.99	-43.3
Corticated folious species	O=0.86*P+7.2	0.44	0.44	18.5
Corticated species	O=1.0*P-14.5	0.50	0.42	-22.7
Eelgrass	O=0.97*P+2.0	0.28	0.27	6.4
Overall	O=0.85*P+0.35	0.60	0.57	-16.1
Seasonal comparison				
Without outlayer	O=0.76*P+6.0	0.62	0.52	-12.0
With outlayer	O=1.1*P+5.2	0.82	0.81	-5.0

Finally, a linear regression analysis has been performed for data used in the seasonal comparison of biomass (macroalgae and eelgrass) as shown in Figure App A21.



FigureApp A21 Comparison and regression analysis of observed and modelled seasonal distribution of the three macroalgal and eelgrass.

Discussion

The above comparisons of model predicted biomasses against measured data for three groups of macroalgae (filamentous, corticate foliose and corticate macroalgae) and eelgrass (rooted vegetation), show that the model generally is able to reproduce the observed biomass distribution.

Deviations from measurements are found for the vertical biomass distribution. However, the model results are safely within the Standard Deviation of the measurements.

The coefficients of determination found from linear regression analysis of all spatial data are found to be low, especially for filamentous macroalgae and eelgrass. Nevertheless, the ME and Pbias values indicate that the model is good to excellent. Only the Pbias value for filamentous species is >40 and thus indicate that the model has a tendency to overestimating the biomasses for this algae group. It should, however, be noted that model predictions are based on input parameters for the physical conditions controlling the benthic vegetation, estimated with uncertainties due to the nature of numerical modelling (stone coverage, depth profiles), which means that some discrepancy between model and measurement is acceptable. The seasonal data are reproduced by the model with a reasonably high degree of agreement with measurements.

The fact that the model is deterministic-based, with explicit biological descriptions of growth and death processes driven by the controlling physical factors, is viewed as strong advantage of the model complex to serve the purpose of the modelling. It should be noted that the established model is the primary tool for the benthic vegetation impact assessment of suspended sediment from sediment spills caused by the dredging and reclamation works.

It was found that the performance comply with the upper bound of model performance of complex aquatic biogeochemical models and almost in all cases the variability in measurements (expressed as Standard Deviation) overlaps with the variability in the modelled biomass, which indicates a robust model.

A P P E N D I X   B

Description of calculations, area and biomass of potential flora of new solid substrate areas in depth intervals for tunnel and bridge alternatives

Peninsulas. Altogether 552 m of new shore line is planned for Lolland, a 931 m is planned at the Fehmarn coast (for dikes and embankments: technical drawings A4429-C-P-DWG-35-30451, Lolland and A4429-C-P-DWG-35-30401, Fehmarn).

Type II, III, IV Piers. The Type II to IV Piers have a similar layout, but the dimensions differ (type IV), A4429-C-P-DWG-33-52082 (Type III) and A4429-C-P-DWG-33-52081 (Type II). The piers are made of a baseplate with a range of triangular supporting structures (winglets) and the virtual caisson. Figure App. B1 and B2 show the layout of a Type IV Pylon. For each pier the surface of all geometrical elements was calculated separately and finally added together.

For the calculation baseplate was divided into a rectangular baseplate and a number of winglets (12 winglets for Type II and Type III, 10 winglets for Type IV). The caisson was divided into two trapezia for the two longitudinal profiles, and four trapezia for the two transversal profiles.

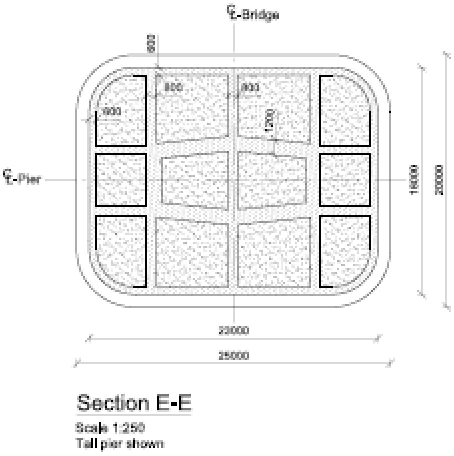


Figure App. B1 Baseplate of a Type IV Pier (technical drawing A4429-C-P-DWG-33-52071)

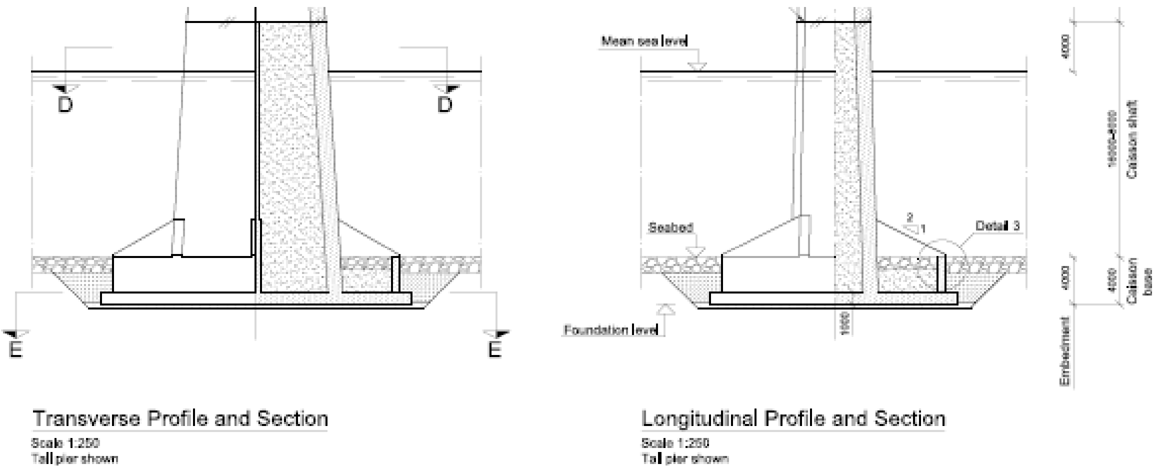


Figure App. B2 Type IV Pier (technical drawing A4429-C-P-DWG-33-52071)

Centre Pylon. The Centre Pylon has a cylindrical shaped basis (Figure App B3). The areas of outer and inner lateral structures at the top and the two base areas of the pylon with their lateral surface was calculated.

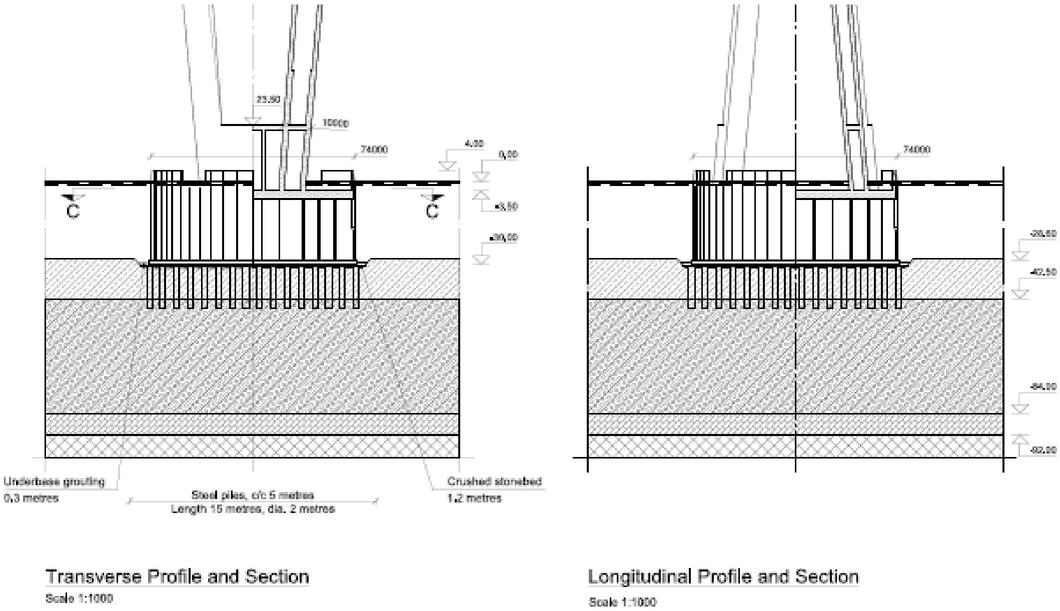


Figure App. B3 Center Pylon (taken from technical drawing A4429-C-P-DWG-32-81101)

Outer Pylon. The two Outer Pylons have an elliptic base area which tapers towards the top. The top part is in contrast to the conical base cylindrical-shaped (Figure App. B4). The additional solid substrate deriving from the Outer Pylons was calculated by dividing the underwater part of the pylon into the elliptic surface, the inner and outer lateral surface of the cylindrical surface and the outer surface of the conical part. Additionally the base area and lateral surface area of the pylon was calculated.

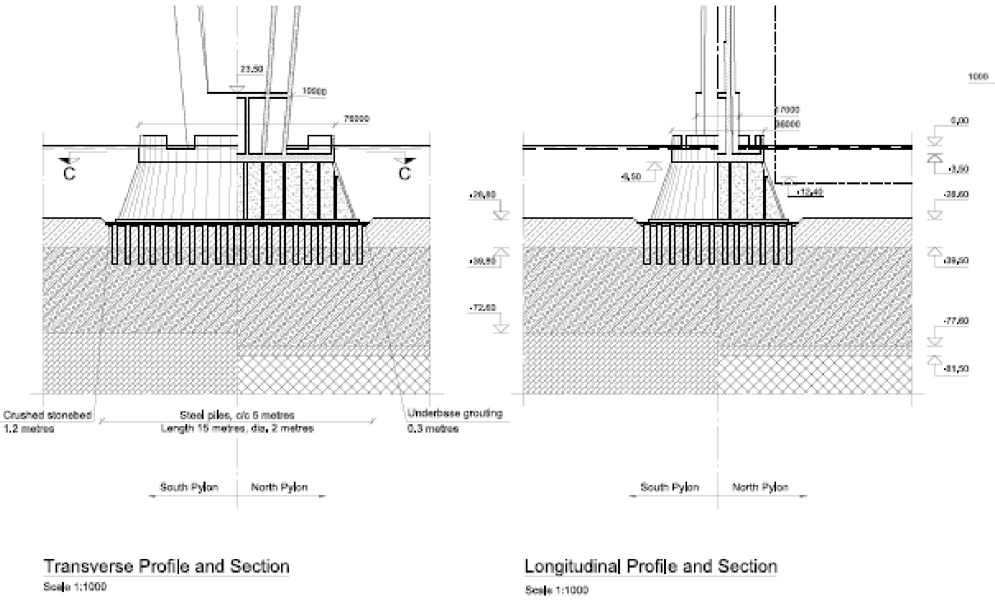


Figure App. B4 Outer Pylon (taken from technical drawing A4429-C-P-DWG-32-81201)

Anchor and Transition Piers. The two Anchor and Transition Piers consist of an elliptical conical basis, with an elliptical cylindrical top. Figure App. B5 shows the layout for an Anchor Pier, the layout for a Transition Pier can be taken from drawing A4429-C-P-DWG-32-82201 The additional solid substrate was calculated by dividing the structure in the surface area, inner and outer lateral surface and the pylon itself.

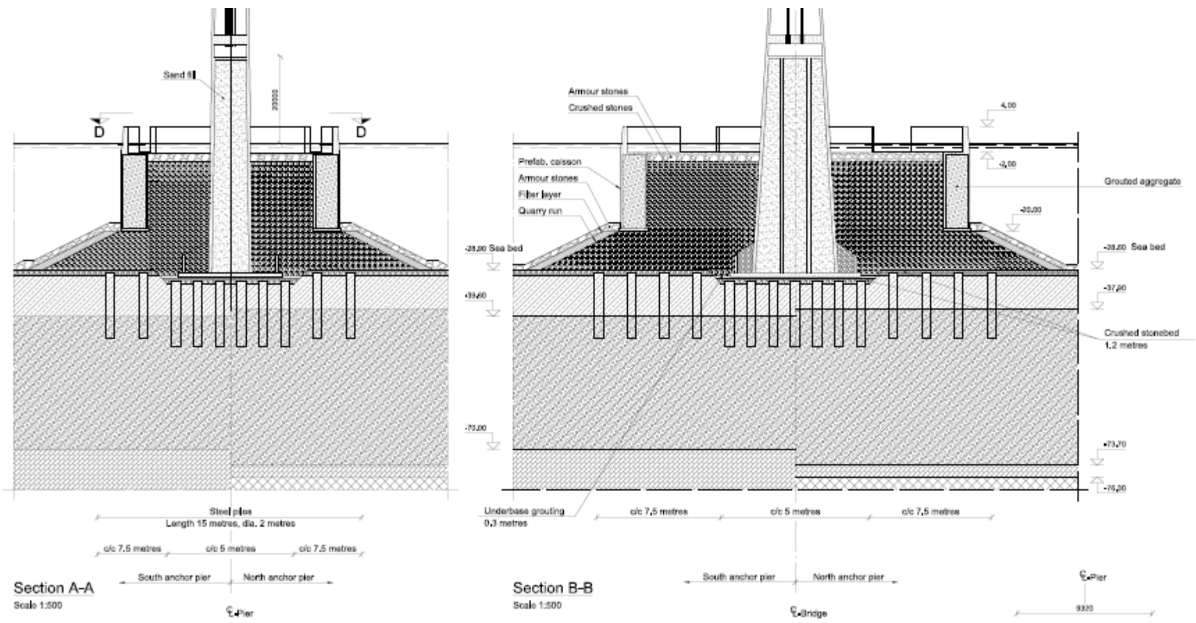


Figure App. B5 Anchor Pier (taken from technical drawing A4429-C-P-DWG-32-82101)

Table App B-1. Area (m2) of additional solid substrate and in depth intervals for the tunnel alternative.

Additional solid substrate in depth	0-1 m²	1-2 m²	2-3 m²	3-4 m²	4-5 m²	5-6 m²	6-7 m²	7-8 m²	8-9 m²	9-10 m²
Danish Waters	9930	9930	9930	9930	60723	18156	25769	52481	29051	10253
German Waters	1008	1008	1008	1008	3024	46723	13049	14775	6856	10692
German Coastal Zone	1008	1008	1008	1008	3024	46723	13049	14775	6856	10692

Additional solid substrate in depth	10-11 m²	11-12 m²	12-13 m²	13-14 m²	14-15 m²	15-16 m²	16-17 m²	17-18 m²	18-19 m²	19-20 m²
Danish Waters	17089	29051	19716	51266	32469	31614	78672	28196	26488	33387
German Waters	8544	6836	6836	15380	16234	12817	12817	5981	18798	18798
German Coastal Zone	8544	6836	6836	15380	16234	12817	12817	5981	18798	18798

Additional algae biomass (kg)	0-1 m²	1-2 m²	2-3 m²	3-4 m²	4-5 m²	5-6 m²	6-7 m²	7-8 m²	8-9 m²	9-10 m²
Danish Waters	3589	3215	2880	2580	14134	3786	4813	8782	4355	1377
German Waters	364	326	292	262	704	9742	2437	2472	1028	1436
German Coastal Zone	364	326	292	262	704	9742	2437	2472	1028	1436

Additional algae biomass (kg)	10-11 m²	11-12 m²	12-13 m²	13-14 m²	14-15 m²	15-16 m²	16-17 m²	17-18 m²	18-19 m²	19-20 m²
Danish Waters	2056	3131	1903	4434	2516	2194	4892	1571	1322	1492
German Waters	1028	737	660	1330	1258	890	797	333	938	840
German Coastal Zone	1028	737	660	1330	1258	890	797	333	938	840

Additional algae biomass (kg)	0-20 m²
Danish Waters	75021
German Waters	27875
German Coastal Zone	27875

Table App B-2. Area (m2) of additional solid substrate in depth intervals for the bridge alternative.

	0-1 m²	1-2 m²	2-3 m²	3-4 m²	4-5 m²	5-6 m²	6-7 m²	7-8 m²	8-9 m²	9-10 m²
Pylons and Pillars										
Danish Waters	2797	2842	2890	2998	3178	3446	4393	5193	3860	3350
German Waters	6926	16242	5557	11344	3793	3898	4419	4383	4319	3807
German Coastal Zone	1470	1494	1518	1572	1653	1747	2253	2167	2122	1593
German EEZ	5119	14406	3691	9418	1780	1786	1796	1806	1816	1827
Scour Protection										
Danish Waters	1599	1599	1599	3996	4185	1599	1652	3304	1652	826
German Waters	2356	2356	2356	5890	5700	2356	0	1054	1054	1054
German Coastal Zone	2356	2356	2356	5890	5700	2356	0	1054	1054	1054
German EEZ	0	0	0	0	0	0	0	0	0	0
Total Area										
Danish Waters	4396	4441	4489	6994	7363	5045	6045	8497	5512	4176
German Waters	9282	18598	7913	17234	9493	6254	4419	5437	5373	4861
German Coastal Zone	3826	3850	3874	7462	7353	4103	2253	3221	3176	2647
German EEZ	5119	14406	3691	9418	1780	1786	1796	1806	1816	1827

	10-11 m²	11-12 m²	12-13 m²	13-14 m²	14-15 m²	15-16 m²	16-17 m²	17-18 m²	18-19 m²	19-20 m²
Pylons and Pillars										
Danish Waters	3374	3883	3539	4905	3377	4144	3553	3187	1413	1614
German Waters	3867	4378	3958	4921	4345	3846	4354	3875	4254	4200
German Coastal Zone	1637	2133	1697	2644	2052	1537	2029	1534	1897	1828
German EEZ	1837	1848	1858	1869	1879	1890	1900	1911	1921	1932
Scour Protection										
Danish Waters	826	1652	826	3304	952	2856	2856	2856	0	3808
German Waters	0	0	1054	1054	1054	1054	1207	0	1207	1207
German Coastal Zone	0	0	1054	1054	1054	1054	1207	0	1207	1207
German EEZ	0	0	0	0	0	0	0	0	0	0
Total Area										
Danish Waters	4200	5535	4365	8209	4329	7000	6409	6043	1413	5422
German Waters	3867	4378	5012	5975	5399	4900	5561	3875	5461	5407
German Coastal Zone	1637	2133	2751	3698	3106	2591	3236	1534	3104	3035
German EEZ	1837	1848	1858	1869	1879	1890	1900	1911	1921	1932

Table App B-3. Area (m2) of additional solid substrate in depth intervals for the bridge alternative.

Additional algae biomass (g)

Pylons and Pillars	**0-1 m^2**	**1-2 m^2**	**2-3 m^2**	**3-4 m^2**	**4-5 m^2**	**5-6 m^2**	**6-7 m^2**	**7-8 m^2**	**8-9 m^2**	**9-10 m^2**
Danish Waters	1010851	920124	838200	778949	739705	718535	820581	868973	578632	449871
German Waters	2503093	5258497	1611722	2947430	882852	812783	825437	733431	647439	511241
German Coastal Zone	531266	483696	440272	408441	384749	364272	420844	362616	318098	213924
German EEZ	1850034	4664075	1070517	2447011	414310	372404	335480	302208	272227	245347
Scour Protection										
Danish Waters	577887	517691	463765	1038252	974093	333412	308582	552876	247643	110923
German Waters	851471	762777	683321	1530357	1326722	491256	0	176371	158000	141541
German Coastal Zone	851471	762777	683321	1530357	1326722	491256	0	176371	158000	141541
German EEZ	0	0	0	0	0	0	0	0	0	0
Total Area										
Danish Waters	1588738	1437815	1301965	1817201	1713798	1051947	1129162	1421849	826275	560794
German Waters	3354564	6021273	2295043	4477787	2209573	1304038	825437	909802	805438	652783
German Coastal Zone	1382737	1246473	1123594	1938798	1711471	855528	420844	538987	476097	355465
German EEZ	1850034	4664075	1070517	2447011	414310	372404	335480	302208	272227	245347

Additional algae biomass (g)

Pylons and Pillars	**10-11 m^2**	**11-12 m^2**	**12-13 m^2**	**13-14 m^2**	**14-15 m^2**	**15-16 m^2**	**16-17 m^2**	**17-18 m^2**	**18-19 m^2**	**19-20 m^2**
Danish Waters	405897	418471	341670	424221	261645	287626	220918	177519	70507	72148
German Waters	465205	471817	382122	425605	336644	266943	270723	215842	212270	187745
German Coastal Zone	196933	229874	163835	228673	158986	106680	126159	85445	94658	81714
German EEZ	220994	199159	179379	161645	145582	131181	118138	106445	95856	86363

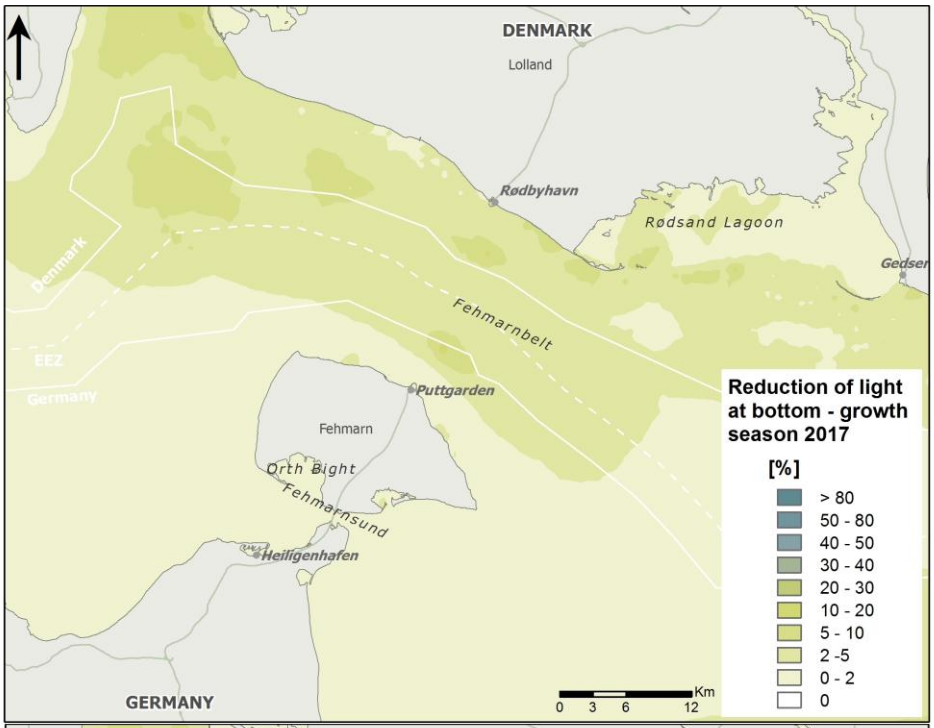
Scour Protection										
Danish Waters	99369	178036	79745	285755	73759	198229	177580	159082	0	170222
German Waters	0	0	101757	91158	81662	73156	75049	0	60228	53954
German Coastal Zone	0	0	101757	91158	81662	73156	75049	0	60228	53954
German EEZ	0	0	0	0	0	0	0	0	0	0
Total Area										
Danish Waters	505266	596507	421415	709976	335404	485855	398498	336602	70507	242370
German Waters	465205	471817	483879	516763	418306	340098	345771	215842	272498	241699
German Coastal Zone	196933	229874	265593	319831	240648	179836	201208	85445	154886	135668
German EEZ	220994	199159	179379	161645	145582	131181	118138	106445	95856	86363

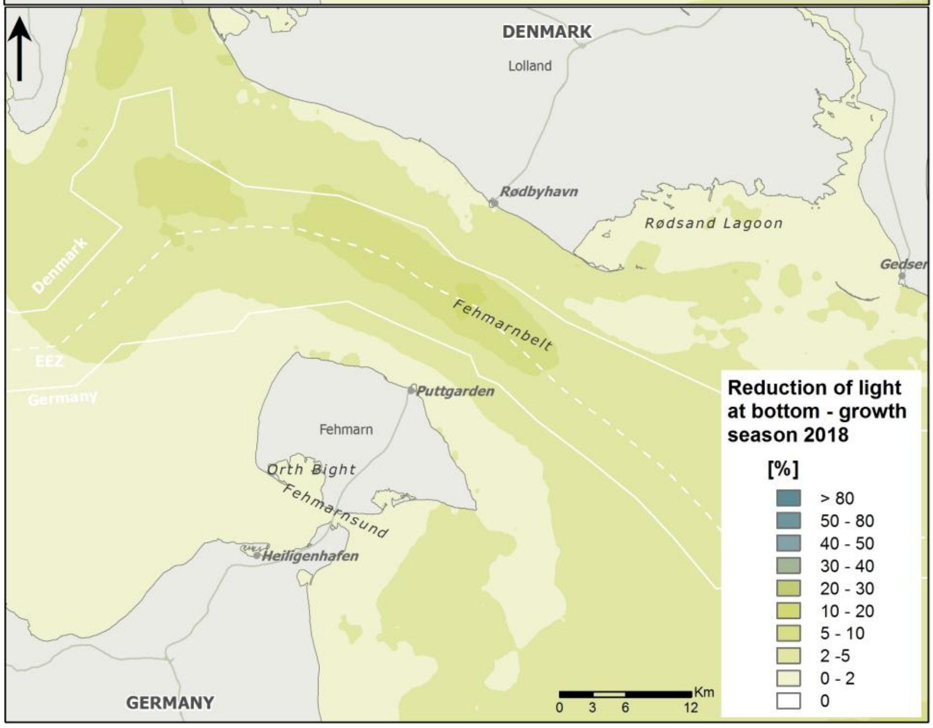
APPENDIX C

Assessment of suspended sediment, supplementary maps and tables

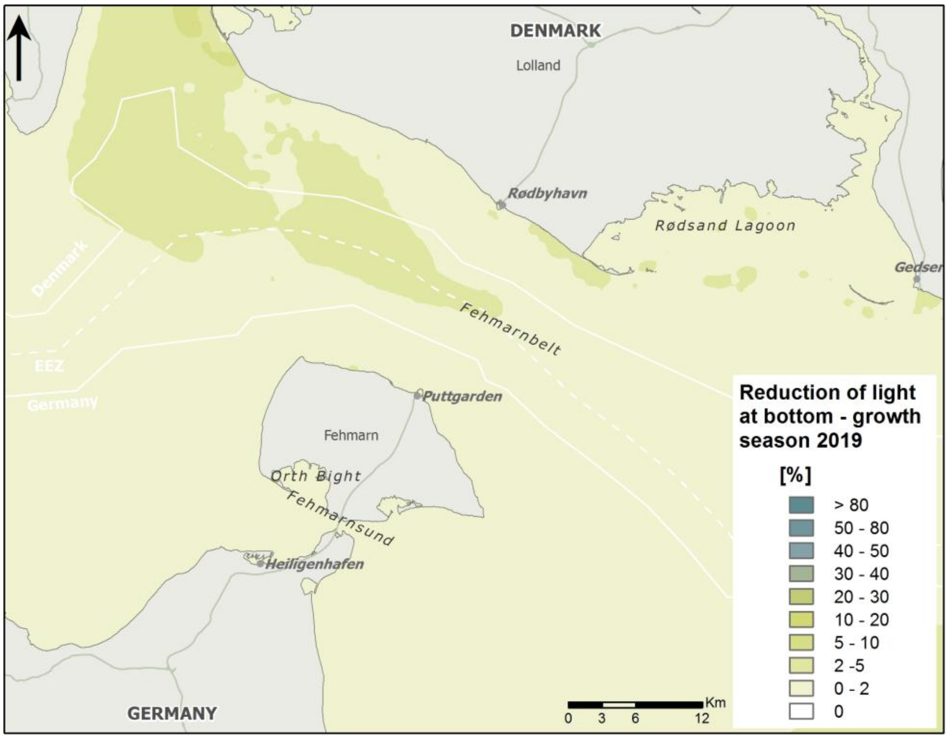
Suspended sediment, supplementary maps for magnitude of pressure.

Tunnel alternative. Reduction in light at bottom in 2017 and 2018

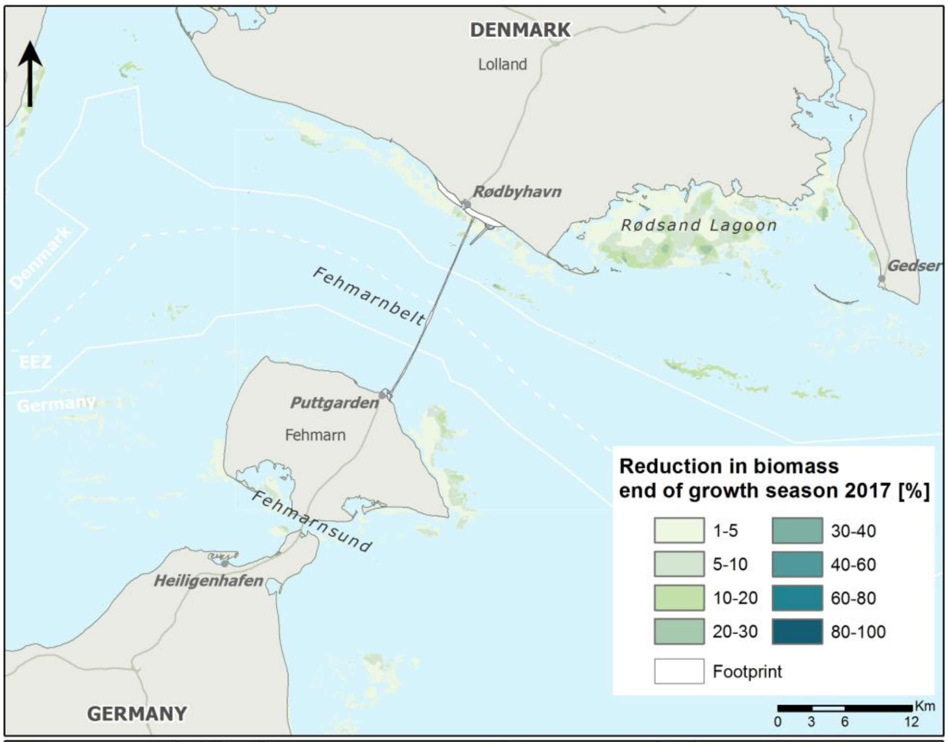


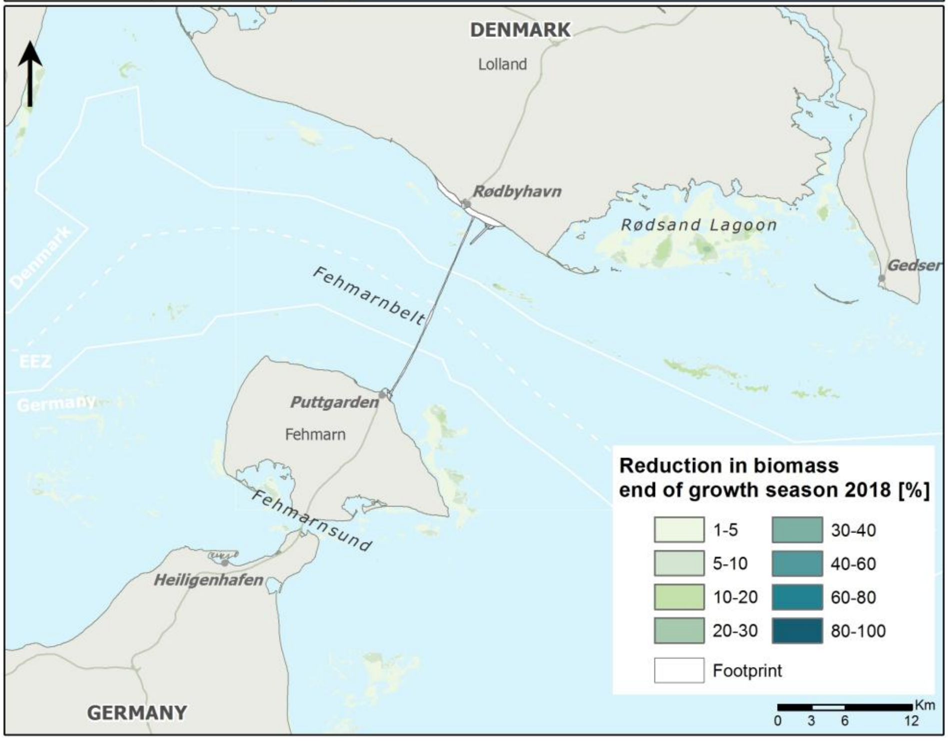


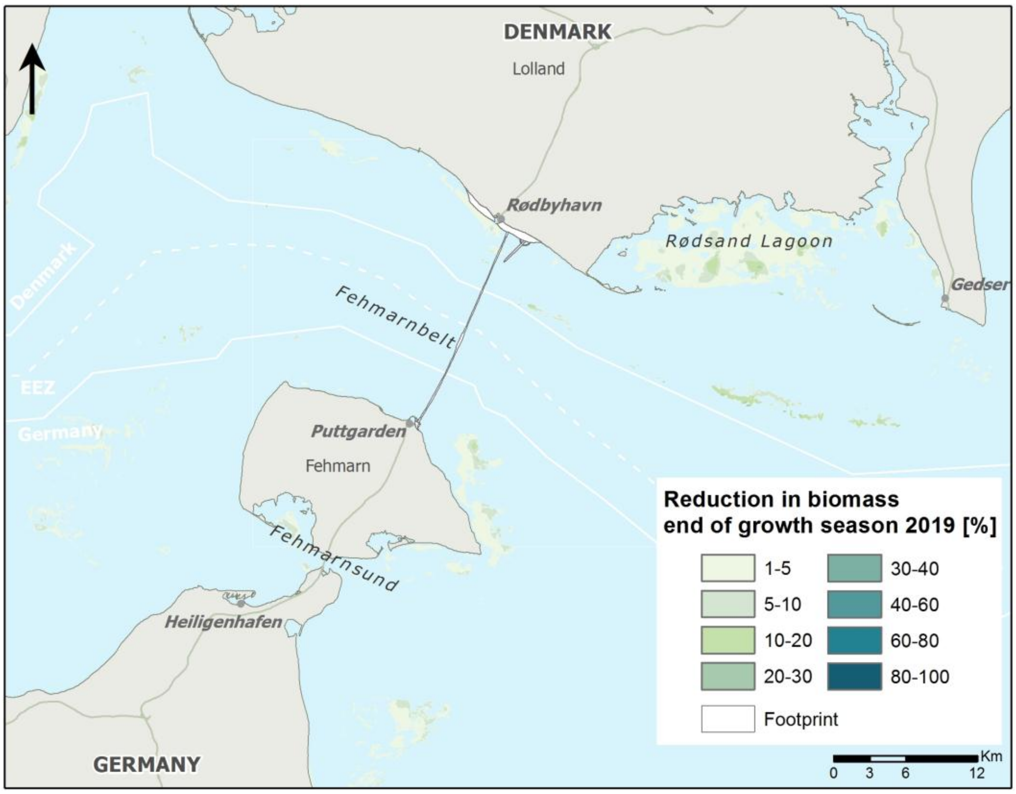
Tunnel alternative, Reduction in light at bottom in 2019



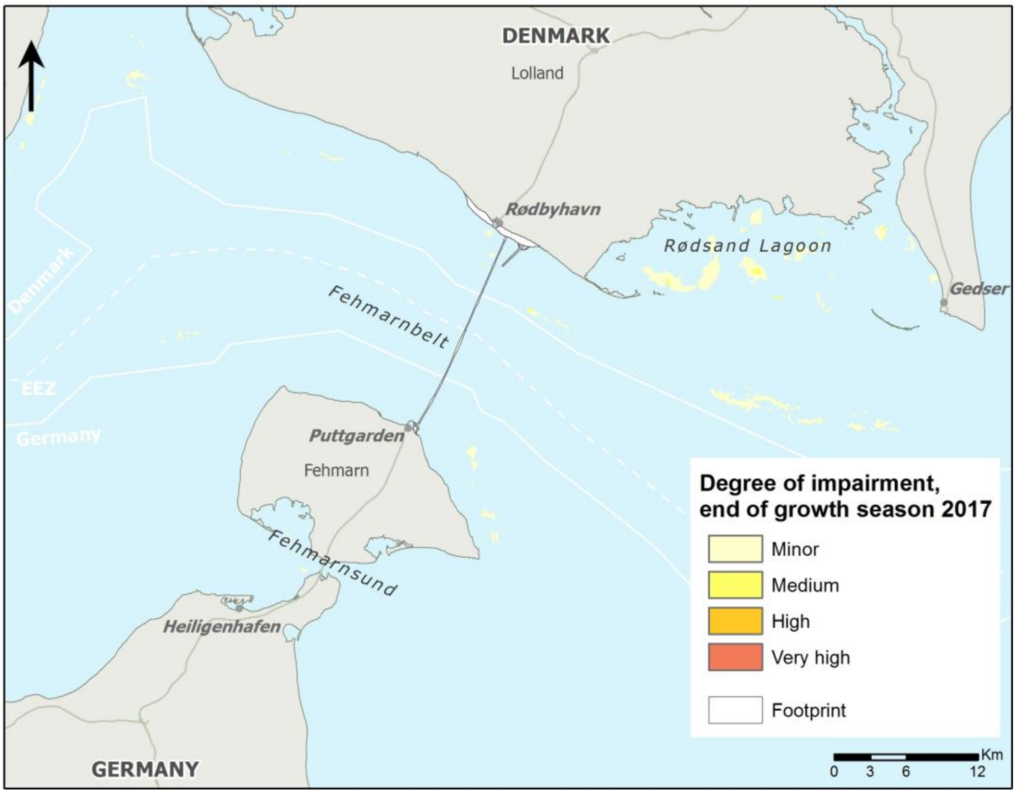
Assessment of tunnel alternative, reduction in biomass

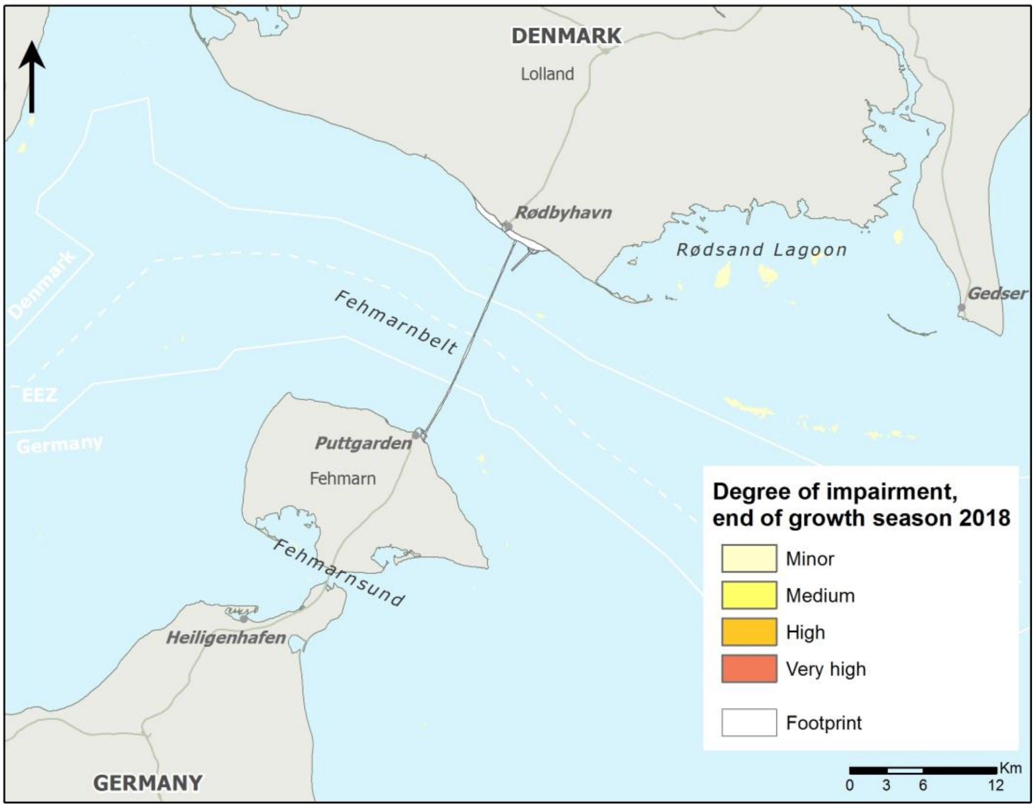


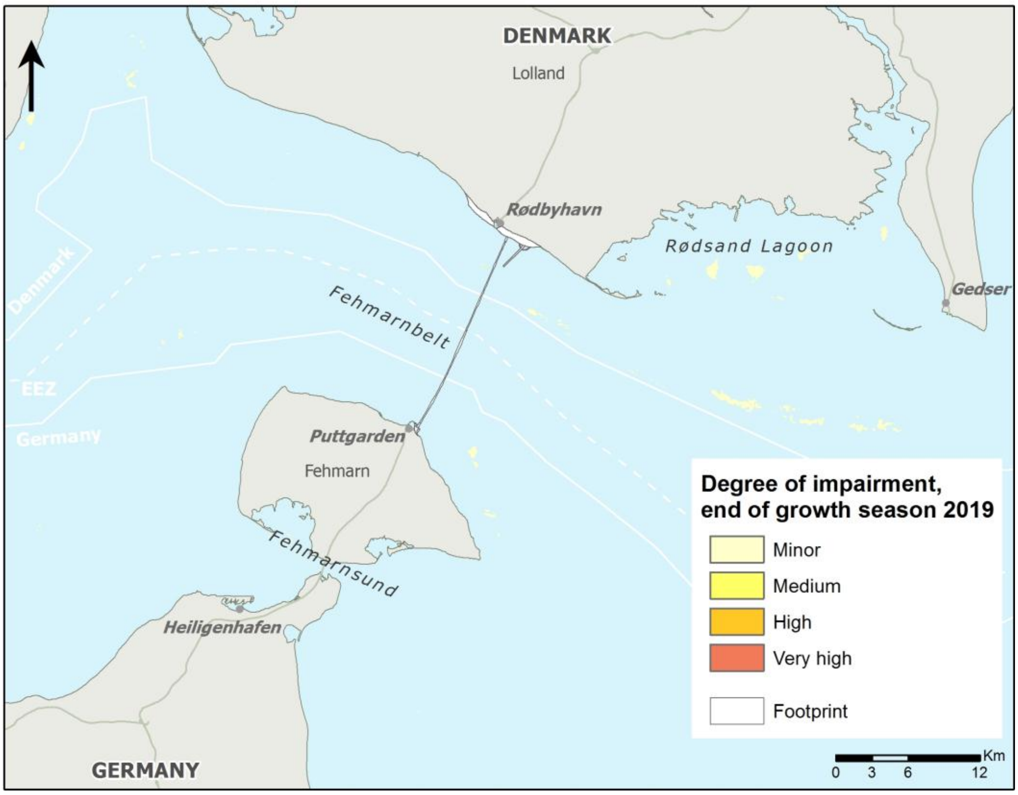



DENMARK
Lolland
Rødbyhavn
Rødsand Lagoon
Gedser
Denmark
EEZ
Germany
Fehmarnbelt
Puttgarden
Fehmarn
Fehmarnsund
Heiligenhafen
GERMANY
Reduction in biomass
end of growth season 2019 [%]
1-5
5-10
10-20
20-30
30-40
40-60
60-80
80-100
Footprint
Km
0 3 6 12

Assessment of tunnel alternative, degree of impairment




DENMARK
Lolland
Rødbyhavn
Rødsand Lagoon
Gedser
Fehmarnbelt
Denmark
EEZ
Germany
Puttgarden
Fehmarn
Fehmarnsund
Heiligenhafen
GERMANY
Degree of impairment, end of growth season 2018
Minor
Medium
High
Very high
Footprint
0 3 6 12 Km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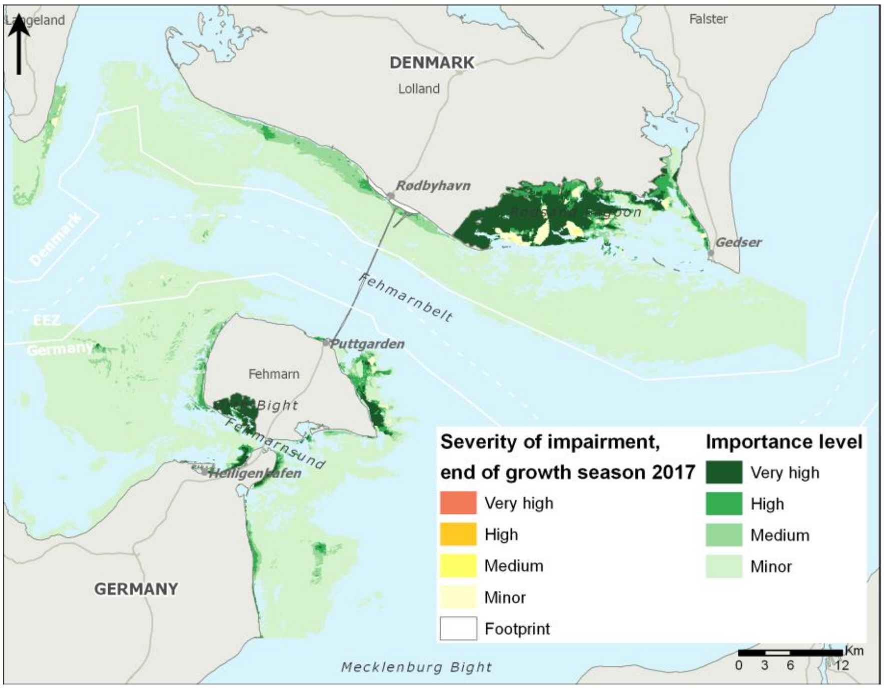
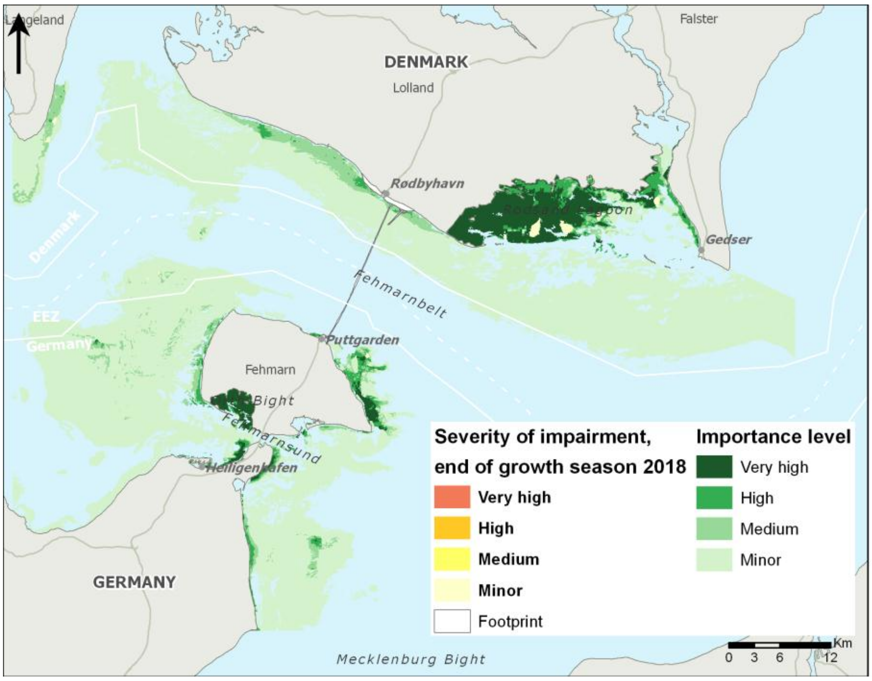
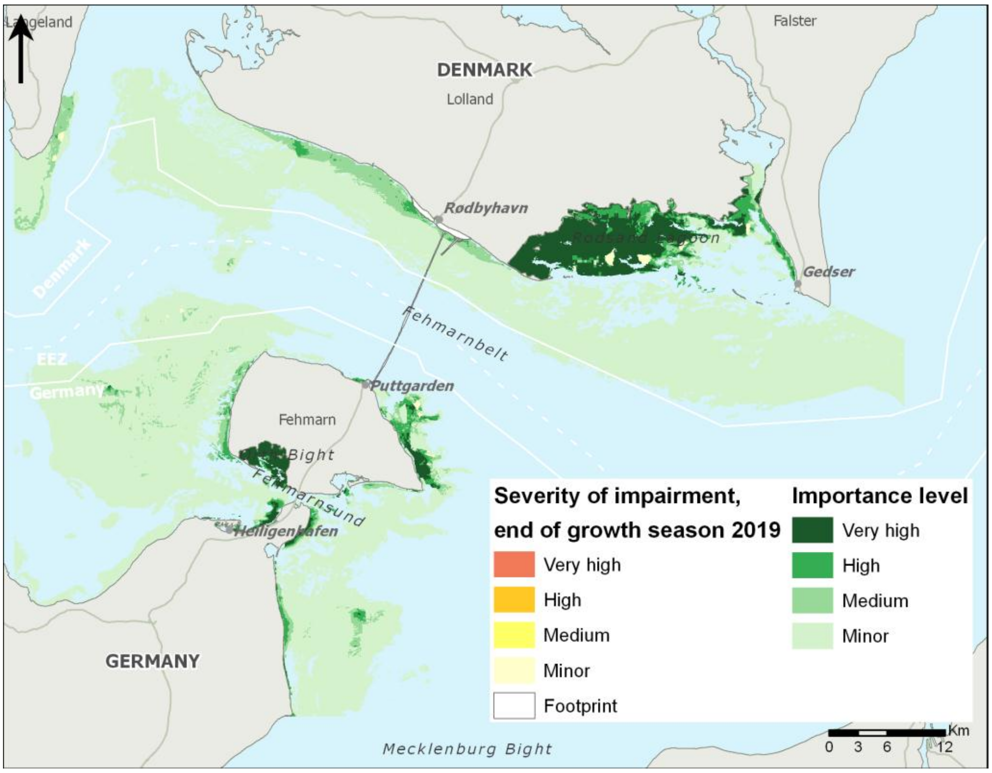
Rødsand Lagoon
Gedser
Fehmarnbelt
Denmark
EEZ
Germany
Puttgarden
Fehmarn
Fehmarnsund
Heiligenhafen
GERMANY
Degree of impairment, end of growth season 2019
Minor
Medium
High
Very high
Footprint
0 3 6 12 Km

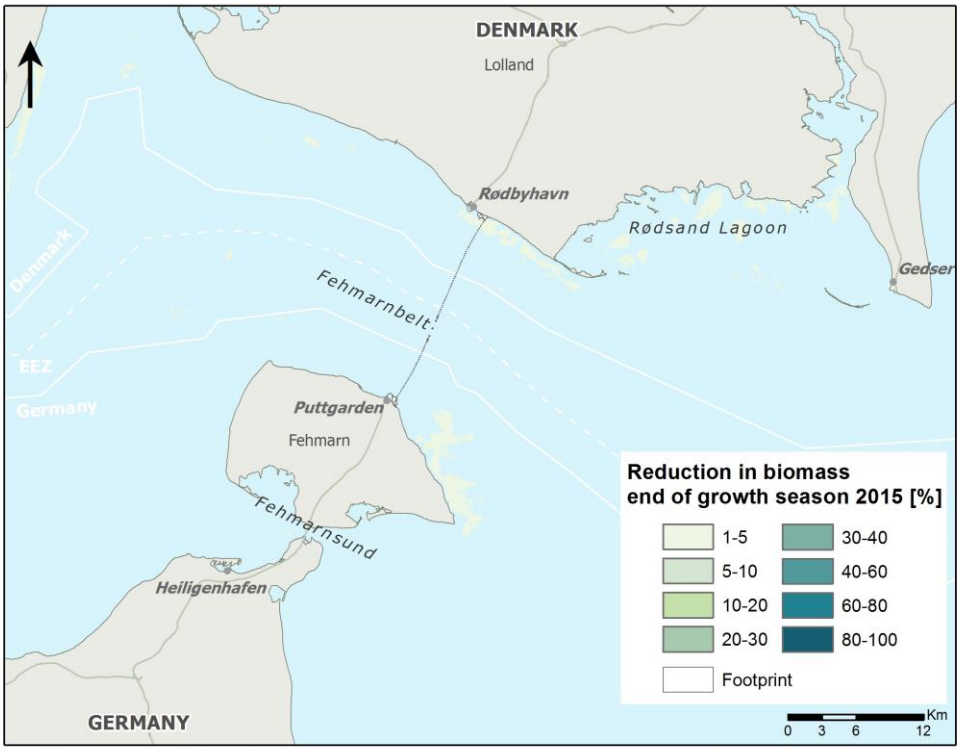
Assessment of tunnel alternative, Severity of impairment

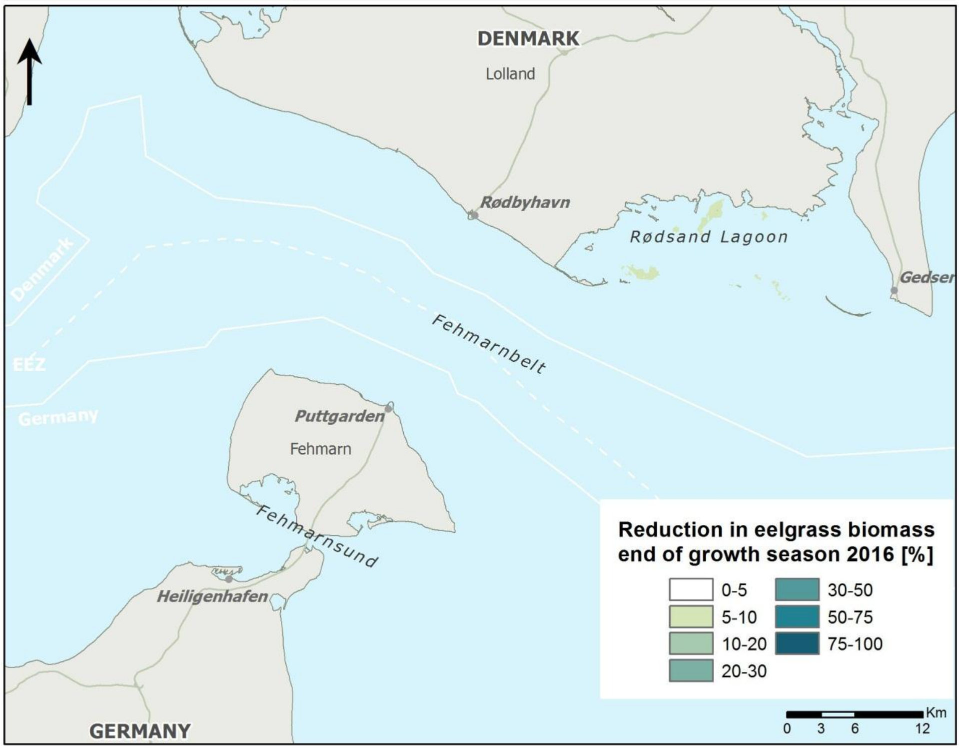


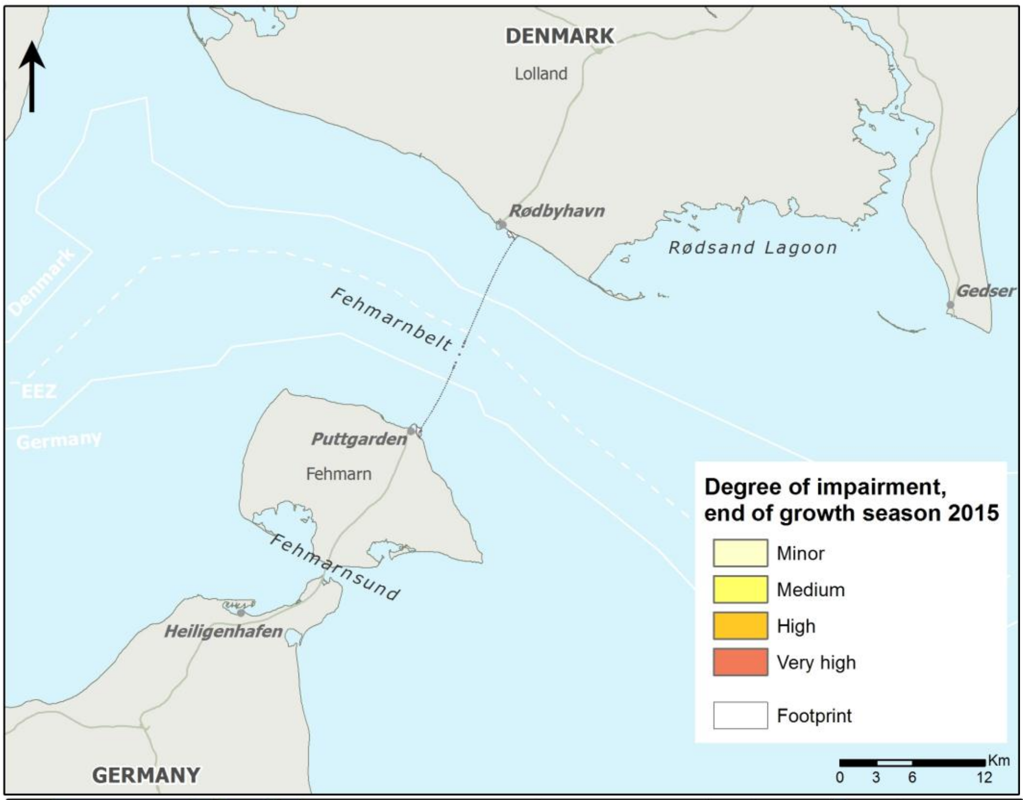


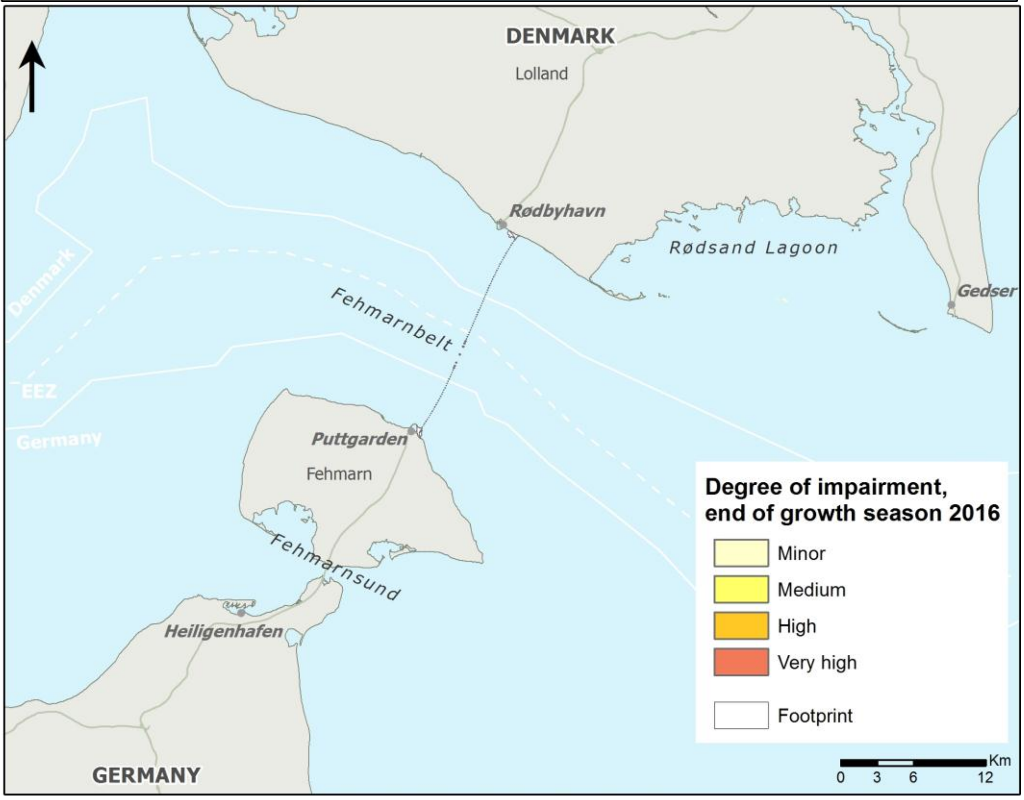

Langeland
DENMARK
Lolland
Falster
Rødbyhavn
Gedser
Denmark
EEZ
Germany
Fehmarnbelt
Puttgarden
Fehmarn
Bight
Fehmarnsund
Heiligenhafen
GERMANY
Mecklenburg Bight
Severity of impairment,
end of growth season 2019
Very high
High
Medium
Minor
Footprint
Importance level
Very high
High
Medium
Minor
Km
0 3 6 12

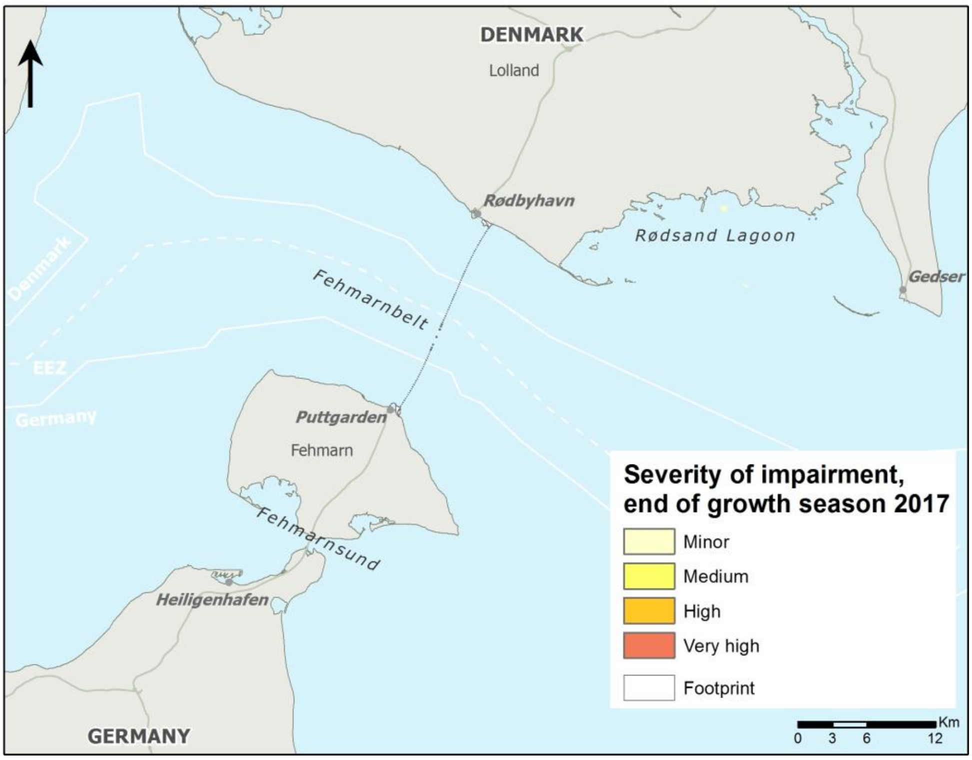
Bridge alternative, reduced biomass, degree of impairment and severity of impairment






DENMARK
Lolland
Rødbyhavn
Rødsand Lagoon
Gedser
Denmark
EEZ
Germany
Fehmarnbelt
Puttgarden
Fehmarn
Fehmarnsund
Heiligenhafen
GERMANY
Degree of impairment, end of growth season 2015
Minor
Medium
High
Very high
Footprint
Km
0 3 6 12


DENMARK
Lolland
Rødbyhavn
Rødsand Lagoon
Gedser
Denmark
EEZ
Germany
Fehmarnbelt
Puttgarden
Fehmarn
Fehmarnsund
Heiligenhafen
GERMANY
Degree of impairment, end of growth season 2016
Minor
Medium
High
Very high
Footprint
Km
0 3 6 12


DENMARK
Lolland
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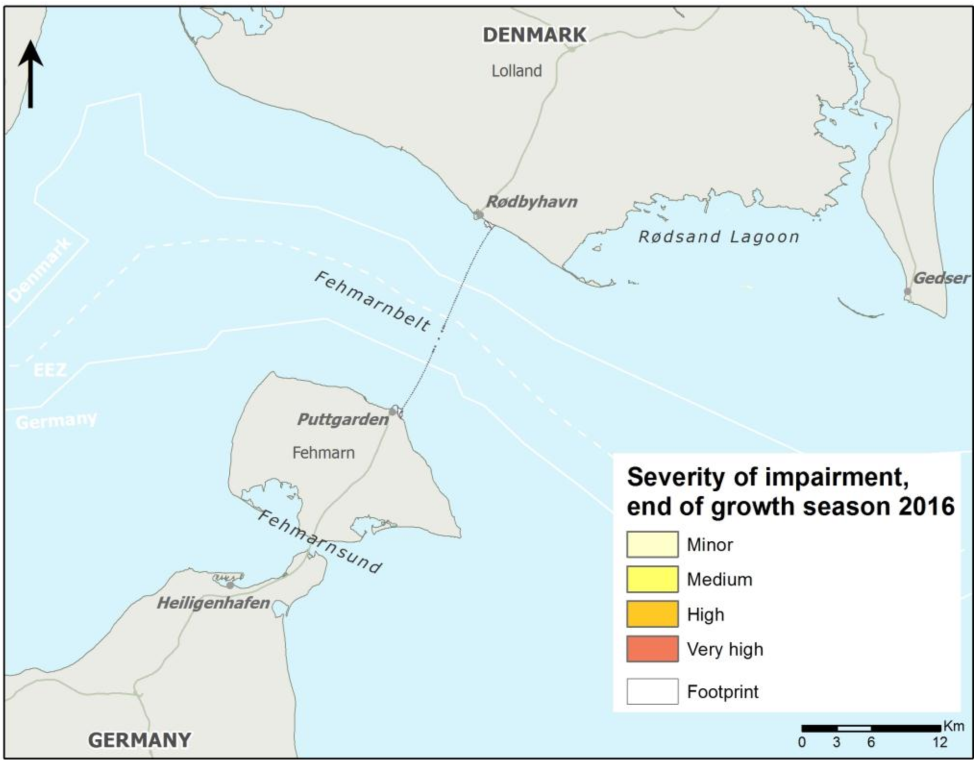
Rødsand Lagoon
Gedser
Fehmarnbelt
Denmark
EEZ
Germany
Puttgarden
Fehmarn
Fehmarnsund
Heiligenhafen
GERMANY
Severity of impairment, end of growth season 2017
Minor
Medium
High
Very high
Footprint
0 3 6 12 Km


DENMARK
Lolland
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Rødsand Lagoon
Gedser
Fehmarnbelt
Denmark
EEZ
Germany
Puttgarden
Fehmarn
Fehmarnsund
Heiligenhafen
GERMANY
Severity of impairment, end of growth season 2016
Minor
Medium
High
Very high
Footprint
0 3 6 12 Km

Table 14-1 Degree of impairment (areas in ha) caused by suspended sediments for the tunnel alternative in 2015. The geographical zone Transboundary is left out as no impacts occur in this zone. No impact on Fucus.

	Total	Near zone	Local zone	DK national + EEZ	DE national	DE EEZ
Eelgrass						
Very high						
High	98			98		
Medium	1922			1922		
Minor	7206			6124	1082	
Eelgrass/algae						
Very high						
High						
Medium						
Minor	891				891	
Furcellaria						
Very high						
High	142	128	4	142	0	0
Medium	604	229	356	604	0	0
Minor	2127	31	1083	2127	0	0
Phycodrys/ Delesseria						
Very high						
High						
Medium						
Minor	487	0	0	467	0	20
Saccharina						
Very high						
High						
Medium						
Minor	122	0	1	61	1	60
Tasselweed/dwarf eelgrass						
Very high						
High						
Medium	22			22		
Minor	135			135		
Filamentous species						
Very high						

	Total	Near zone	Local zone	DK national + EEZ	DE national	DE EEZ
High	11	5	6	11		
Medium	1667	71	698	1667		
Minor	1354	70	340	1349	5	

A P P E N D I X   D

Light attenuation of suspended sediment

Background

Suspended solids such as spilled sediments from dredging operations add to light attenuation in the water column thereby reducing light intensity reaching the seabed, and thus affecting the benthic vegetation. Suspended solids differ in their optical properties, where the organic content, size distribution and shape of particles are important for the mass-specific light attenuation (Baker and Lavelle 1984; Bowers and Binding 2006; Woźniak et al. 2010).

The attenuation of light is the combined effects of two processes in the water column, namely the scattering of light and absorption of light. The scatter of light scales to cross-sectional area of particles (living and dead, inorganic), while the mass-specific scatter (b*) including a diffraction effect can be described by:

$$b^* = \frac{3}{D\rho_P}$$

where D is the diameter of a (spherical) particle and ρP is the density of the particle (Bowers and Binding 2006). Besides area, surface properties of particles such as their refractive index are important for the mass-specific scatter (Babin et al. 2003). It should be noted that in the real aquatic environment, suspended particles are not perfect spheres and the projected area of a natural inorganic particle can easily be an order of magnitude higher than a sphere of similar mass leading to higher mass-specific scatter (Peng and Effler 2007).

Although scattering does not “remove” photons from the water column, scattering is considered a light extinction phenomenon because it increases the path length of photons and thus the probability of photons being absorbed by the absorbing components in the water column.

Several constituents in natural waters can absorb light. Ranged in decreasing order, chlorophyll pigments and other light harvesting pigments in planktonic algae have the highest the mass-specific absorption coefficients, followed by organic matter (living, dead and dissolved), inorganic particles and water itself. If follows from the above, that all particles contribute both to scatter and absorption, but that absorption dominates in organic particles (especially in phytoplankton due to light-harvesting pigments), while scatter dominates in inorganic particles (see Figure App. D-1).

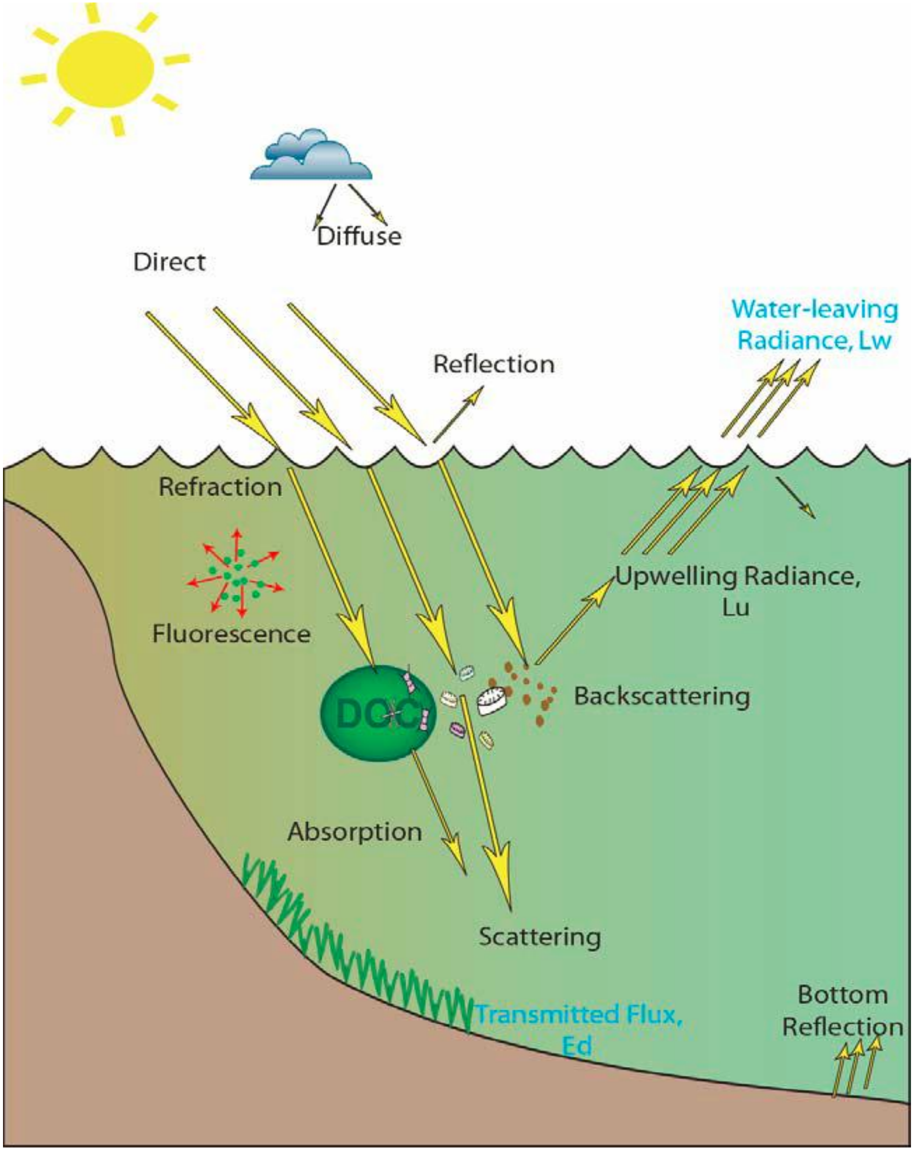

Figure App. D-1 Conceptual figure showing how light is absorbed and scattered in the water column

The combined effect of scatter and absorption of suspended particles on light attenuation varies between and within coastal areas, shelf and off-shore seas, both as a function of differences in concentrations of chlorophyll-a, detritus, inorganic suspended solids and dissolved organic matter, but also caused by variation in the optical properties of suspended particles. In the scientific literature, in situ mass-specific light attenuation coefficient of suspended solids (primarily inorganic) has been found to vary between 0.04 and > 0.5 m2 g-1 (Bowers et al 2009, Campbell and Spinrad 1987, Devlin et al 2008, Dixon and Kirkpatrick 1995, Gallegos 2001, William et al 2002, Lund-Hansen et al. 2010), with highest values in waters dominated by small-sized particles and/or with some contribution of organic matter in the particulate pool (Hill et al 2011). With such a large range in mass-specific light attenuation coefficients "standard" coefficients cannot be applied universally to any dredging situation, as it can lead to serious bias in prediction in effects. Instead, one should use site-specific attenuation coefficients, when predicting effects of sediment spills from dredging works. To this end, three experiments with different sediment types from the alignment area were carried out.

Method

Light attenuation of suspended sediment from two different stations and 3 depth strata was quantified by measuring light transmission in laboratory experiments. Briefly, a 50 W water-proof halogen lamp (beam angle 30-35 degrees) fitted with a BG-34 filter (mimicking the spectrum of natural light) was used as light source, and a Licor LI-192 (π) Underwater Quantum Sensor placed at a distance of 37 cm was used to quantify light intensities. Both the lamp and Licor sensor were fixed to a common bar. The light transmission over time (7-8 sample times over 24 h) was measured in a 100 L circular black-walled container filled with 'artificial' seawater (20 ‰ NaCl) and added suspended sediment. Light intensities were recorded on a LI-1000 Data Logger. Position of sediment samples used in experiments and brief characteristics of whole sediment are shown in Table App. D-1.

Table App. D-1 Position where sediment sample was taken, sediment depth interval and loss on ignition and organic carbon in sediment sample.

Sample	Latitude	Longitude	Sediment depth interval	LOI / DOC (% of DW)
A002-1	54.50950	11.2500	0-30 cm	3.15 / 0.95
A006-1	54.55833	11.30617	0-30 cm	2.96 / 1.07
A006-3	54.55833	11.30617	70-100 cm	1.41 / -

Preparation of sediments

Using a syringe with a cut end subsamples of sediment (approx. 10 ml) from selected sediment strata were transferred to 2 L Erlenmeyer flasks filled with 20 psu 'artificial' seawater and placed on a magnetic stirrer for 12 h. Prior to experiments the stirrer was stopped and larger particles (i.e. fine sand) allowed to settle for 30 min.

Experiment

A subsample (≈ 20%) of the supernatant was added to the 100 L experimental container to reach a final concentration of suspended sediments between 10 and 20 mg/l. After thorough mixing, measurements of light transmission were initiated after 10 min and continued at increasing time intervals until 12-24 h after start. During this period the suspension in the container was left unmixed. Light transmission measured prior to adding suspended solids provided data on 'background' transmission related to artificial seawater only. At termination of an experiment the entire volume of water was filtered through a 1 µm in-line filter connected serially to a peristaltic pump, and the light transmission through filtered water was measured after thorough cleaning of the experimental container. The light transmission through filtered experimental water was carried out to quantify the attenuation due to dissolved organic matter and colloid material originating from the sediments (e.g. from pore water).

Particle sizes

Along with the light transmission measurements, water samples were taken at the depth-level of light beam (3 positions sampled simultaneously using a peristaltic pump) and the particle size distribution (264 bins) was measured using an electronic particle counter (Coulter Counter Multiseizer, fitted with a 70 µm tube measuring range: diameter 1.3 µm – 42 µm), see below. At the start of sampling and at the end 1 L samples from the "light beam" height in the container were filtered onto combusted and pre-weighed 47 mm GF/C filters for determination of suspended solid concentration and Loss on Ignition.

During experiments water was sampled and analysed using an electronic particle counter to quantify concentrations of different sized particles. During the course of an experiment the number and the volume of particles decreased, especially the larger particles, while the reduction in concentration of small particles below 2-3 µm was much less (Figure App. D-2) due to a lower settling velocity.

After subtraction of the attenuation value from filtered experimental water, the attenuation of light due to particles was related to concentration of suspended solids described by the total volume (summed for all size classes of particles), and the cross-sectional area of particles (summed for all size classes), assuming that particles were present as spheres. The attenuation by dissolved organic matter (in post-filtered experimental water) was related to the initial particle volume and initial dry weight of suspended matter in the individual experiments.

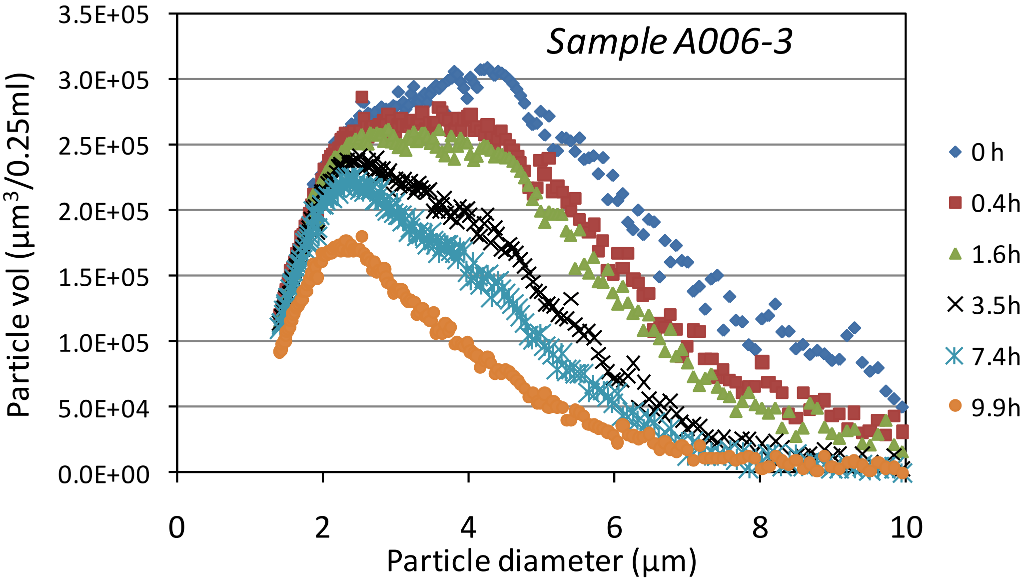

Figure App. D-2 Size distribution of particle volume over incubation time (0-9.9h) in light attenuation experiments using suspended sediments from sample A006-3 (Station A006; 90-120 cm depth). Concentration of 6 µm particles is reduced by 90% after 9.9h at depth of light path, while 1.5 µm particles are reduced by 12-15% only, due to a lower settling velocity.

Results

Light attenuation varied between sediment samples due to differences in concentration and size distribution, and, caused by variation over time, due to differential settling of different sized particles (Figure App. D-3).

For the individual experiments with the same sediment type, the light attenuation coefficient scaled almost linearly to the total particle volume, but relations differed markedly between experiments with different sediment types, because of different size distribution between sediments from station A002 and station A006 (Figure App. D-3, upper).

In contrast, if attenuation was plotted against total cross-sectional area of particles all samples fitted to a common line, irrespective of differences in size distribution (Figure App. D-3, lower panel). The fact that light attenuation scaled linearly to cross-sectional surface area of particles is a strong indication that attenuation primarily is due to light scattering rather than absorption.

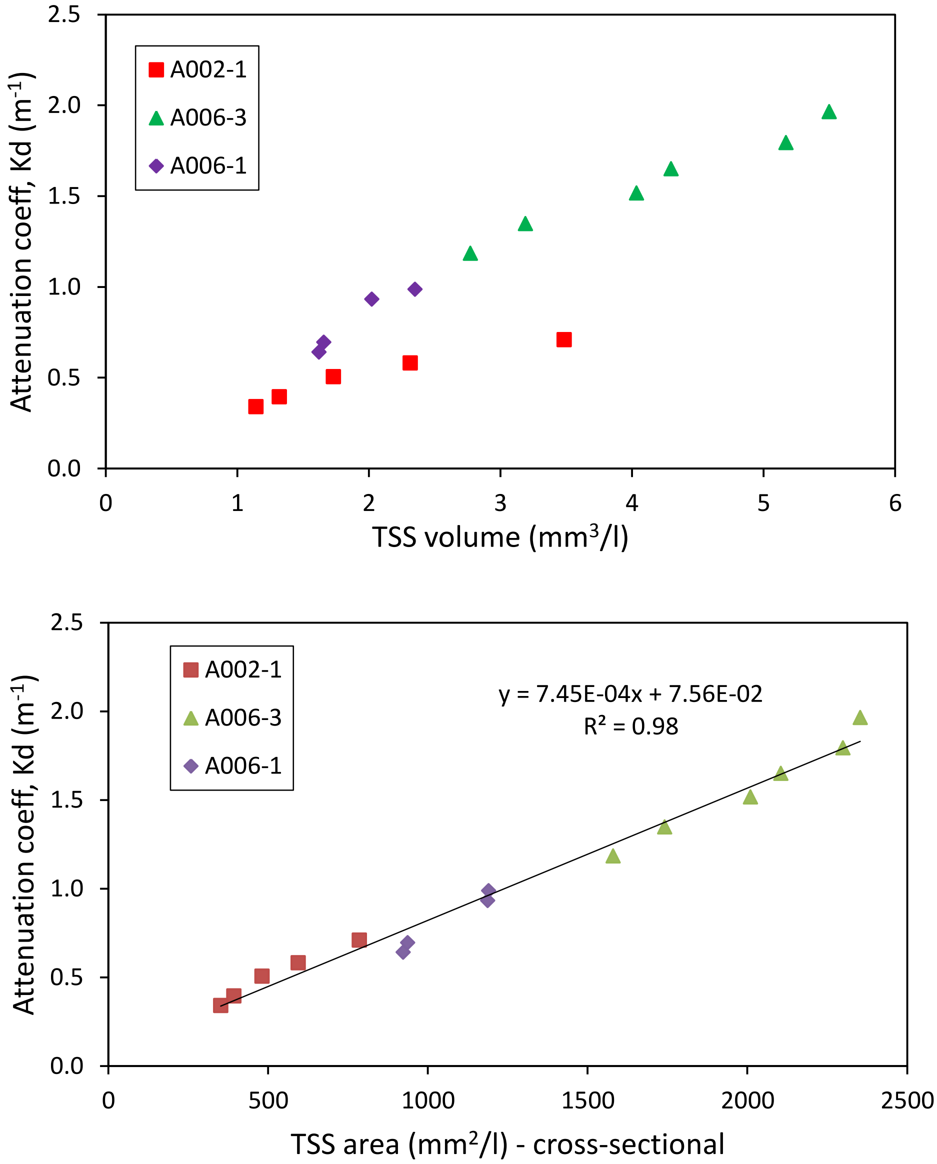

Figure App. D-3 Light attenuation coefficient, Kd as function of total (summed) particle volume (upper panel) and total cross-sectional particle area (lower panel). Common linear regression line and equation relating summed cross-sectional area and Kd shown for the 3 experiments conducted.

Based on the results of the above-described experiments, sediment and size-specific attenuation coefficients for model predictions were established.

A P P E N D I X   E

Photosynthesis – irradiance experiments for macroal-gae

Background

Seasonal growth dynamics of macroalgae and relationships between changes in light availability (e.g. incremental concentration of suspended sediment) and photosynthesis and growth rates are typically modelled via a lumped description of one species. Hence the level of uncertainty in a quantitative impact assessment is relatively high. In order to reduce the uncertainty, and to model species-specific growth rates and light dependences as an integral part of the ecological prediction modelling complex, photosynthesis-light relationships for key- macroalgae species was experimentally determined and incorporated in the ecological model.

Macroalgae grow in patches on solid substrate, which is represented by stone coverage in the model. Biomass within communities can be high, even though the biomass per m^2 estimated by the model within the individual model grids is low, due to the depiction of suitable substrate in the model domain. In dense communities, photosynthesis and growth can be limited by low light availability caused by self-shading within the community. Photosynthetic characteristics of plants therefore change with scale so that the relationship between photosynthetic production and irradiance (P-I) of a single thallus piece cannot be used directly in numerical models without accounting for the effect of self-shading. The actual light absorption and utilisation in macroalgae depends on the canopy structure and density.

Light utilisation per biomass depends on how even the irradiance is distributed in the canopy. Maximum photosynthesis per area is obtained when light is distributed and absorbed evenly among photosynthetic tissue in the canopy, so that each of them experience irradiance below saturation. And there will be an almost linear relationship between photosynthesis per area and incident light up to high light intensities. However, if the irradiance is unevenly distributed so that most light is absorbed at high intensities in the upper layer, photosynthesis per area will gradually saturate.

Self-shading can be described by the species-specific light attenuation per biomass in key-species communities. Additional measurements of community photosynthesis (e.g. photosynthesis per area) provide data on the relationship between photosynthesis and irradiance at the same scale as the model.

The aim with the conducted experiment was to provide input to the model on a) self-shading and on b) photosynthesis-irradiance curves for key-species in the Fehmarnbelt area on thallus and community scale.

Methods

Three different species of macroalgae was collected by diver in Fehmarnbelt in April-May 2010. The red algae *Furcellaria lumbricalis*, *Delesseria sanguinea* and *Ceramium virgatum* was chosen to represent the dominant shallow and deep water species and the filamentous species that are widespread in both shallow and deep water in Fehmarnbelt. The algae also differ in form and morphology. Prior to experiments they were kept in aerated buckets with seawater at 4° C. Most experiments were conducted within a few days after collection. In few experiments algae were used on the fifth or sixth day after collection, and in those cases the activity of the algae was checked before experiments by comparing their photosynthetic rates with measurements made within the first four days. If there was any discrepancy between photosynthetic rates before and after the fourth day, the algae were discarded. Large epiphytes were removed but small epiphytes were left to avoid breaking the algae.

Photosynthetic production of thallus pieces.

A closed cylindrical Plexiglas chamber (50 ml) was used for measuring the photosynthesis-irradiance response of thallus pieces. Measurements were performed in natural seawater from Fehmarnbelt, kept close to 16° C, by performing the experiments in a 16° C thermostatically regulated room. Algae were fixed vertically on a plastic net in the chamber and stirring was assured by a magnetic stirrer bar. Irradiance was supplied by a Philips IP65, 250 W HPI Plus lamp and variable irradiance (~ 0, 20, 40, 60, 100, 150, 230, 360 µmol photons m^{-2} s^{-1}) was obtained by inserting neutral density filters between the lamp and the chamber. Temperature was recorded before and after the experiment. Temperature changes were less than 0.1 °C min^{-1} and had no significant influence on the calculated photosynthetic productions.

Photosynthetic production and respiration were measured as oxygen evolution rates by means of a Clark-type microsensor (Revsbech and Jørgensen 1986) connected to a picoamperemeter (Unisense, Denmark). The microsensor has a linear response to increasing oxygen concentration and was calibrated from readings in air-saturated and oxygen-free seawater of constant temperature (16°C). The electrode output was logged on a computer.

Net photosynthesis and respiration were calculated from the linear slope of the curve describing the oxygen concentration versus time when constant rates had been obtained. Gross photosynthesis (*GP*) was calculated as the sum of net photosynthesis and dark respiration ($GP = NP + R$), assuming that dark respiration continued unaltered in the light. Measurements were expressed per unit biomass.

The photosynthesis versus irradiance curves (P-I curves) were characterised by the following photosynthesis parameters. The photosynthetic efficiency at low irradiance (α: mol O2 mol−1 photons) was determined as the initial linear slope between photosynthesis and irradiance at light limitation. This was analysed by a linear regression at irradiances up to 60 µ photons m^{-2} s^{-1}. The photosynthetic efficiency was also used to calculate the light compensation point ($I_c = R/α$) at which gross photosynthesis and respiration are of equal magnitude and net oxygen exchange is zero. The maximum rate of gross photosynthesis (GP_{max}) was determined at light saturation. The onset of light saturation (I_{sat}) was estimated as $GP_{max}/α$.

Photosynthetic production of communities

The photosynthetic production in the algal communities was measured in 27 l glass chamber using the same principles as for thallus pieces. Intact specimens of the 3 different algae were placed in the chamber using sucker discs. The photosynthesis-irradiance relationship was measured at three different plant densities.

The photosynthesis chambers were placed in a thermostatically controlled room to maintain constant temperature and stirring was ensured by 2 submersible pumps. The light source consisted of a 400 W high pressure sodium lamp. Variable irradiances (~0, 30, 70, 130, 300, 500, 750, 1100 µmol photons m–2 s–1) were obtained by inserting neutral filters. All experiments were performed at 16 ± 0.5 °C.

Irradiance above and below the canopy was measured with a calibrated spherical quantum sensor (Biospherical Instruments Inc., San Diego, CA,, USA). Irradiance was measured at nine positions in the photosynthesis chamber. For each position light was measured just below the surface, above and below the canopy. Irradiance measurements were done at 3 densities for each species.

Photosynthesis was measured and logged as described for thallus pieces. Community density was measured as wet weight and converted to dry weight after establishment of the relationship between wet weight and dry weight.

The same terminology and methodology were used to determine the photosynthetic parameters for community photosynthesis as for thallus pieces.

Self-shading

Self-shading was described by the light attenuation per unit biomass. To estimate the specific irradiance extinction per g DW (K, g DW^{-1}), irradiance was measured below the canopy at 3 different biomass densities. The biomass specific attenuation coefficient (K, g DW^{-1}), was determined by fitting irradiance data to an adapted version of Beer's law, where depth in meters are replaced by the optical depth in the community measured as biomass above the measuring point, $I = I_0\ e^{-K \times b}$. Where I_b, I_0 and b is the irradiance below and above the biomass and b is the biomass.

All experiments were done as triplicates.

Results

Self-shading

Self-shading expressed as irradiance extinction per biomass ranged between 0.003 and 0.006 g DW^{-1} (Table App. E-1). An example of the relationship is shown in Figure App. E-1. The results reflect the differences in thallus structure and branching of the species. *Furcellaria* has a thick thallus and few branches. This species had the lowest extinction per biomass. However, *Delesseria* and *Ceramium* are both more delicate species. Attenuation per biomass was found to be at a similar level for those two species.

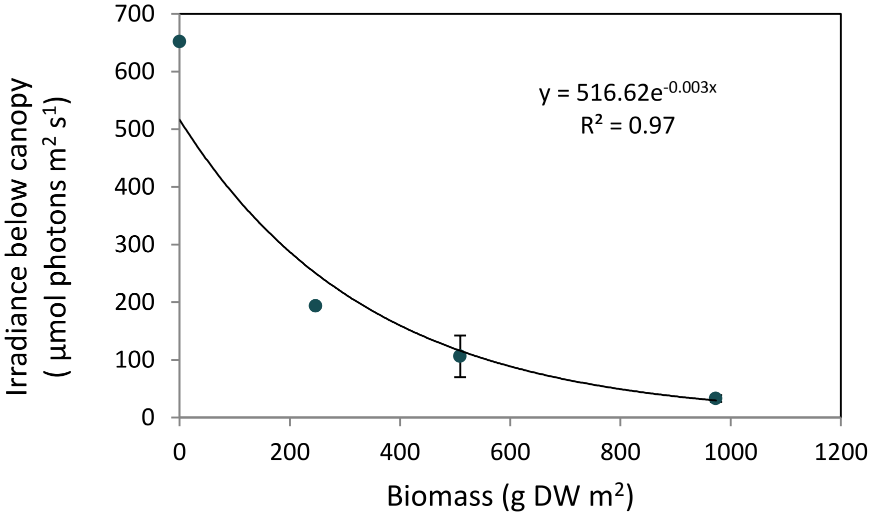

Figure App. E-1 Irradiance below the canopy as a function of biomass above the measuring point for the Furcellaria community.

Table App. E-1 Irradiance extinction per g DW for the three algae species Furcellaria, Ceramium and Delesseria. R2 = 0.99 in all three cases.

Species	**Irradiance extinction** ($K_{(g\ DW)}$, g DW^{-1})
Furcellaria lumbricalis	0.003
Ceramium sp.	0.006
Delesseria sanguinea	0.006

Photosynthesis-irradiance relationships

The P-I curves for all three algal species followed the well-known hyperbolic relation (Figure App. E-2).

The parameters describing the curves were nevertheless quite different in the three species: the specific photosynthesis/irradiance ration (α) ranged from 0.0004 to 0.012 µmol O_2 g DW^{-1} µmol photons^{-1}, while GP_{max} ranged from 0.044 to 0.12 µmol O_2 g DW^{-1} s^{-1} (Table App. E-2). As can be seen, *Furcellaria* had the lowest photosynthetic activity whereas *Ceramium* had the highest.

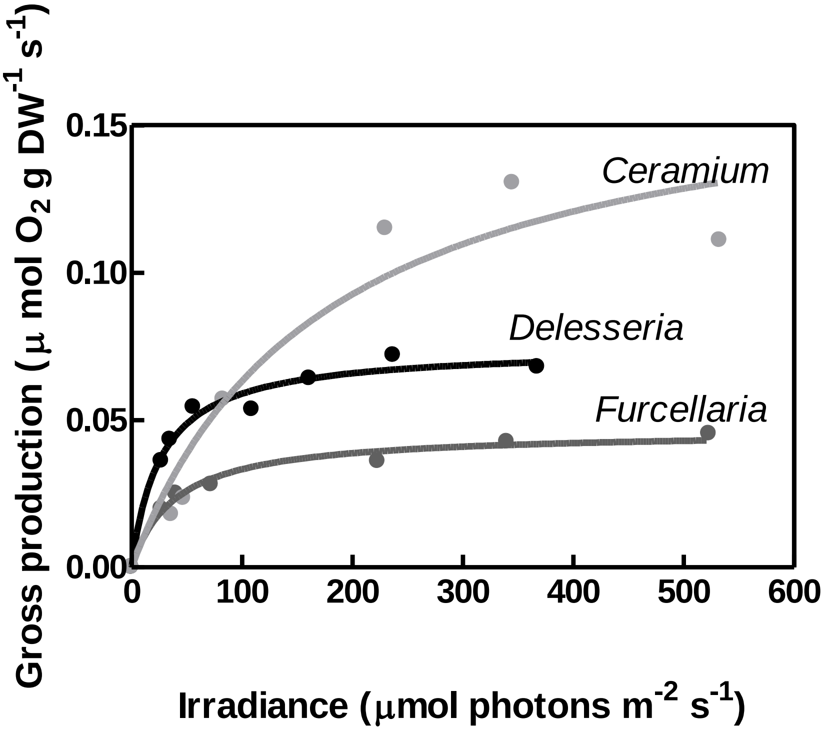

Figure App. E-2 Specific gross photosynthesis as a function of irradiance for thallus pieces of the three macroalgae.

The onset of light saturation (*GP*max /α) ranged from 73 to 178 µmol photons m^{-2} s^{-1} and the light compensation point was between 8 and 17 µmol photons m^{-2} s^{-1}.

Table App. E-2 Photosynthetic characteristics of the thallus from the three algae species.

	GP_{max} µmol O_2 g DW^{-1} s^{-1}	α µmol O_2 m^2 g DW^{-1} µmol $photons^{-1}$	R µmol O_2 g DW^{-1} s^{-1}	I_k µmol photons m^{-2} s^{-1}	I_c µmol photons m^{-2} s^{-1}
Furcellaria lumbricalis	0.041 (0.01)	0.0004 (0.0002)	-0.003 (0.002)	102 (66)	8 (1)
Delesseria sanguinea	0.068 (0.02)	0.001 (0.0004)	-0.0067 (0.0074)	73 (23)	6 (4)
Ceramium virgatum	0.12 (0.02)	0.0007 (0.0002)	-0.012 (0.007)	178 (44)	17 (13)

The curve of photosynthesis in relation to irradiance for communities with a single-species had a markedly different shape than what was found for thallus pieces (Figure App. E-3). Since respiration increases at the community scale (Table App. E-3), the compensation irradiance also increased so that I_c was higher than for thallus pieces, and increased with density. Also irradiance at the onset of saturation increased with density. Photosynthesis saturated at high irradiance in the *Delesseria* community and in less dense *Fur-*

cellaria communities, while the high density *Furcellaria* community and *Ceramium* did not reach the saturation point for irradiance.

Table App. E-3 Photosynthetic characteristics of the three algae species on a community level.

	GP_{max} µmol O_2 m^{-2} s^{-1}	α µmol O_2 µmol photons $^{-1}$	R µmol O_2 m^{-2} s^{-1}	I_k µmol photons m^{-2} s^{-1}	I_c µmol photons m^{-2} s^{-1}
Furcellaria lumbricalis					
250 g DW m^{-2}	6.1 (0.46)	0.045 (0.02)	-0.85 (0.3)	142 (34)	19 (1.1)
500 g DW m^{-2}	10.5 (0.96)	0.070 (0.02)	-1.6 (0.2)	158 (45)	23 (1.8)
1000 g DW m^{-2}	16 .2 (0.84)	0.067 (0.03)	-3.5 (1.0)	162 (40)	34 (3.6)
Delesseria sanguinea					
50 g DW m^{-2}	4.7 (0.69)	0.03 (*)	-0.4 (0.1)	134(*)	10 (*)
100 g DW m^{-2}	6.1 (0.95)	0.05 (0.01)	-0.6 (0.2)	143 (35)	12 (2)
200 g DW m^{-2}	11.5 (0.57)	0.07 (0.02)	-2.1 (0.2)	180 (42)	33 (9)
Ceramium virgatum					
75 g DW m^{-2}	8.5 (1.6)	0.038 (0.015)	-1.03 (0.3)	232 (56)	27 (6.6)
125 g DW m^{-2}	13.0 (5.8)	0.050 (0.007)	-1.54 (0.5)	265 (86)	28 (6.1)
250 g DW m^{-2}	15.8 (4.0)	0.057 (0.009)	-2.5 (0.8)	287 (103)	43 (11)

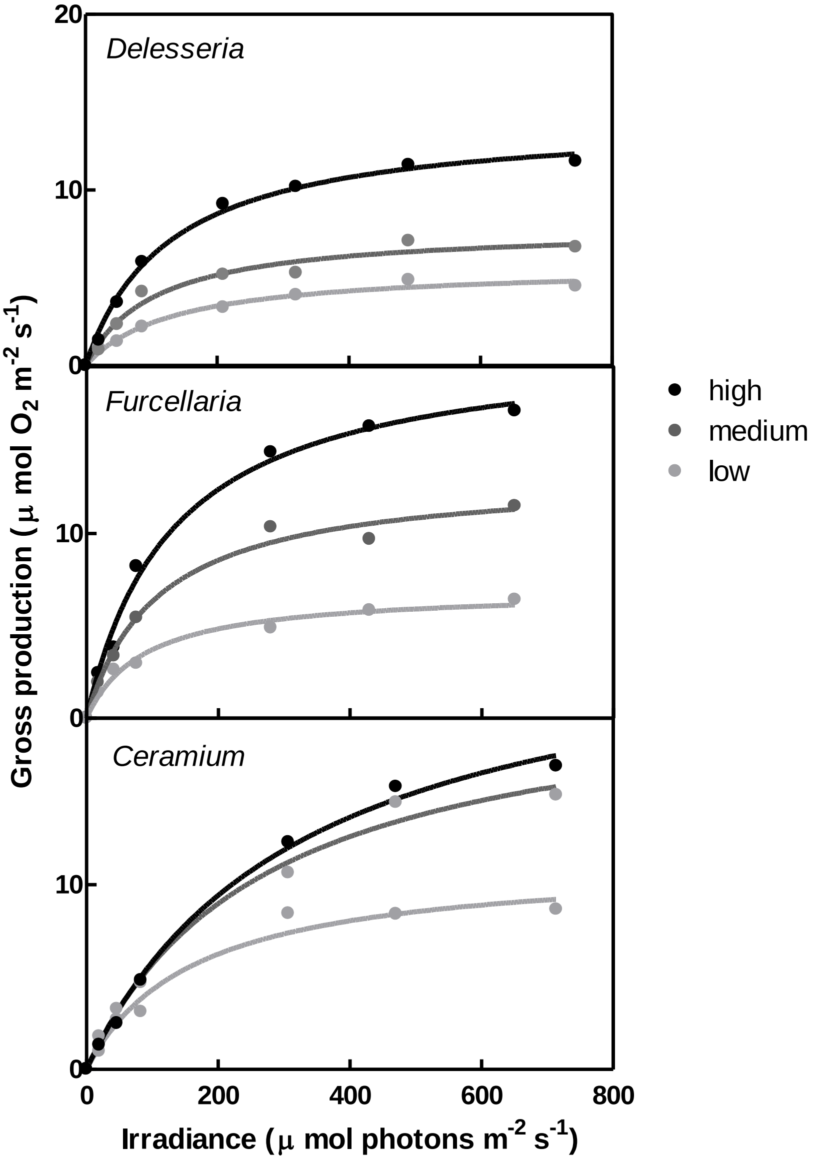

Figure App. E-3 Relationships between irradiance and production on community level