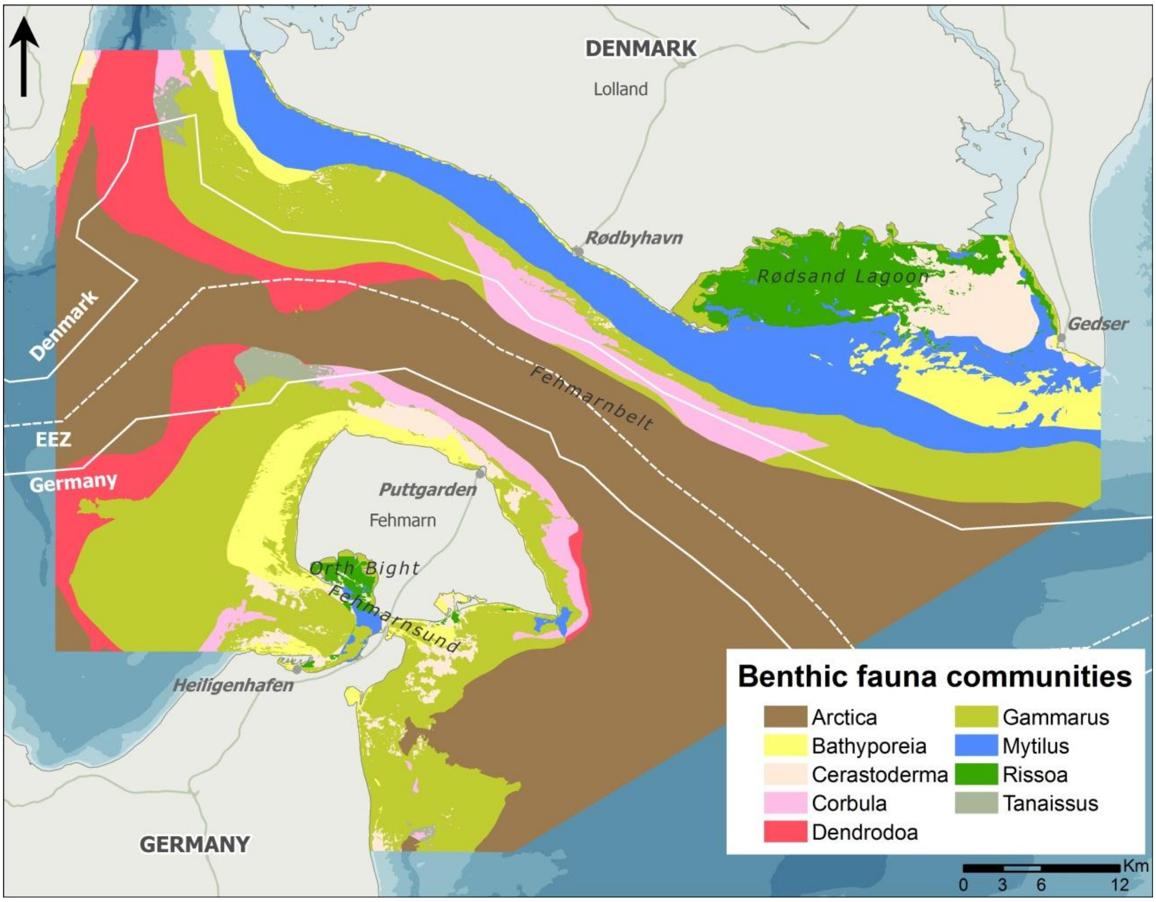
Final Report

FEHMARNBELT FIXED LINK
Marine Biology Services (FEMA)

Marine Fauna and Flora – Impact Assessment

Benthic Fauna of the Fehmarnbelt Area

E2TR0021 - Volume II



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Acronyms and abbreviations

AFDW – Ash free dry weight

BHD – Backhoe Dredgers

CI – Condition index

EEZ – Exclusive economic zone

EIA – Environmental Impact Assessment

GD – Grab dredgers

ME – Model efficiency

MOP – Magnitude of pressure (see section 1)

MSFD – Marine Strategy Framework Directive

PAH – Polycyclic Aromatic Hydrocarbons

PCB – Polychlorinated Biphenyls

TBT – Tributyltin

UVS – Umweltverträglichkeitsstudium (German term for EIA)

VVM – Vurdering af Virkninger på Miljøet (Danish term for EIA)

WFD – Water Framework Directive

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APPENDICES

A Risk assessment of the 23 known non-indigenous species

B Description of the numerical model for the mussel population

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).

EXECUTIVE SUMMARY

Present report

Denmark and Germany are planning a Fixed Link between Denmark and Germany across the Fehmarnbelt. One important part of this work is to prepare an Environmental Impact Assessment (in Denmark VVM and in Germany UVS) in order to get approval of the project by the authorities in Denmark and Germany. This report is Volume III of a number of background reports forming the base of the Environmental Impact Assessment (EIA) for the Fehmarnbelt Fixed Link and presents the impact assessment for marine benthic fauna communities in the Fehmarnbelt area of identified pressures resulting from the construction, operation and structure of the Fixed Link.

Fauna communities

The benthic fauna communities of Fehmarnbelt are categorised into nine in- and epifauna communities (FEMA 2013a). The communities have been classified according to the presence of specific characteristic species and the abundance, biomass and importance of all community species for the community structure. Each particular benthic fauna community has been named according to a discriminating species of that community. The communities are the basic entities on which the impact assessment is based (Figure 0.1).

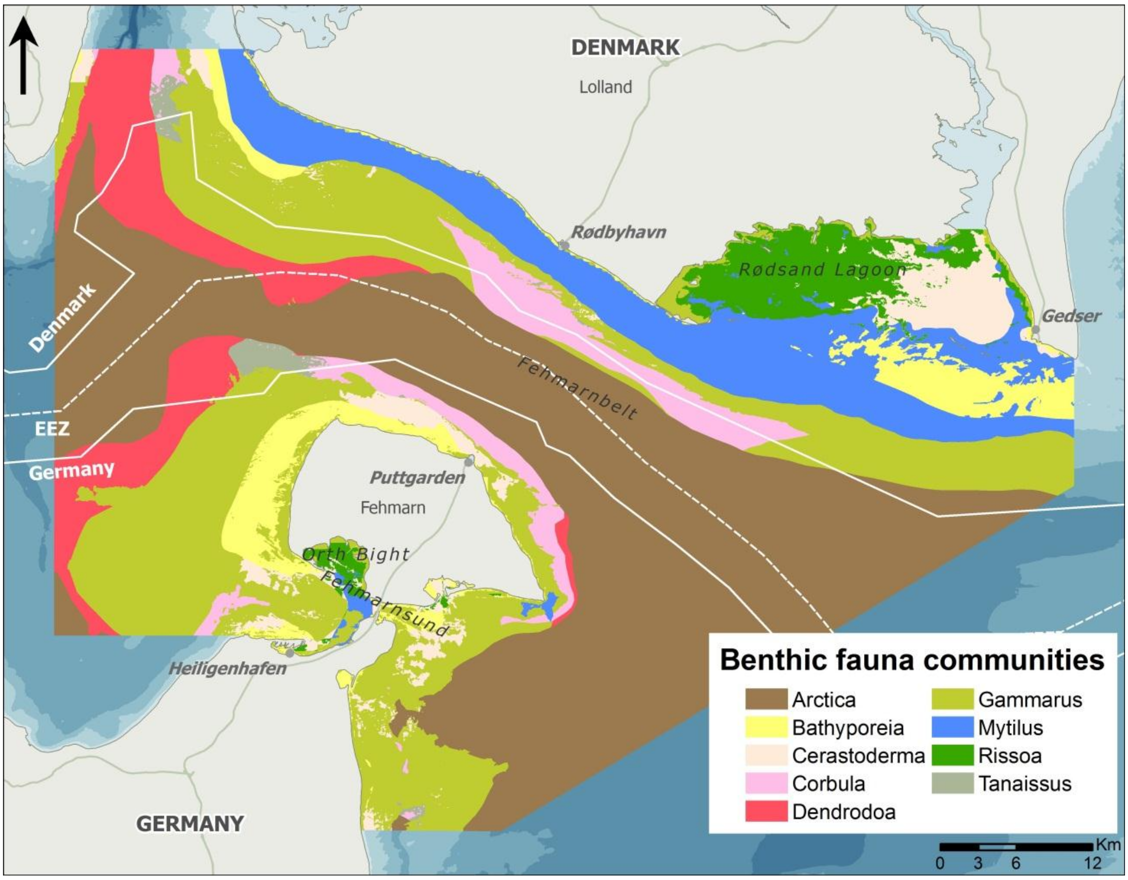


Figure 0.1 Predicted spatial distribution of the benthic fauna communities in Fehmarnbelt.

Project pressures

Nine pressures have been determined to have a potential impact on the benthic fauna (Table 0.1), four of the pressures are acting in the construction phase, four pressures are due to the project structures and one pressure is acting during the operation phase.

Table 0.1 Potential pressures on the benthic fauna communities from the Fixed Link across the Fehmarnbelt.

Phase	Pressure	
Construction	Suspended sediments	All kind of solid particulate sediments (solids) that are suspended in water, including other possible suspended particles that are contained in the sediment.
	Sedimentation	All kind of material that is spilled and deposits on the seabed during the construction works.
	Toxic substances	All substances harmful to living organisms, either by killing (poison) or damaging them.
	Construction vessels and imported material	All kind of material with an origin outside the assessment area. This is e.g. sand from sand extraction sites or stones from land or marine areas.

Structure	Footprint	Areas that will be lost temporarily or permanently due to constructions like reclamation areas, ramps, pillars or the tunnel trench.
	Solid substrate	All structure-related solid structures that are located underwater and are available as potential settling ground for marine organisms.
	Seabed and coastal morphology	The spatial distribution and appearance of the seabed from the largest depths and to the coastline.
	Hydrographic regime and water quality	Current speed, salinity and temperature of the bottom waters.
Operation	Drainage	Freshwater outlets coming from the accumulation of water from the project structures.

Assessment methods and data
The EIA assessment area is 292,739 ha and identical to the investigation area of the baseline survey. Two zones are defined within the area: a near zone which extends 500 m around all project structures during the construction phase (500 m on each side on the alignment), and a local zone which is 20 km wide around the alignment (and not including the near zone).

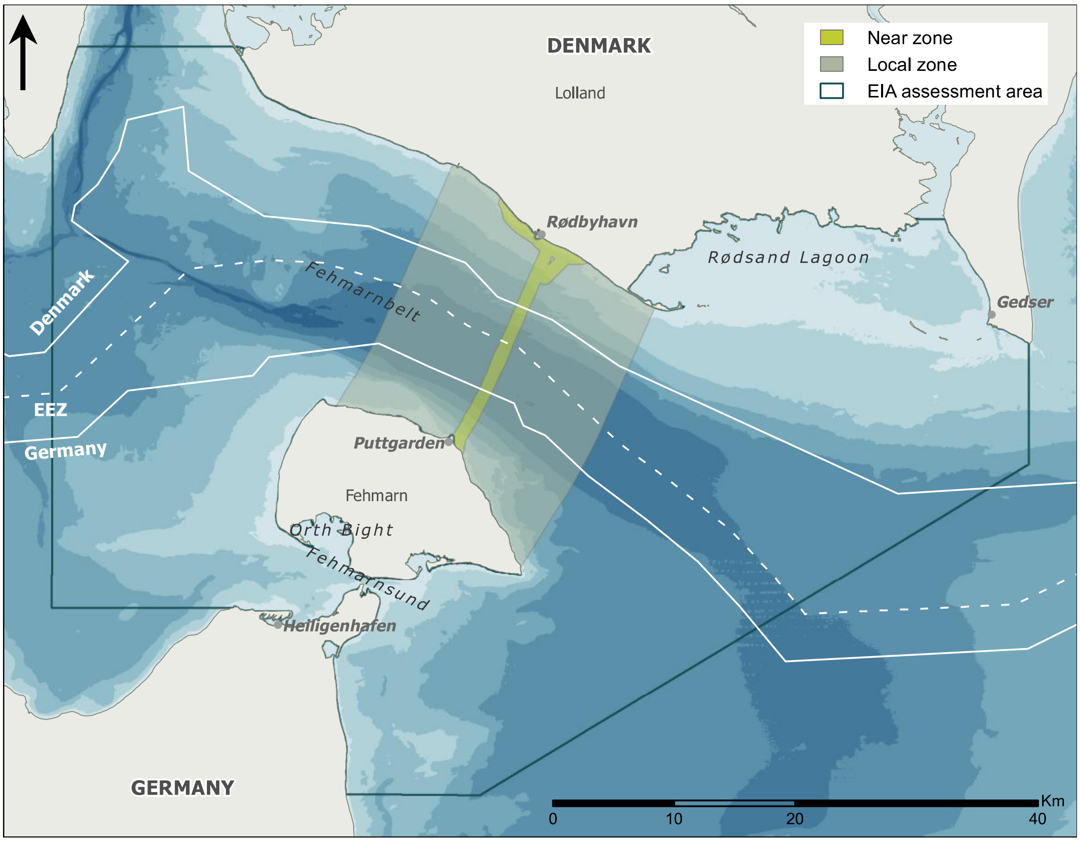


Figure 0.2 Tunnel assessment: Geographical borders of the complete EIA assessment area, and near zone and local zone for the tunnel alternative.

Besides this biological differentiation, a distinction into administrative zones (national, coastal, EEZ) and into buffer zones around the alignment and the project (near and local zone) is made. The location of the zones with respect to the EIA assessment area is shown in Figure 0.2 for the tunnel alternative and in Figure 0.3 for the bridge alternative. Besides these, also a distinction into national administrative zones and into the fauna communities is used.

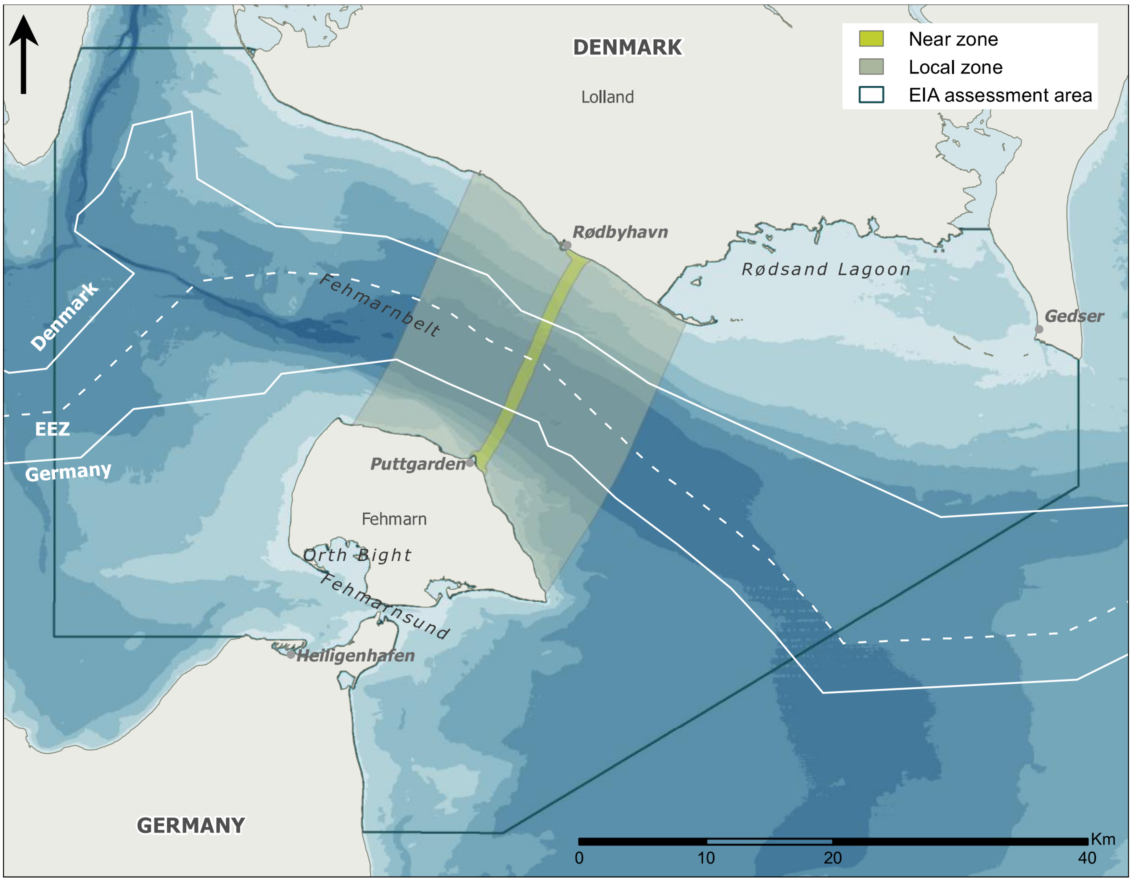


Figure 0.3 Bridge assessment: Geographical borders of the complete EIA assessment area, near zone and local zone for the bridge alternative.

Generally, the impact assessment is done using the following five distinct steps for each pressure and each of the design alternatives (immersed tunnel and cable stayed bridge):

1. Determination of the abiotic *magnitude of pressure*
2. Determination of the biotic *sensitivity* of the fauna communities towards the pressure
3. Derivation of the *degree of impairment* or the *severity of loss*, depending on the magnitude of pressure
4. Assessment of the *severity of impact* (either impairment or loss)
5. Assessment of the *impact significance*

In steps 1 to 4 a classification into four categories (minor, medium, high and very high) is used in order to rate the results.

An exception to the general assessment scheme is the result for the pressure suspended sediments on the mussel population (*Mytilus edulis*) that is obtained via numerical modelling and directly yields *degree of impairment* measured as the reduction in mussel biomass. Also, one aspect of the pressure solid substrate where *sensitivity* does not apply is assessed differently.

The degree of impairment (step 3) determines the biological reaction of the fauna communities to the pressure and thus the environmental impact. The impact can have a varying severity, depending on the importance and biological characteristics of the affected fauna communities (step 4). The significance assessment determines the spatial extent of the impacts in relation to a comparison zone (20 km corridor around the alignment) as well as the duration and relevance of the impact (step 5). This determines the environmental significance and relevance of the impact.

Magnitude of pressure
The magnitude of pressure is analysed for each of the nine pressures. The pressures which have a magnitude ranging within the natural variability or below a legal threshold value are rendered negligible and thus not considered further in this assessment since they do not exhibit any threat to the benthic fauna. This is the case for the following pressures:

- Toxic substances – magnitude is below national and international guidelines and regulations
- Construction vessels and imported material – no enhanced risk of introduction of non-indigenous species
- Seabed and coastal morphology – changes are within natural variability and only affect small regions within the assessment area
- Hydrographic regime and water quality – changes are within natural variability and only affect small regions within the assessment area
- Drainage – changes are within natural variability and only affect small regions within the assessment area

Four pressures have magnitudes of pressure that may exceed natural levels and are thus assessed in detail. These pressures are: suspended sediments, sedimentation, footprint and solid substrate (Table 0.2).

Table 0.2 List of the four pressures on the benthic fauna communities that are treated with a detailed assessment.

Phase	**Pressure**	**Pressure indicator**	**Method and data input**
Construction	Suspended sediments	Dilution of suspended food particles Abrasion and/or clogging of filtration organs (mg l^{-1} suspended sediment concentration in the near-bottom layer and days of duration, community-dependent)	GIS analysis Ecosystem modelling (impact on mussels) Data input: Modelled sediment spill Benthic community map Data on sensitivity
	Sedimentation	Burial by sediment (depth, duration and deposition rate – impact is community dependent)	GIS analysis Data input: Modelled sediment spill Fauna community map Data on sensitivity
Structure	Footprint	Footprint area on top of the present benthic fauna communities	GIS analysis Data input: Footprint map Importance map

Phase	Pressure	Pressure indicator	Method and data input
	Solid substrate	Increase in solid substrate area available for new colonisation Deposition of organic matter and muddy material on the surrounding soft-bottom communities Solid substrate as vector for non-indigenous species	GIS analysis Qualitative and quantitative analysis Data input: Data on additional solid substrate Fauna community map Data on sensitivity

Furthermore the indirect assessment of the impact on the benthic fauna due to reduction of eelgrass biomass in some areas and the impact on biodiversity is additionally assessed.

Impact assessment
Table 0.3 summarizes the principal assessment criteria used. The column "Possible impacts" can be loss of function or impairment of function and corresponds to "severity of loss" and "degree of impairment". The magnitude of pressure is categorized into four classes as described above.

Table 0.3 Criteria for the assessment of pressures.

Phase	Pressure	Possible impact	Magnitude of pressure
Construction	Suspended sediments	Very high change of viability and food availability, high mortality	very high
		High change of viability and food availability, low mortality	high
		Minor to medium change of viability and food availability	medium
		Minor change of viability and food availability	minor
Construction	Sedimentation	Very high change of viability and food availability, high mortality	very high
		High change of viability and food availability, low mortality	high
		Minor to medium change of viability and food availability	medium
		Minor change of viability and food availability	minor
Construction	Toxic substances	Case-specific criteria	case-specific
Construction	Construction vessels and imported material	Case-specific criteria	case-specific
Structure	Footprint	Habitat loss. The criteria correspond to the importance of the communi-	very high

Phase	Pressure	Possible impact	Magnitude of pressure
		ties	
Structure	Solid substrate	Case-specific criteria based on - the amount on existing solid substrate in a specific distance from the structure - water depth - local change of currents suitability of the solid substrate - potential for non-indigenous species	case-specific
Structure	Seabed and coastal morphology	Habitat loss. The criteria correspond to the importance of the communities	case-specific
Structure	Hydrographic regime and water quality	case-specific criteria: - baseline situation of communities - predicted changes in salinity, temperature, oxygen and currents - sensitivity of the communities against changes in these parameters	
Structure	Drainage	case-specific	case-specific

0-alternative
All impacts from the construction phase are compared to the baseline conditions without forecasting. Impacts from the operation phase should be assessed as projected into the years 2025 and 2030. For benthic fauna, this projection would be identical to the baseline conditions and additionally include the WFD and the MSFD realisation. This is impossible with the required level of confidence. As a consequence, a projection into the years 2025 and 2030 is not done and the baseline conditions serve as the 0-alternative. The impacts from the operation phase on the marine benthic fauna are assessed by comparison with the baseline conditions.

Impacts of main tunnel alternative
The tunnel alternative impairs all benthic fauna communities. None of the impacts are significant. Most of the communities are impaired with minor severity of impact followed by medium severity. Impacted areas are large for the pressures suspended sediment and sedimentation and exceed the local zone. In terms of area, the pressure suspended sediments causes the largest impact. The second-largest extent is seen for the pressure sedimentation (Table 0.4). It is assessed that there is no impact on the biodiversity of the benthic fauna because no communities re impacted significantly. The indirect impact of the temporary reduced eelgrass biomass can also temporarily impact the Rissoa community as it is tightly linked to eelgrass habitats. The impact is assessed to be temporary and not significant.

The Mytilus community is impacted most, with suspended sediments on 19,617 ha with minor severity being the largest impact. The next communities are the Gammarus, Bathyporeia and Rissoa communities, also exposed to predominantly minor severity and mainly affected by suspended sediments. The remaining communities are affected much less with the Arctica and Corbula communities impacted mostly by sedimentation and the Cerastoderma community impacted mostly by suspended sediments. The Tanaissus community is affected least. This is because the community is located outside the near zone and away from the pressures from footprint and solid substrate.

Table 0.4 Severity of impact (either impairment or loss) for benthic fauna from the tunnel alternative. Numbers indicate the impaired/lost areas (in ha) for the respective communities and the four severity classes. For solid substrate, the number indicates the area added to the community. Impacts below 1% of the total area are left out.

	Suspended sediments	Sedimentation	Footprint	Solid substrate
	impairment	Impairment	loss	addition
Arctica				99
Very high			99	
High				
Medium		680		
Minor		1,628		
Bathyporeia				0.2
Very high				
High				
Medium				
Minor	8,803	1,187	112	
Cerastoderma				4
Very high				
High				
Medium		126	20	
Minor	3,029	725		
Corbula				50
Very high				
High				
Medium		13		
Minor	910	1,880	49	
Dendrodoa				-
Very high				
High				
Medium	530	50		
Minor				
Gammarus				19
Very high				
High		2		
Medium		267	66	
Minor	12,593	1,703		
Mytilus				32
Very high				
High		8	238	
Medium	2,913	353		
Minor	21,126	1,638		
Rissoa				-
Very high				
High		6		
Medium	209	246		
Minor	7,799	1,354		
Tanaissus				-
Very high				
High				

	Suspended sediments	Sedimentation	Footprint	Solid substrate
	impairment	Impairment	loss	addition
Medium		2		
Minor		2		
Total*	**57,941**	**11,872**	**584**	**204**
Very high	0	0	99	
High	0	16	238	
Medium	3,652	1,737	86	
Minor	54,289	10,119	161	

*Incl. impairments < 1 %

Suspended sediments

57,942 ha of benthic fauna communities are affected by suspended sediment from the construction phase. 99% of this area is impacted with a minor degree of impairment, 1% is impaired to a medium degree, mostly in the Mytilus community (Figure 0.4). None of the impacts affect mortality but only viability. Most of the impact is observed in the shallow waters along the Lolland coast, a smaller area is observed along the northern and eastern coast of Fehmarn. The maximum decrease in mussel biomass is estimated to 10% with local reductions of 5–6 g m^{-2} (AFDW). In most of the impacted area, the reductions will be lower than 2.5 g m^{-2}. Thus, the severity of the impact is also largely minor and not significant.

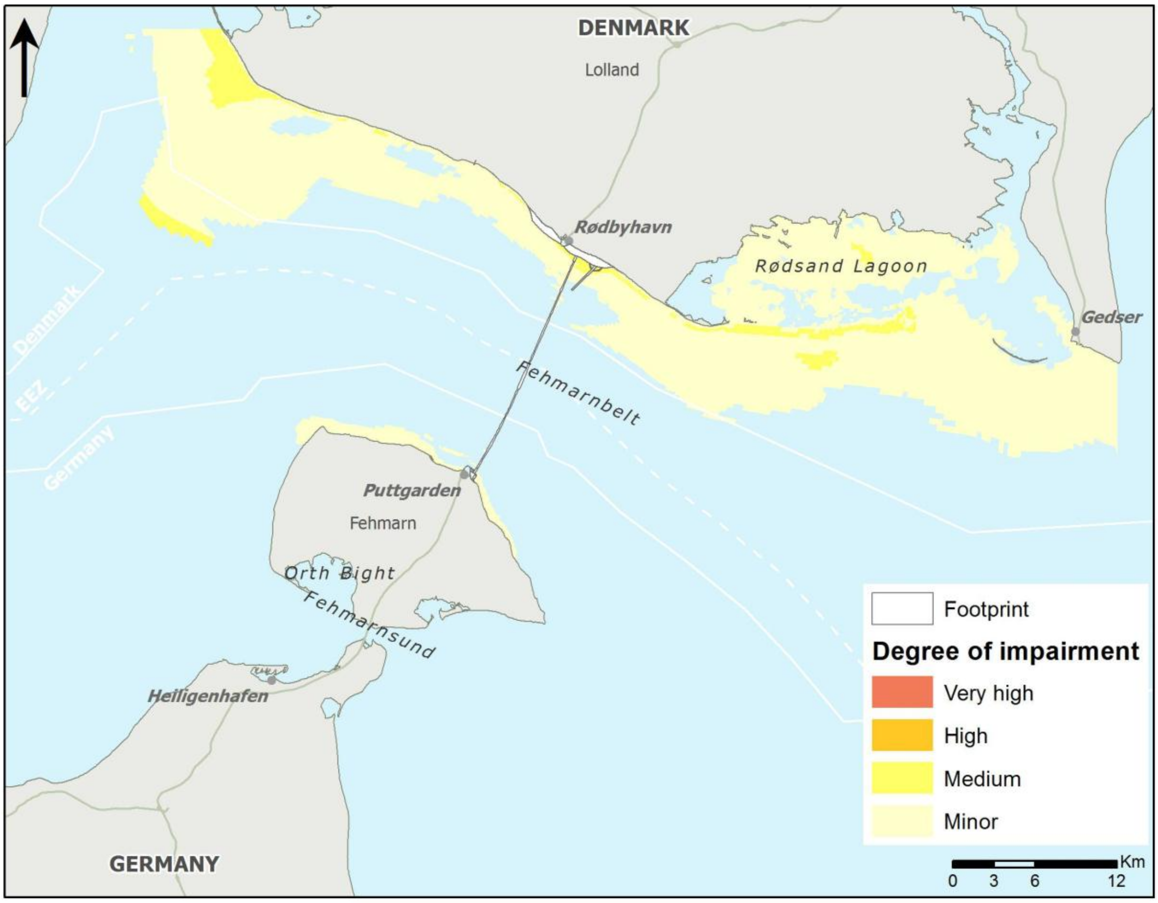


Figure 0.4 Degree of impairment of the pressure suspended sediments for the tunnel alternative.

Sedimentation

11,871 ha of benthic fauna communities are affected by sedimentation. 85% of this area is impaired to a minor degree of impairment, nearly 15% are impaired to a medium degree and 16 ha are impaired to a high degree (Figure 0.5). The impact is distributed across all fauna communities and the Arctica community is affected most in terms of area. The impact is located largely around the tunnel trench (in the near zone) and in the Rødsand Lagoon. The maximum accumulation of sediment is modelled to 7 cm near the tunnel trench. In the remaining part of the impacted areas, sedimentation rates are typically below 1 mm d^{-1}. The severity of the impact is therefore also largely minor and the impact is not significant.

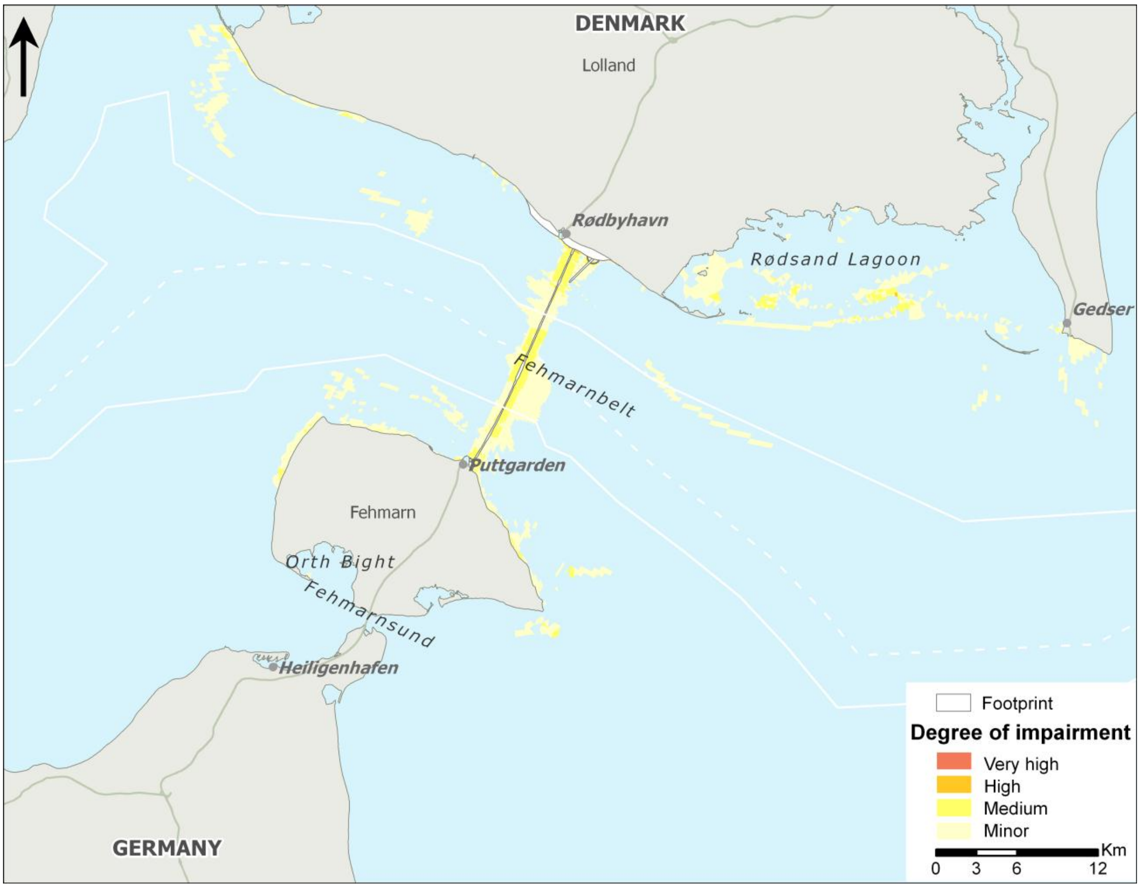


Figure 0.5 Degree of impairment of the pressure sedimentation for the tunnel alternative.

Footprint
584 ha of benthic fauna communities are affected by footprint. Most of the impact is from the permanent loss due to reclamations areas at Lolland and Fehmarn and from temporary loss due to the tunnel trench. The severity of loss is obtained by intersecting the importance with the footprint. 41% of the impacted area has a high severity of loss due to the important Mytilus community at Lolland. 28% of the impacted area has a minor severity of loss and is located in the Bathyporeia and Corbula community. 17% has a very high severity of loss and is located in the Arctica community, 14% has a medium severity of loss and is located in the Gammarus and Cerastoderma community. All temporary impacts are recovered within 5–28 years, depending on the location and the affected community. The impact is not significant.

Solid substrate
204 ha of solid substrate are added due to the structures of the tunnel alternative, mainly (85%) due to the temporary protection layer on top of the tunnel elements. Most solid substrate is introduced into the soft-bottom Corbula and Arctica communities. A maximum of 0.6% of community area compared to the comparison zone is added as solid substrate. The impact is not significant.

Impacts of main bridge alternative
The bridge alternative impairs all benthic fauna communities except the Dendrodoa community. None of the impacts are significant. The communities are impaired with minor severity of impact, only the Cerastoderma community shows medium severity of impact (due to sedimentation). Impacted areas are in general small compared

to the total assessment area. The spatial range of the impacts exceeds the local zone for sedimentation. The other pressures are restricted to the near zone. There is no impact from suspended sediments. The amount of solid substrate introduced is small compared to the other two pressures. In terms of area, the pressure sedimentation causes the largest impact, though mainly with minor severity. The second-largest extent is seen for the pressure footprint (Table 0.5). None of the impacts are estimated as being significant.

The Arctica community is impacted most, with sedimentation on 498 ha with minor severity being the largest single impact. The next communities are the Bathyporeia, Corbula and Gammarus communities, exposed to only minor severity and mainly affected by sedimentation. The remaining communities are affected much less and by sedimentation only. The Tanaissus community is affected least (1 ha). This is because the community is located outside the near zone and away from the pressures from footprint and solid substrate.

Table 0.5 Severity of impact (either impairment or loss) for benthic fauna from the bridge alternative. Number indicate the impaired/lost areas (in ha) for the respective communities and the four severity classes. For solid substrate, the numbers indicate the area added to the community. Impacts below 1% of the total area are left out.

	Suspended sediments	**Sedimentation**	**Footprint**	**Solid substrate**
	no impact	**impairment**	**loss**	**addition**
Arctica				15.78
Very high				
High				
Medium				
Minor		498		
Bathyporeia				-
Very high				
High				
Medium				
Minor		242	23	
Cerastoderma				1.28
Very high				
High				
Medium		23		
Minor		36		
Corbula				5.58
Very high				
High				
Medium				
Minor		242		
Dendrodoa				-
Very high				
High				
Medium				
Minor				
Gammarus				0.58
Very high				
High				
Medium				
Minor		232		
Mytilus				2.16
Very high				
High				
Medium				
Minor		72		

	Suspended sediments	Sedimentation	Footprint	Solid substrate
	no impact	impairment	loss	addition
Rissoa				-
Very high				
High				
Medium				
Minor		23		
Tanaissus				-
Very high				
High				
Medium				
Minor		1		
Total*	**0**	**1,524**	**80**	**25**
Very high		0	13	
High		0	13	
Medium		178	27	
Minor		1,346	27	

*Incl. impairments < 1 %

Suspended sediments
The magnitude of pressure from the bridge alternative is approximately 10 times lower than from the tunnel alternative. The levels are within the natural variability and no impact is expected.

Sedimentation
1525 ha of benthic fauna communities are affected by sedimentation. Only minor (88% of the impacted area) and medium (12% of the impacted area) degree of impairment occurs (Figure 0.6). The main impact is observed for the Arctica and Gammarus communities. A quick recovery is expected for the impacted communities and the severity of impact is largely minor. The impact is not significant.

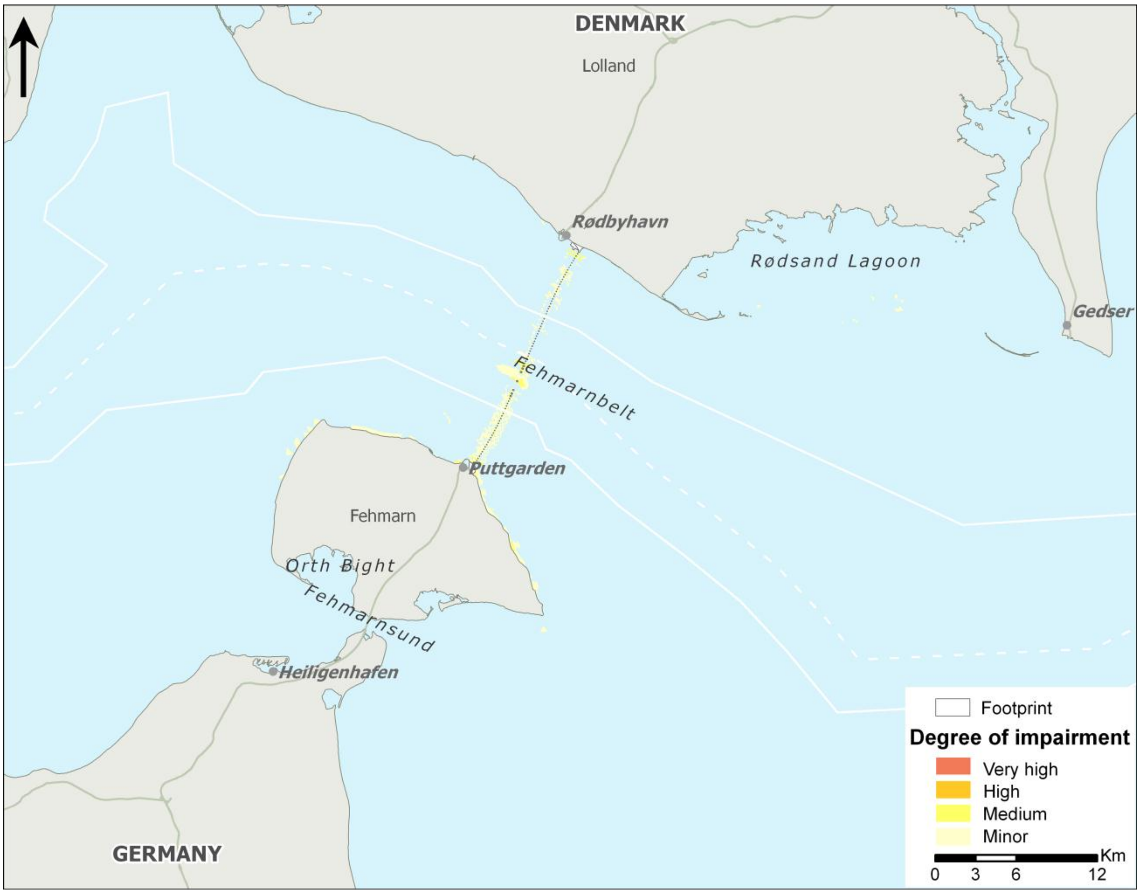


Figure 0.6 Degree of impairment of the pressure sedimentation for the bridge alternative.

Footprint
80 ha of benthic fauna communities are affected by footprint. The main impact is from reclamation areas, piers, pillars and scour protection. The severity of loss is obtained by intersecting the importance with the footprint. All impact is in the near zone and mainly of minor and medium severity. The largest impact is observed in the Bathyporeia community. The remaining impacts area is distributed relatively evenly among the Cerastoderma, Mytilus, Arctica and Gammarus communities. All impacted areas are small compared to the comparison zone and the impact is not significant.

Solid substrate
25 ha of solid substrate are added due to the structures of the bridge alternative, mainly (93%) due to the piers and pillars. Most solid substrate is introduced into the soft-bottom Corbula and Arctica communities. A maximum of 0.01% of community area compared to the comparison zone is added as solid substrate. The impact is not significant.

The fauna communities settling on the introduced solid substrate have an impact on the existing surrounding soft-bottom communities. This affects the three Arctica, Cerastoderma and Corbula communities that are located in the near zone. 201 ha of soft-bottom communities are estimated to be affected, mainly (126 ha) by a minor degree of impairment. The impact is concentrated in the deep waters and the Arctica community shows the largest single impact with 95 ha of minor degree of impairment. Directly at the piers and pillars, loss of function occurs. This zone is, however, very small and amounts to 2.5 ha in total. Also this impact is not significant.

Comparison of tunnel and bridge

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 their severity, summarized in Table 0.6.

Table 0.6 Summary of overall impacts from all relevant pressures for the tunnel and bridge alternatives.

Pressure	Description of impact	Tunnel	Bridge
Suspended matter	Severity of loss	-	-
	Severity of impairment	Medium – minor	-
	Range	Complete EIA assessment area	Complete EIA assessment area
	Duration	Spatially and temporally varying	Spatially and temporally varying
	Significance	Not significant	Not significant
Sedimentation	Severity of loss	-	-
	Severity of impairment	High – minor	Medium – minor
	Range	Complete EIA assessment area	Complete EIA assessment area
	Duration	Spatially and temporally varying	Spatially and temporally varying
	Significance	Not significant	Not significant
Footprint	Severity of loss	Very high – minor	Very high – minor
	Severity of impairment	-	-
	Range	Near zone	Near zone
	Duration	Temporary and permanent	Temporary and permanent
	Significance	Not significant	Not significant
Solid substrate	Severity of loss	-	Very high – minor
	Severity of impairment	-	High – minor
	Range	Near zone	Near zone
	Duration	Permanent	Permanent
	Significance	Not significant	Not significant

The main comparison is shown in Table 0.7 stating for each pressure the preferred alternative. For the component benthic fauna the bridge is consequently the overall preferred alternative.

Table 0.7 Comparison of alternatives. ++ = clear advantage, + = advantage.

Pressure	Tunnel	Bridge	Preferred alternative
Suspended sediments		+	bridge
Sedimentation		++	bridge
Footprint		++	bridge
Solid substrate	+		tunnel
Summary		**++**	**bridge**

No impact is present from *suspended sediments* of the bridge alternative, since the concentrations of suspended sediments are within the natural variability. For the tunnel alternative, mainly minor severity is present. The impacted area from *sedimentation* of the tunnel alternative is more than twice as large as the impacted area for the bridge alternative. The severities are similar with the tunnel alternative having small areas with high severity while the bridge alternative is maximum causing medium severity. The impacted area from *footprint* of the tunnel alternative is more than twice as large as the impacted area for the bridge alternative. The severities are similar with the tunnel alternative. The amount of *solid substrate* added by the project structures is much higher for the tunnel alternative, but most of solid substrate added by the tunnel structures is temporary. The solid substrate of the bridge alternative has a limited influence on the surrounding soft-bottom communities. In terms of severity, no differentiation can be done.

Other issues

Protected species
None of the species found in the assessment area during the baseline studies are listed in the annexes of the Habitats Directive or in the German or Danish lists of protected species.

WFD and MSFD
None of the German or Danish WFD water bodies located within the assessment area will probably be affected by the construction of the Fixed Link to a degree that it will change the ecological status. The effect in terms of the MSFD cannot be determined, because this Directive is not yet fully implemented.

Climate change
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 communities. The most likely factors 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, since there are no permanent pressures that significantly impact the fauna communities.

1 INTRODUCTION

1.1 Environmental theme

Femern A/S is designing and planning a Fixed Link between Denmark and Germany across the Fehmarnbelt. One important part of this work is to prepare an Environmental Impact Assessment (in Denmark VVM and in Germany UVS) in order to get approval of the project by the authorities in Denmark and Germany. In the process baseline investigations have been carried out from 2008 to 2010 and baseline reports have been prepared to describe the Fehmarnbelt area in detail (FEMA 2013a).

This report is part of a number of reports forming the base of the Environmental Impact Assessment (EIA) for the Fehmarnbelt Fixed Link. It is Volume II of the background report on impact assessment for marine fauna and flora and contains the impact assessment on the marine benthic fauna communities in the Fehmarnbelt area of identified pressures resulting from the construction, operation and structure of the Fixed Link.

1.1.1 Impacts

Large infrastructure projects can potentially have an impact on the surrounding environment and therefore also on the benthic fauna communities. The pressures occur during the construction phase, are caused by the structures forming the project or occur during the operation phase. Furthermore, the pressures can be direct e.g. by the loss of habitat or increased sedimentation or indirect by e.g. decreased food supply or changes in hydrographic regime.

The scoping report lists the potential pressures that have been identified as relevant in relation to the benthic fauna communities, hereunder loss of habitat (footprint), increased suspended sediment concentrations, sedimentation and increased additional solid substrate from new structures (Femern and LBV-SH-Lübeck 2010). The pressures have been identified to have possible impacts on the benthic fauna communities during the construction or operation phases and from the permanent structures of the Fixed Link.

In this impact assessment the severity of loss and the degree and severity of impairment of each identified pressure on the benthic fauna communities has been assessed, together with the significance of the loss and impairments. The method is presented in the Data and Methods chapter (section 3).

1.1.2 Benthic fauna communities

The benthic fauna communities in Fehmarnbelt are important components of the marine ecosystem. Benthic fauna functions as a key link between primary producers and the higher trophic levels and many benthic fauna communities also act as ecosystem engineers that actively shape their surroundings. Benthic fauna are all invertebrate animals larger than 1 mm (Rumohr 2009) and can be divided into two habitat groups, the infauna that lives in the sediments and the epifauna that lives on top of the sediment, e.g. on the seabed, on vegetation, on mussels etc. Within each group the species can be divided into different feeding strategies (e.g. filter feeders, deposit feeders, suspension feeders, predators).

The benthic fauna communities of Fehmarnbelt are categorised into nine in- and epifauna communities (FEMA 2013a). The communities have been classified according to the presence of specific key species and the abundance, biomass and importance of all community species for the community structure (Table 1.1). Each particular benthic fauna community has been named according to a discriminate species of that community.

Table 1.1 Summary of the benthic fauna communities in the Fehmarnbelt: Distribution, number of species, biomass (AFDW) and key features (FEMA 2013a). Mytilus edulis occuring in the communities are not included in biomass estimates.

Community	Area (ha)	Depth zone	Total species number	Mean total biomass (g m^{-2})	Key features
Arctica	112,239	deep	261	47	infauna – muddy sediments
Bathyporeia	15,635	shallow	61	1	infauna – exposed sand
Cerastoderma	11,171	shallow	87	32	infauna – sheltered immobile soft bottom
Corbula	13,246	deep	180	12	in-/epifauna – transitional along pycnocline
Dendrodoa	21,251	deep	271	46	epifauna – hard substrate/algae
Gammarus	74,243	shallow/ deep	196	7	epifauna – hard substrate/algae
Mytilus	30,935	shallow/ deep	152	8	epifauna – hard substrate
Rissoa	11,635	shallow	42	6	epifauna – eelgrass
Tanaissus	2,333	deep	182	20	infauna – exposed sand and gravel
Total	292,739				

The spatial extent of communities in the Fehmarnbelt is shown in Figure 1.1, which also delineates the investigation area for the baseline survey. In the following text, this area is used as the assessment area and termed accordingly (see also section 3.1).

The blue mussel (*Mytilus edulis*) population is distributed unevenly throughout the Fehmarnbelt area. Where present, they dominate the biomass in shallow waters of the Fehmarnbelt. In deeper waters, the abundance and biomass is lower and they are missing in some parts. Within the Fehmarnbelt area, the total mussel biomass was predicted to 27,000 tons AFDW via modelling (FEMA 2013a). Besides the assessment of the Mytilus community, the blue mussel population is also assessed separately as it is important food for birds and is a major feeder on plankton.

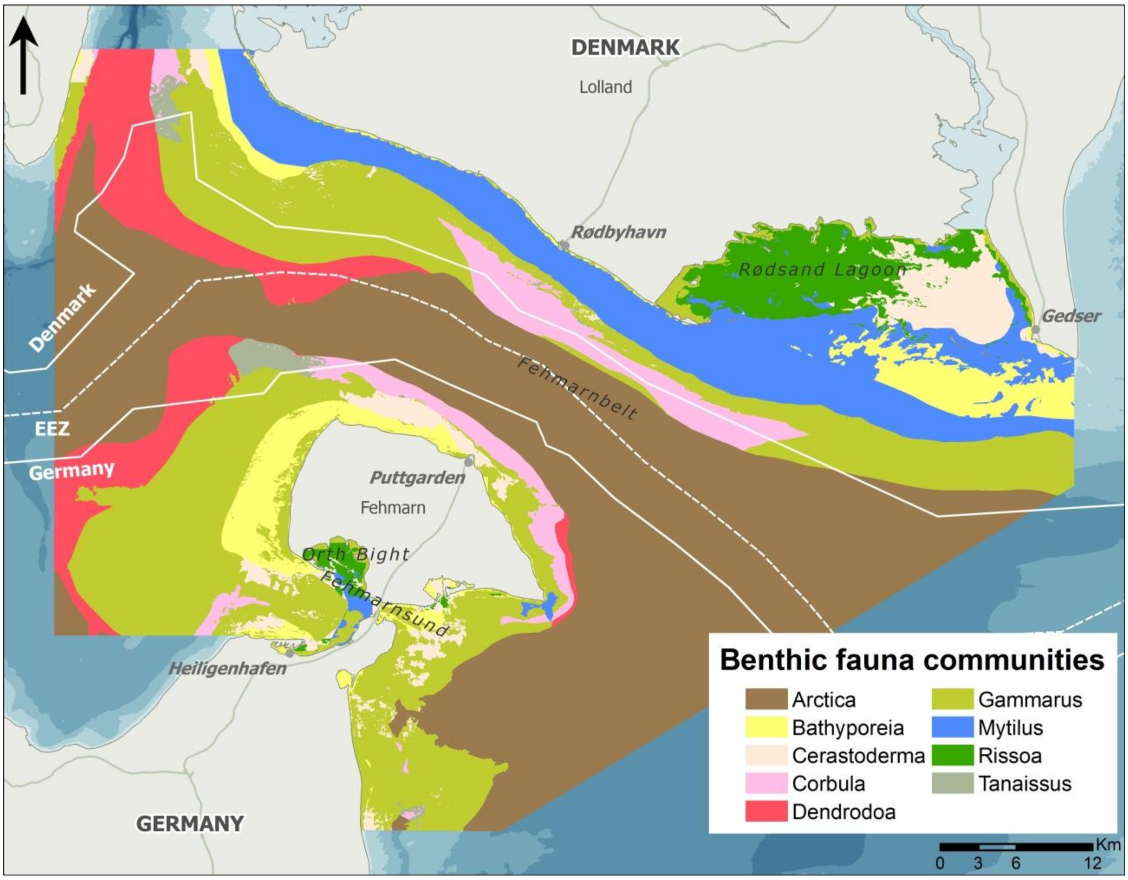


Figure 1.1 Predicted spatial distribution of the benthic fauna communities in Fehmarnbelt (FEMA 2013a).

1.1.3 Importance

The importance of the nine benthic fauna communities is based on the definition given in FEMA (2013a) which contains five different criteria. These criteria were evaluated with regard to fauna community and characteristic species. Characteristic species in this context are species that discriminate fauna communities from each other but also common typical species. The resulting classification of the benthic fauna communities is repeated here in Table 1.2 and Figure 1.2.

Table 1.2 Importance classification of the nine benthic fauna communities from (FEMA 2012FEMA 2013a).

Community	Importance
Arctica	very high
Bathyporeia	minor
Cerastoderma	medium
Corbula	minor
Dendrodoa	high
Gammarus	medium
Mytilus	high
Rissoa	very high
Tanaissus	high

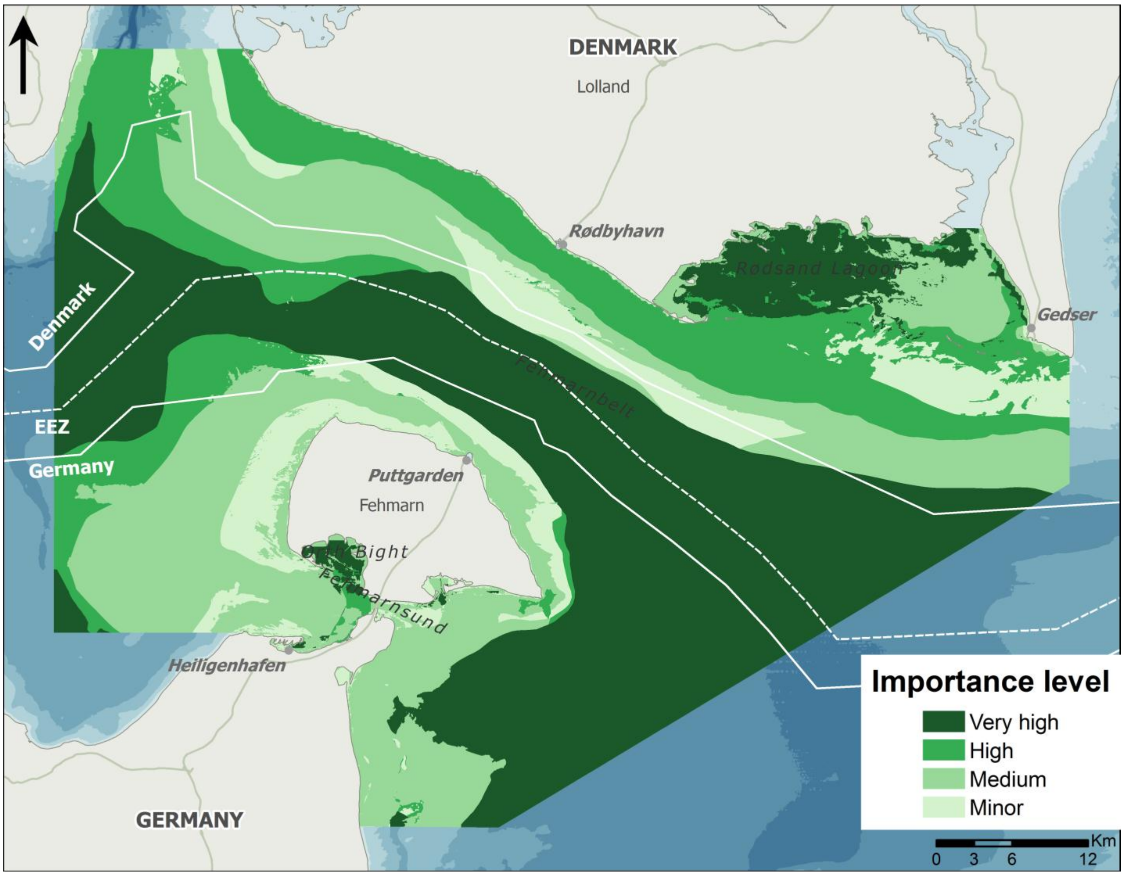


Figure 1.2 Importance of the modelled benthic communities within the EIA assessment area.

1.2 *Environmental components assessed*

Table 1.4 presents the factors, sub-factors and components assessed. Marine benthic fauna is a sub-factor under the "Fauna and flora (including biodiversity)" factor. The components assessed are the benthic in- and epifauna communities and blue mussels.

Table 1.3 Assessed components and how they fit into the environmental factor framework. The component assessed in this report is highlighted using italics.

Factor	Sub-factor	Components	Sub-components
Fauna and flora (including biodiversity)	Marine plankton	Planktonic flora Planktonic fauna Jellyfish	
	Marine benthic fauna	In- and epifauna communities and Blue mussels	Fauna communities: Arctica Bathyporeia Cerastoderma Corbula Dendrodoa Gammarus Mytilus Rissoa Tanaissus
	Marine fish	Migration Spawning Feeding/nursery	
	Marine mammals	Harbour Porpoise	

Factor	Sub-factor	Components	Sub-components
		Harbour Seal Grey Seal	
	Birds	Non-breeding water birds Breeding water birds Bird Migration	
	Migrating bats	-	
Soil	Marine Soil (including marine landscape)	Seabed morphology Coastal Morphology Seabed Chemistry	
Water	Marine waters	Seawater Hydrography Seawater Quality	
Cultural heritage	Marine archaeology	-	
Other material assets	Other marine material assets	-	

2 THE FEHMARNBELT FIXED LINK PROJECT

2.1 General description of the 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 site.

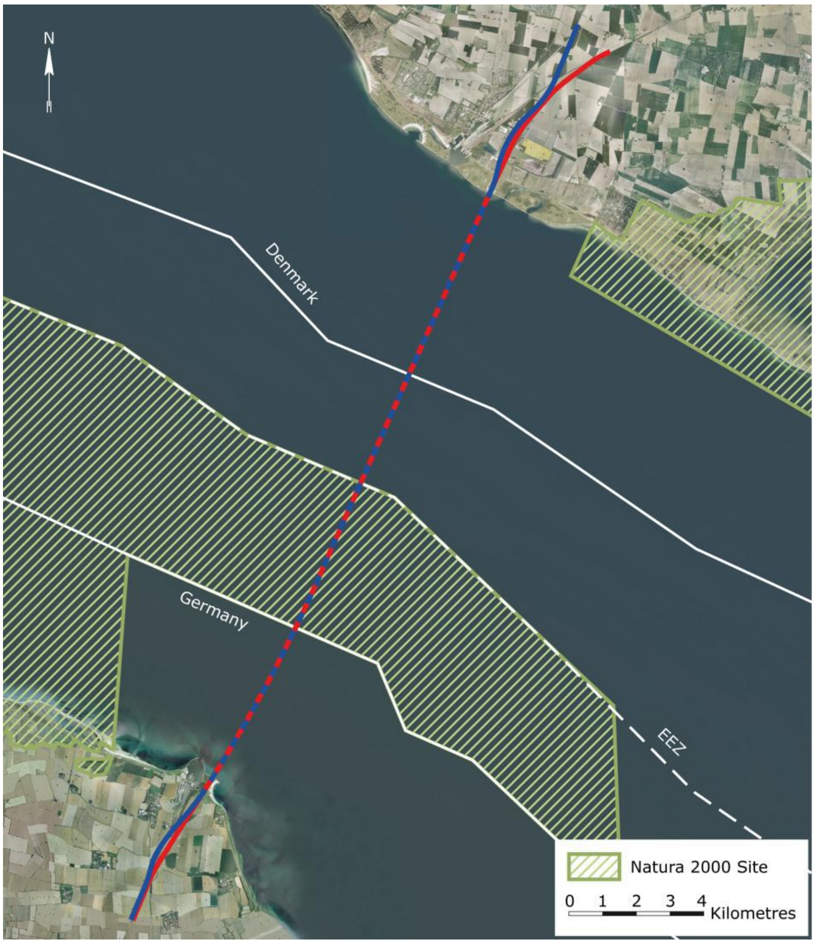


Figure 2.1 Proposed alignment for immersed tunnel E-ME (August 2011).

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 25 m 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.

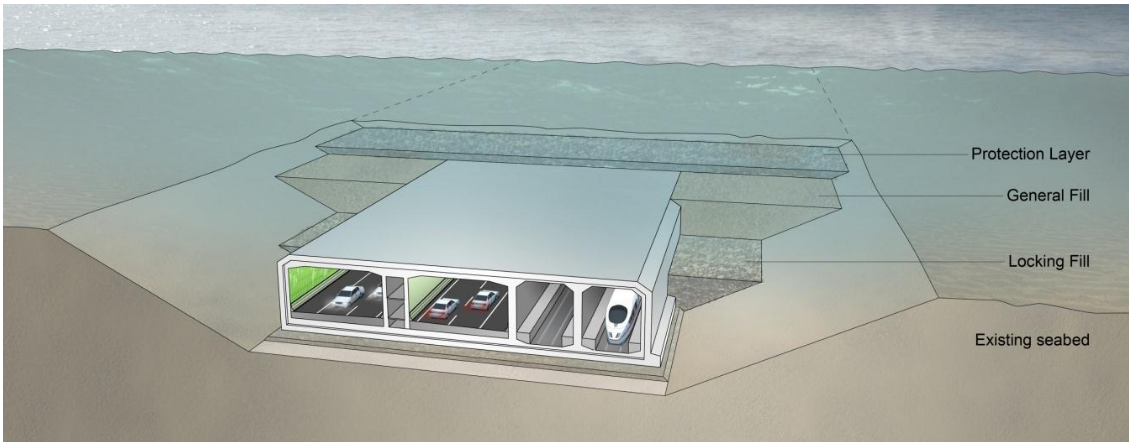


Figure 2.2 Cross section of the dredged trench with tunnel element and backfilling.

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 500-700 m 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, 42 m wide and 9 m 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 46 m long, 45 m wide and 13 m tall. After placement of the elements, the tunnel trench will be backfilled with marine material, potentially partly from Krieger's Flak.

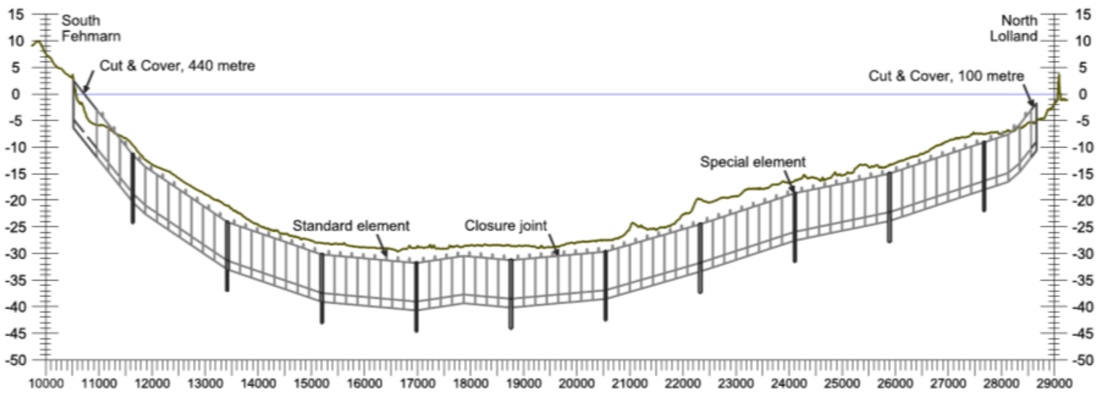


Figure 2.3 Vertical tunnel alignment showing depth below sea level.

The cut and cover tunnel section beyond the light screens is approximately 440 m long on Lolland and 100 m 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 500 m 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 3.5 m 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 3.5 km 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 3.7 km east and 3.4 km west of the harbour and project approximately 500 m 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 +3 m 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 +7 m. 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 sea-side 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 4.5 km 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 4.5 km 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 harbor 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.

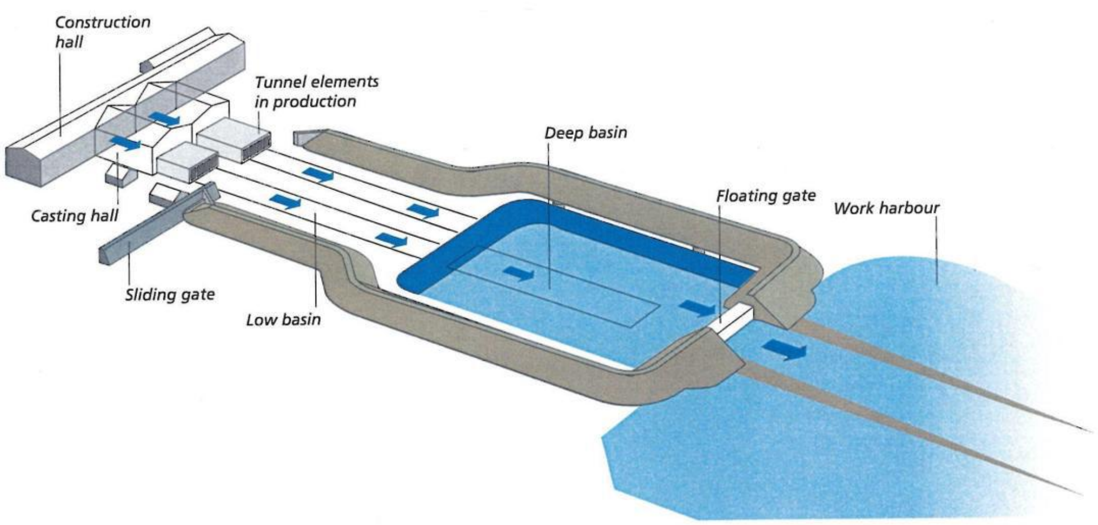


Figure 2.6 Production facility with two production lines.

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 layout 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 724 m 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 272 m above sea level and are V-shaped in transverse direction. The main bridge girders are made up of 20 m long sections with a weight of 500 to 600 t. The standard approach bridge girders are 200 m long and their weight is estimated to ~ 8,000 t.

Caissons provide the foundation for the pylons and piers of the bridge. Caissons are prefabricated placed 4 m below the seabed. If necessary, soils are improved with 15 m long bored concrete piles. The caissons in their final positions end 4 m 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 5,748 m long and consists of 29 spans and 28 piers. The northern approach bridge is 9,412 m 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 580 m long, measured from the coastline, see Figure 2.9. The gallery structure on Fehmarn is 320 m long and enables a separation of the road and railway alignments. A 400 m long ramp viaduct bridge connects the road from the end of the gallery section to the motorway embankment. The embankments for the motorway are 490 m 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 480 m long, measured from the coastline. The gallery structure on Lolland is 320 m long. The existing railway tracks to Rødbyhavn will be decommissioned, so no overpass will be required. The viaduct bridge for the road is 400 m long, the embankments for the motorway are 465 m long and for the railway 680 m 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 backfilled, 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.

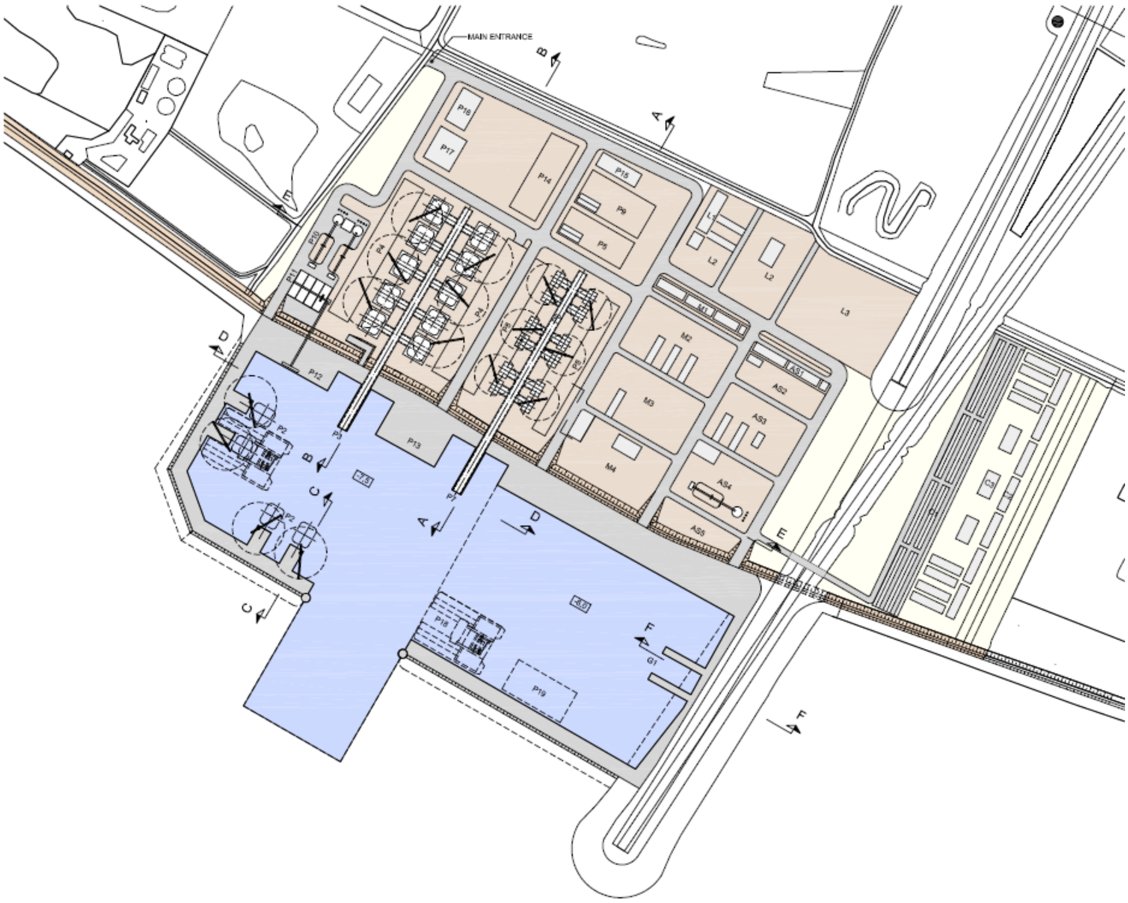


Figure 2.10 Proposed layout of the production site at Lolland east of Rødbyhavn.

2.2 *Relevant project pressures*

The scoping report (Femern and LBV-SH-Lübeck 2010) lists all potential pressures that have been identified to have a potential impact on the marine benthic fauna communities. Table 2.1 presents these potential pressures. They are defined and described in the following sections. The pressure "nutrients" will not be treated here, since it is not relevant for benthic fauna. It is listed here for completeness, since it is important for the other two marine components benthic flora and plankton.

Table 2.1 Potential pressures on the benthic fauna communities from the Fixed Link across the Fehmarnbelt. The pressure "nutrients" is not relevant for the benthic fauna.

Phase	Pressure
Construction	Suspended sediments
	Sedimentation
	Toxic substances
	Nutrients
	Construction vessels and imported material
Structure	Footprint
	Solid substrate
	Seabed and coastal morphology
	Hydrographic regime and water quality
Operation	Drainage

Pressure classification

In the following sections, the pressures are classified by type, duration, intensity and range. The two main parameters that account for the magnitude of the pressure are intensity and duration. The **type** of the pressure is related to the phases of the project and determines to which phases of the project the pressure applies. There can be structure-related, construction-related and operation-related types of pressures. Strictly speaking, the type of the pressure has no influence on the magnitude of the pressure. The **duration** of the pressure determines the time or time span in which the pressure is present. Some pressures (like footprint) do not have a finite duration, other pressures (like sedimentation) occur in events of different duration. The **intensity** of the pressure is defined by the amount of the indicating factor for the pressure. As an example, for the pressure "sedimentation" the intensity is defined as the thickness of the added sediment. For the pressure "suspended sediments" the intensity is defined as the concentration of suspended sediments in the water. The **range** of the pressure defines the spatial extent in which the magnitude of pressure is present. Outside the range, the pressure is regarded as non-existent or negligible. The range is given in terms of the zones defined for the EIA assessment area (see section 3.1).

Dredging during construction phase

The first two pressures in Table 2.1 are the main pressures from the project concerning the benthic fauna. During the construction phase various dredging activities (e.g. dredging, backfilling, establishment and decommissioning of work harbours and access channels) will cause seabed sediment to be spilled. The spilled sediment causes an immediate increase of the concentration of suspended sediments in the surrounding water. The suspended sediments will deposit on the seabed (sedimentation). The location, intensity and spatial extent of sedimentation depend on the size distribution of the spilled particles, the hydrographic regime in the Fehmarnbelt and the local weather and current conditions during the dredging.

2.2.1 *Suspended sediments*

Suspended sediments are defined as all kinds of solid particulate matter that have been part of sediments, and that are suspended in water either by natural resuspension or as a result of dredging. The suspended sediments can include a variety of particles, including detritus (particulate organic matter), minerals, siliceous and calcareous deposits originating from planktonic and benthic flora and fauna and clay. Generally, the concentration of suspended sediments is correlated to the local wave and current conditions. Under storms the waves resuspend the finer fractions in the shallow parts of the Fehmarnbelt, and the currents spread the suspended fines over larger areas.

During dredging, sub-surface soils will be exposed and subject to dispersal, deposition and resuspension. In the Fehmarnbelt a large variety of soil types are present in the dredged alignment area including sand, till, clay and marine sediments. Depending on the content of finer fractions in the dredged material resuspended material may stay in suspension for long time because settling velocities are very low for fractions below 63 µm and decreasing with the diameter of particles.

The pressure is classified as

- type: construction-related
- intensity: spatially and temporally varying (see section 4.1)
- duration: spatially and temporally varying (see section 4.1)
- range: complete EIA assessment area and beyond

An increase in suspended sediments potentially has an impact on the benthic fauna communities, e.g. by reducing the viability of the fauna. Several functional groups of benthic invertebrates can be affected. Suspension feeders such as mussels, clams and other bivalves, barnacles or tunicates are most sensitive to high concentrations of suspended sediments because the solids can dilute their prime food (i.e. phytoplankton), cause mechanical clogging of the filtering apparatus and overload it. In general, other feeding groups are less sensitive as long as other water quality issues such as dissolved oxygen and toxic substances are not affected negatively along with high loads of suspended sediments. High concentrations of suspended sediments can lead to reduced growth, in extreme cases also to a reduction of the biomass. Depending on the concentrations, mortality can be the result if the exposure duration is long compared to the typical turnover of body mass for a specific species and individual. In this EIA both the effect on the benthic fauna communities and the effect on the blue mussel (*Mytilus edulis*) population is assessed.

2.2.2 *Sedimentation*

Sedimentation poses a direct pressure on benthic fauna related to the construction of the proposed Fixed Link. It is defined as all kind of material that is spilled and deposits on the seabed during the construction works. This is caused e.g. by dredging, backfilling or the establishment or decommissioning of work harbours and access channels.

The pressure is classified as

- type: construction-related
- intensity: spatially and temporally varying (see section 4.2)
- duration: spatially and temporally varying (see section 4.2)
- range: complete EIA assessment area and beyond

The hydrodynamic regime of the Fehmarnbelt is important to the fate of the sediment and thus the sediment deposition and resuspension patterns (e.g. Kuhrts et al. 2004).

Effects of sedimentation and subsequent recovery of benthic communities will vary depending on sedimentation rates, depth of deposition, previous life history of the community and structure of the habitat. The possible impacts of sedimentation on benthic fauna range from a decrease in the viability of species to lethal events that destroy the benthic communities. The broad range in between these two extremes is the sublethal sedimentation that can alter the functional stability of a community through the alteration of food supply and physical structure of the habitat (Lohrer et al. 2004). Both the intensity and frequency of sedimentation events and the sedimentation rates (see section 4.2) are important in determining the effect on benthic community (Gibbs and Hewitt 2004). Also, the sensitivity of macrofauna by functional groups (see section 5.2.2) and the natural sedimentation rates are critical (Miller et al. 2002).

Adverse effects of even moderate sedimentation may appear when sedimentation takes place over longer periods, e.g. by deteriorated conditions of animals due to affected feeding rates (Essink 1999). Re-structuring of the community may also be a result of sedimentation caused by the retreat of mobile species that do not favour the adverse conditions, or by increased predation of infauna organisms forced to approach the sediment surface if the oxygen ventilation in the sediment becomes obstructed (e.g. in tubes of polychaetes). Clay sedimentation on a diverse sand flat community will presumably have a more severe effect than the same sedimentation on a low-diverse mudflat community adapted to a silt/clay habitat (Gibbs and Hewitt 2004). Series of sedimentation events at shorter intervals than the recovery time can induce cumulative effects. On the other hand benthic fauna communities may quickly recover from single sedimentation events under favourable conditions.

2.2.3 Toxic substances

Toxic substances are defined as all substances that are harmful to living organisms, because they either kill (poison) the organism or damage its organs, physiology or reproduction. This includes e.g. heavy metals, PAHs (polycyclic aromatic hydrocarbons), TBT (tributyltin), PCBs (polychlorinated biphenyls) and pesticides. The pressure is classified as

- type: construction-related
- intensity: see section 4.3
- duration: construction phase
- range: near zone and local zone

Depending on local conditions and especially nearby pollutant sources (present and historic) in addition to the sedimentation regime, dredged material can contain a variety of toxic substances. During dredging and disposal these contaminants can be spread with the fine material (see section 2.2.1) or be released into the water column, with the risk of accumulation in biota or poisoning. The likelihood of such spreading of contaminants depends on the type and degree of sediment contamination. The highest levels of contaminants generally occur in industrialised areas and where fine sediment is accumulated.

2.2.4 Construction vessels and imported material

Construction vessels will transport material from and to the project area during the construction phase. The imported material is all kind of material with an origin outside the EIA assessment area. This is e.g. sand from sand extraction sites or stones from land or marine areas.

The pressure is classified as

- type: construction-related
- intensity: varying with amount of material and its origin (see section 4.4)
- duration: construction phase
- range: complete EIA assessment area

The vessels and the imported material are a potential pressure to the benthic fauna because they can transport non-indigenous species into the project area. Non-indigenous species are here defined as alien (non-native) species that are new to a given area and have directly or indirectly been introduced by anthropogenic vectors (e.g. ships) regardless of them exhibiting a harmful influence (i.e. being invasive species) on the existing native benthic fauna (Nehring 2000, Gollasch and Nehring 2006). Two categories of non-indigenous species are considered:

- Potential new species, not yet observed in the EIA assessment area
- Existing species in the EIA assessment area

The non-indigenous species can be introduced as part of the vessels (attached to the hull or in ballast water) or as part of the imported material. Ballast water will, however, not be considered here, since the international Ballast Water Convention (IMO 2004) stipulates that all ballast water must be treated on board before disposal into the sea.

The effect of non-indigenous species range from a mere incorporation of the new species into an existing fauna community, without any other alterations, to a change in abundance of existing species, and in extreme cases in a complete change of existing communities and suppression of species.

2.2.5 Footprint

The pressure footprint is defined as areas that will be lost due to constructions like reclamation areas, ramps, pillars or the tunnel trench. Footprint is classified as

- type: structure-related and construction-related
- intensity: very high (by definition)
- duration: temporary (construction phase), permanent (operation phase)
- range: near zone

The impact of footprint on the benthic fauna communities is habitat loss. Two types of footprint are distinguished, which differ in their recovery potential and recovery time:

Structure-related footprint: No re-establishment of the former seabed and the benthic fauna communities is possible. This is the permanent footprint forming the project.

Construction-related footprint: Re-establishment of the former seabed and the benthic fauna communities is possible. There are two types of construction-related footprints. When recovery depends on natural erosion and sedimentation processes, it takes between 1 and 30 years until the seabed is recovered, depending on the location and kind of footprint (FEHY 2013c). On top of the seabed recovery time, the recovery time of the benthic fauna community is added. This depends on the composition, ecology and functioning of the respective community.

2.2.6 Solid substrate

Solid substrate is defined as all structure-related solid or hard structures that are located underwater and are available as potential settling ground for marine organisms. This can be e.g. bridge pillars and piers, protection reefs or embankments. The pressure is classified as

- type: structure-related
- intensity: depending on the aspect (see section 4.6)
- duration: permanent
- range: near zone

In this assessment the solid substrate that is introduced by the work harbours is ignored, since it constitutes a small area compared to the structure-related solid substrate and only remains in place for a few years during the construction phase. Only the structure-related substrates and the protection layer on top of the tunnel trench are considered. The protection layer on top of the tunnel alternative is regarded as footprint (see section 2.2.5 on footprint), since it will remain exposed to seawater for a longer period. It will be covered by natural sedimentation. There are three aspects of the pressure solid substrate:

Aspect 1 – This aspect is the added solid substrate itself which is located at the edge or on top of certain parts of the footprint. It will create settling grounds for marine species forming hard-bottom communities. The area of this new substrate is not identical to the footprint area and different for the tunnel and bridge alternative.

Aspect 2 – This aspect covers the influence of the new hard-bottom communities (settling on the project structures) onto the surrounding benthic fauna communities (Zettler and Pollehne 2006). Organic matter is sinking to the seabed from bridge piers and pillars as dead or loose mussels and other marine organisms and as faecal material. This can alter the dominance structure of the surrounding communities and change their species composition and biomass. This aspect is only relevant for the piers and pillars of the bridge alternative. An effect from the embankments in general is considered negligible as they are slanted structures and on average only extend 4 m vertically into the water. The faecal material or dead mussels will nearly exclusively deposit within the embankment structure. An effect from the protection layer on the tunnel elements is also considered negligible, since the layer is below the surrounding sea floor level and transport of faecal material or dead mussels is improbable.

Aspect 3 – This aspect covers the risk of introducing new non-indigenous species or accelerating such an introduction using the solid substrate as a vector. It can also increase the risk of further spreading of existing non-indigenous species that are already living in the area (see also section 4.4 on construction vessels and imported material).

2.2.7 Seabed and coastal morphology

Seabed and coastal morphology is the spatial distribution and appearance of the seabed from the largest depths and to the coastline. It can be impacted by changes in the sediment transport capacity. Changes are related to the structures of the proposed Fixed Link across the Fehmarnbelt. Structures like protection reefs and new land reclamations introduce new or changed barriers in the natural current regime and can change surface wave patterns. Barriers at the coastline can cause variations in the alongshore drift and barriers or trenches at the seabed can cause variations in water currents near the bottom. Both situations can cause a shift in the natural sedimentation and erosion processes close to new structures and the pressure is therefore relevant in the near and local zone. The pressure is classified as

- type: structure-related (indirect pressure)
- intensity: depending on the project structures (see section 4.7)

- duration: 5 to more than 30 years
- range: near zone and local zone

Changes in natural sedimentation and erosion processes can impact the benthic fauna by changes in the sediment composition (habitat) or by habitat loss. Changes in the habitat consequently also change the fauna community structure. The pressure from the structures is hence indirect on the benthic fauna.

2.2.8 *Hydrographic regime and water quality*

The hydrographic regime of the bottom waters in Fehmarnbelt is defined by current speed, salinity and temperature of the bottom waters. Water quality is here defined in terms of the concentration of chlorophyll-a and dissolved oxygen. Both factors are interacting and determine the environmental conditions for the benthic fauna (Laine 2003, Zettler et al. 2007).

The patterns of currents and turbulence and the general water flow through the Fehmarnbelt may be changed by new structures such as reclamation areas, ramps and bridge pillars. Such changes in the hydrographic regime may subsequently alter the water quality in terms of salinity, temperature and oxygen concentrations and thus also affect the distribution of chlorophyll-a. The pressure is classified as

- type: construction and structure-related (indirect pressure)
- intensity: depending on the project structures (see section 4.8)
- duration: temporary for construction phase, permanent for operation phase
- range: near zone and local zone

A shift in environmental conditions caused by the bridge or tunnel structures can ultimately change the species composition and abundance causing a shift in benthic fauna community structure. The pressure is then an indirect pressure on the benthic fauna.

2.2.9 *Drainage*

Drainage comprises several kinds of mainly freshwater outlets coming from the accumulation of water from the project structures. The water needs to be transported away from the structures, possibly treated in a water treatment plant and subsequently discharged. The drainage water comprises:

- rainwater = water that has no contact with the railroad or highway and does not need to be treated
- wastewater = water that has contact to the railroad or highway and needs to be treated

Depending on its origin the waste water may contain heavy metals, polycyclic aromatic hydrocarbons (PAH), oils, soap, salt from winter salting or suspended solids. Water treatment includes e.g. traps for suspended solids or oil separators. The timing of discharge events and the amount of water is depending on the specific drainage process and is partly unpredictable. At the outlets the discharged water will be diluted within the surrounding water. The pressure is thus restricted to the direct outlet area.

The varying salinity of the drainage water is the main characteristic for discharged water independent of its origin. In the surrounding marine waters at the outlet salinity will show a higher variability compared to natural conditions due to the discharge. Quick or major changes in water quality (salinity) may affect the benthic fauna by a change in the community composition or biomass.

The pressure is classified as:

- type: operation-related (indirect pressure)
- intensity: minor (see section 4.9)
- duration: varying depending on amount of drainage water
- range: near zone

3 DATA AND METHODS

This report is based on the data collected during the benthic fauna baseline study (FEMA 2013a), the assessment study on seabed and coastal morphology (FEHY 2013d), the assessment of the predicted sediment spill from the tunnel and bridge alternative (FEHY 2013e) and the impact assessment of the hydrography of the Fehmarnbelt area (FEHY 2013a, FEHY 2013b).

3.1 Areas of assessment

The EIA assessment area (Figure 3.1) is identical to the investigation area defined for the baseline survey (FEMA 2013a). The assessment results presented in this EIA generally apply to this total EIA assessment area (292,739 ha) or to areas or zones that form a part of the EIA assessment area. Pressures that have an extent reaching beyond the assessment area are additionally assessed qualitatively for these outside regions. For certain pressures, the results are also given with respect to the predicted fauna communities (FEMA 2013a) and their extent within the EIA assessment area (Figure 1.1).

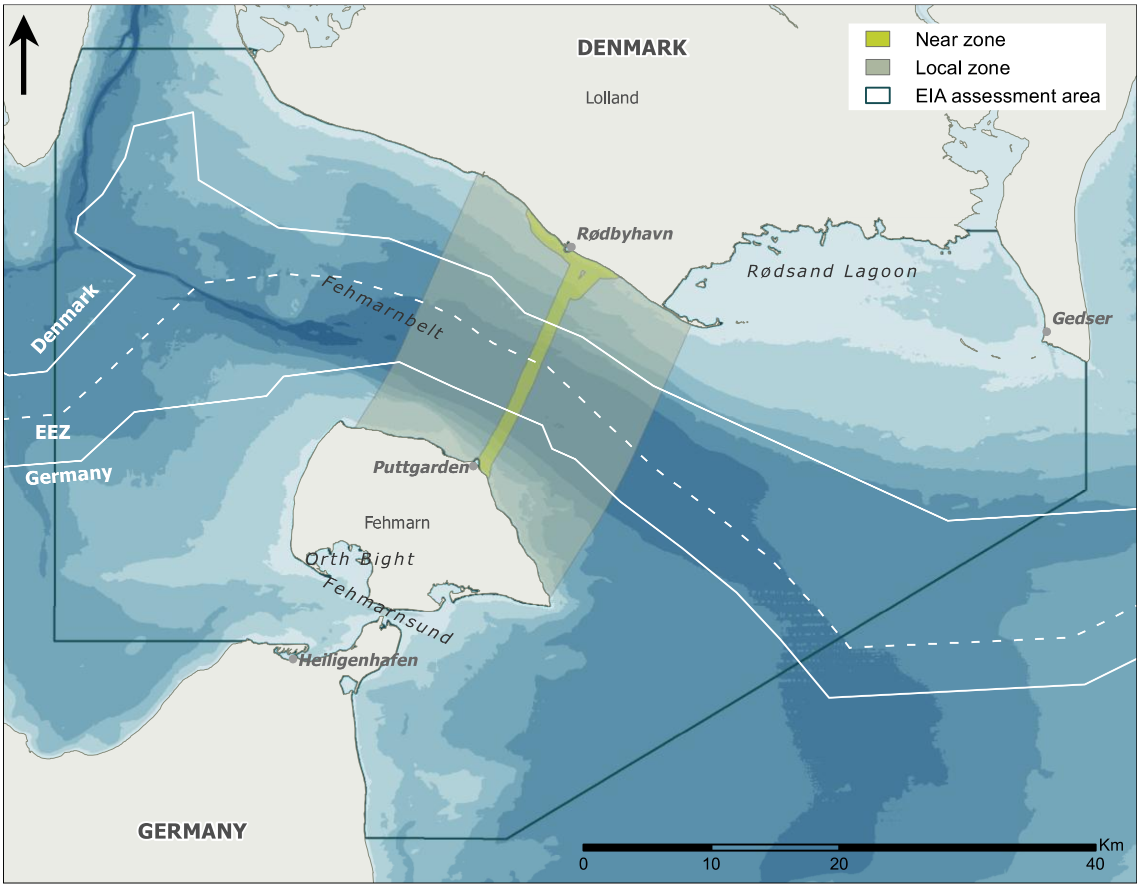


Figure 3.1 Tunnel assessment: Geographical borders of the complete EIA assessment area for which this EIA applies, and near zone and local zone for the tunnel alternative.

Besides this biological differentiation, a distinction into administrative zones (national, coastal, EEZ) and into buffer zones around the alignment and the project (near and local zone) is made. The location of the zones with respect to the EIA assessment area is shown in Figure 3.1 for the tunnel alternative and in Figure 3.2 for the bridge alternative.

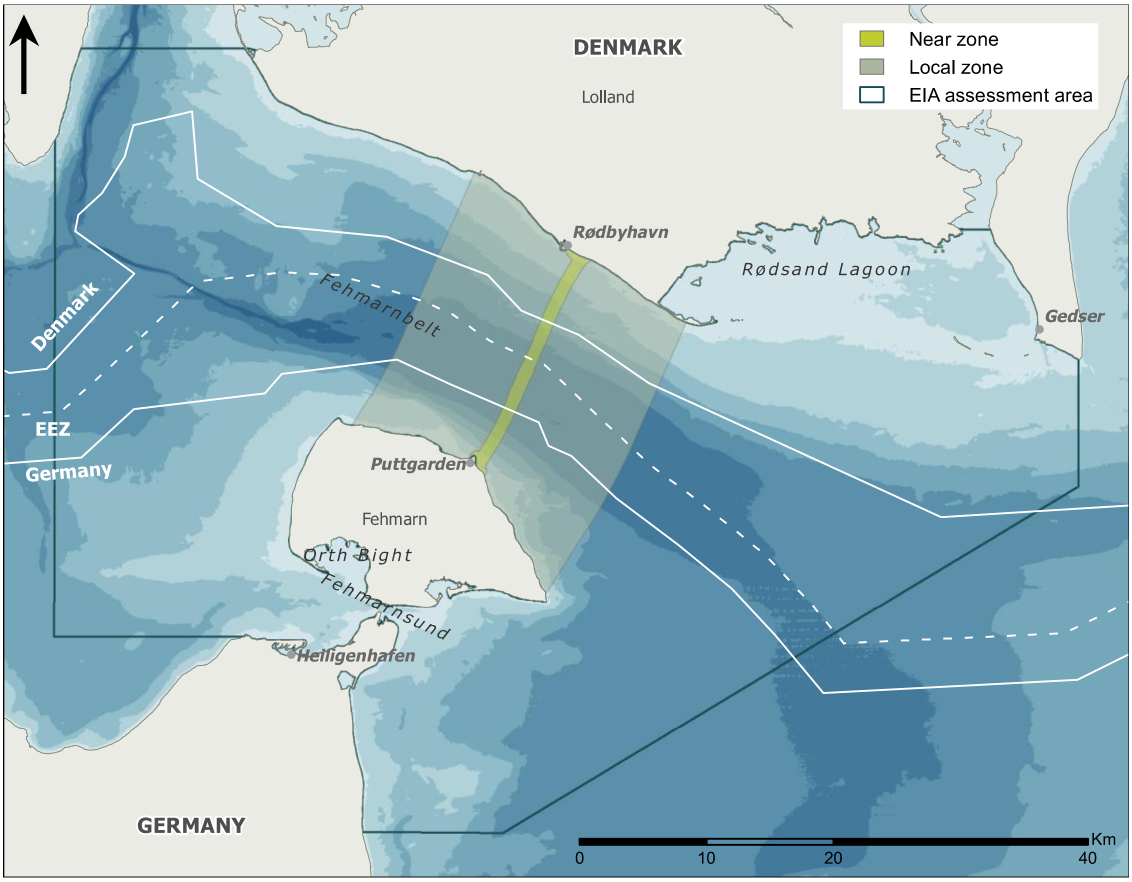


Figure 3.2 *Bridge assessment: Geographical borders of the complete EIA assessment area for which this EIA applies, near zone and local zone for the bridge alternative.*

Table 3.1 *Names, definitions and areas of the zones within the EIA assessment area. These zones are used where applicable to present the results of the EIA.*

Zone name	Zone definition	Area (ha)
near zone	A 500 m zone around the project structures during the construction phase (for tunnel: IMT-E-ME August 2011 design; for bridge: Var2-BE-E October 2010 design)	bridge: 2,030 tunnel: 2,968
local zone	A zone from the outer border of the near zone and up to 10 km to both sides of the centre of the tunnel trench (IMT-E-ME August 2011 design)	bridge: 39,366 tunnel: 38,427
DK	The national territory of Denmark plus its EEZ within the total assessment area	150,402
DE national	The national territory of Germany within the total assessment area	106,467
DE EEZ	The EEZ of Germany within the total assessment area	35,870

Transboundary impacts are impacts that reach outside the Danish and German territories.

3.2 Impact assessment methodologies

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.

3.2.1 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 and sub-components	To assess the impacts on the sub-factors, a number of components 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 to assess 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).	Component/sub-komponent	Komponente
Construction phase	The period when the Project is constructed; including permanent and provisional structures. The construction is planned for 6.5 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 struc-	Anlæg	Anlage

Term	Explanation	Term DK	Term DE
	tures such as work harbours and the tunnel trench.		
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.	Belast-nings-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 area.	Areal-inddragelse	Flächeninan-spruchnahme
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 duable. Grading of magnitude of pressure and sensitivity is method dependent. Grading of importance and impairment is as far as possible done for all factors.	Vurderings-kriterier og graduering	Bewertungs-kriterien 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.	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	Tab af areal	Flächenverlust

Term	Explanation	Term DK	Term DE
	is described by the intensity, the duration and if feasible, the range.		
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 Flächenver-lust
Impairment	An impairment is a change in the function of an environmental factor.	Forringelse	Funktionsbe-einträchtigung
Degree of impairment	The degree of impairments is assessed by com-bining 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 af forringelser	Schwere der funktionsbe-einträchtigung
Severity of impairment	Severity of impairment expresses the conse-quences of the Project taking the importance of the environmental factor into consideration; i.e. by combining the degree impairment with im-portance.	Signifikans	Erheblichkeit
Significance	The significance is the concluding evaluation of the impacts from the project on the environ-mental factors and the ecosystem. It is an ex-pert judgment based on the results of all anal-yses.		

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).

3.2.2 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 3.3 - Figure 3.5. More details on the concepts and steps of the schemes are given below. As mentioned above, modification are 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.

3.2.3 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 3.2 and Table 3.3, respectively.

Table 3.2 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 3.3 (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 3.3 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 3.4.

Table 3.4 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**

3.2.4 *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.

3.2.5 *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).

3.2.6 *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.

3.2.7 *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.

3.2.8 *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 3.3). 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 3.2). The loss is estimated as hectares of lost area. As far as possible the spatial distribution of the importance classes is shown on maps.

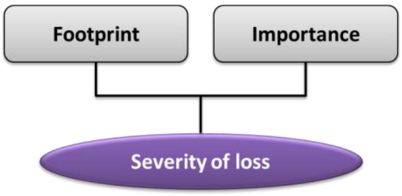


Figure 3.3 The assessment scheme for severity of loss

3.2.9 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 3.4). 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.

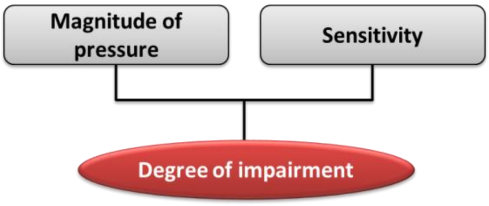


Figure 3.4 The assessment scheme for degree of impairment

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.

3.2.10 Severity of impairment

Severity of impairment is assessed from the grading's of degree of impairment and of importance of the environmental factor (Figure 3.5) using the matrix in Table 3.4. If it is not possible to grade degree of impairment and/or importance an assessment is given based on expert judgment.

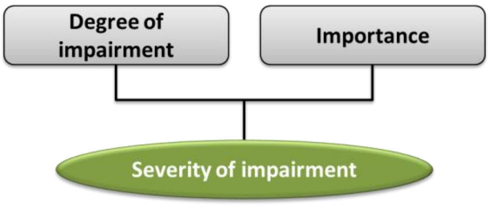


Figure 3.5 The assessment scheme for severity of impairment

3.2.11 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 3.6. 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 are also estimated.

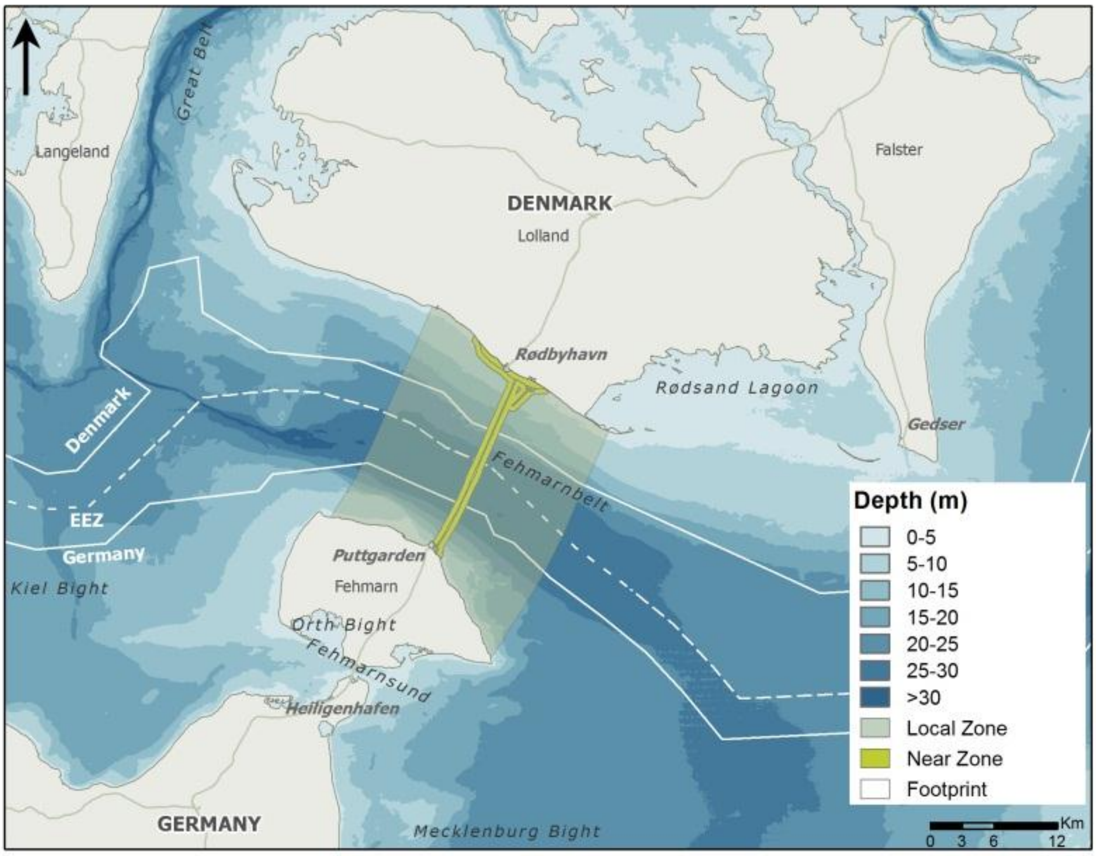


Figure 3.6 The assessment zones applied for description of the spatial distribution of the impacts. The near zone illustrated is valid for the tunnel alternative. It comprises the footprint and a surrounding 500 m band. The local zone is identical for the two alternatives. The eastern and western borders are approximately 10 km from the centre of the alignment.

3.2.12 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

3.2.13 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.

In general, the assessment is only done using scenarios with continued ferry operation. There is no difference with respect to the project pressures between continued ferry operation and without ferry operation. Also, the benthic fauna baseline conditions are not expected to differ between these two modes of operation.

There are two types of impact: loss and impairment. Loss is generally defined as habitat loss (e.g. loss due to the structures). Impairment is defined as the impairment of the biological function of a fauna community. This impairment can reach a degree that result in the loss of the biological function. This loss of function is methodically treated just like habitat loss. Both can be caused by the same specific pressure, but depending on the magnitude of pressure, the impact can be either loss of function or impairment or both.

3.3 Deviations from the general assessment scheme

All measures of magnitude of pressure are scaled such that a very high magnitude of pressure is equivalent to a loss of the biological function or the loss of the habitat of a fauna community, no matter the sensitivity. Thus, under very high magnitude of pressure, the assessment is done following the scheme for the severity of loss as described in section 3.8.

The assessment of severity of impairment is not done using the schematic matrix that links degree of impairment with importance and is part of the general assessment scheme (see section 3.8.2 for the used method). Firstly, the definition of importance of benthic fauna communities is generally not only based on biological (or environmental) factors, but also on legislative regulations. Importance should not be the only factor for deriving the severity of an impairment on biological communities. For pressures such as suspended matter and sedimentation, pressure events (considering both their intensity and duration) are used for the assessment of degree of impairment. The severity of impairment can potentially be different from the degree of impairment to a varying degree, depending on the sedimentation rates that result in the assessed sedimentation events. This cannot be foreseen and implemented in a linking matrix.

3.4 Assessment of magnitude of pressure

The magnitude of pressure is an abiotic measure of the force of the pressure caused by the project. Each pressure is defined by type, duration, intensity and range (see section 2.2). The two main parameters that account for the magnitude of pressure are intensity and duration. From these parameters, a quantitative four-level scale or a qualitative judgement is done of the magnitude of pressure.

Table 3.2 gives a short summary of the nine pressures together with the data used to attribute the magnitude of pressure. The actual detailed analysis is covered in section 1.

Table 3.6 Data used for the analysis of magnitude of pressure on the benthic fauna communities.

Phase	Pressure	Data used for magnitude of pressure
Construc-tion	Suspended sediments	- modelled sediment spill (FEHY 2013e) - FEMA model
	Sedimentation	- modelled sediment spill (FEHY 2013e)
	Toxic substances	- baseline concentrations of of toxic substances in the sediment (FEMA 2013b) - water quality assessment (FEMA 2013d)
	Construction vessels and imported material	- technical design (see section 2.1) - data provided by Femern A/S
Structure	Footprint	- technical design (see section 2.1) - data provided by Femern A/S
	Solid substrate	- technical design (see section 2.1) - data provided by Femern A/S
	Seabed and coastal morphology	- physical assessment of seabed and coastal mor-phology (FEHY 2013c, FEHY 2013d)
	Hydrographic regime and water quality	- physical assessment on hydrographic regime (FEHY 2013a) - water quality assessment (FEMA 2013d)
Operation	Drainage	- technical design (see section 2.1) - data provided by Femern A/S

3.5 Assessment of sensitivity

According to the definition of The Marine Life Information Network (MarLIN 2010), sensitivity is dependent on the *intolerance* of a habitat, community or species to a pressure from an external factor and dependent on the time taken for its subsequent *recovery* (recovery time). For the present EIA, information on intolerance and recovery is derived from literature data and expert judgement. The information is then applied and the two aspects are assessed separately and subsequently combined to four levels of *sensitivity*.

3.5.1 Intolerance

Intolerance is the susceptibility of a species population to damage (reducing the viability) or death (mortality), from an external pressure (Jones et al. 1994). The intolerance of a community to an environmental pressure is primarily dependent on the physiology and behaviour of the community's constituents. For example, individual species may have a higher or lower intolerance to oxygen depletion due to their physiological constitution, their mobility (i.e. possibility to escape out of areas under pressure) or by exhibiting burrowing behaviour (i.e. escaping into the sediment).

Intolerance is both pressure and community specific and is thus defined for each pressure individually. Benthic fauna communities are classified into four intolerance categories (see section 4.7) according to the general susceptibility to the pressure under consideration. The per-pressure classification is always based on the general scheme shown in Table 3.7. This scheme defines the overall criteria for ranking the communities into the four intolerance categories based on the parameters viability and mortality.

Table 3.7 General intolerance definition of the benthic fauna communities. This scheme is applied and interpreted individually for each relevant pressure.

Intolerance category	Definition
Very high	The pressure reduces the viability of the community to such degree that from around half and up to the whole community population is destroyed.
High	The pressure reduces the viability of the community such that up to around half of the community population is destroyed.
Medium	The pressure reduces the viability of the community markedly, but survival is not affected.
Minor	The pressure has a low detectable effect on the viability of the community.

The scale used is relative in the sense that it is not possible to assign a fixed intolerance that is totally independent of the magnitude of pressure. Even species or communities that are in general intolerant to a minor degree can be affected by mortality, if the magnitude of pressure is high enough. Therefore, in each of the assessed pressures, the scales of intolerance and magnitude of pressure are chosen such that the general definitions are satisfied as far as possible. The remaining deviations that cannot be captured using this scheme are consequently treated in the assessment of severity (see section 3.8).

3.5.2 Recovery time

The recovery time as defined here is the time a community needs to recover to a pre-impact state when the community or species were killed by a pressure. The recovery is mainly dependent on the biological structure of the community in terms of the species composition and the age or size distribution of the individuals. A community is considered to be recovered when the population of its structuring elements has reached an age/size distribution similar to what was observed before the particular disturbance. Each benthic fauna community consists of different indicator species (FEMA 2013a, Powilleit et al. 2009), which have distinct ecological characteristics like reproduction strategy, adult mobility and typical density, which again determines the time required for recovery.

The classification of the nine benthic fauna communities into the four recovery categories is identical for all pressures, because the recovery time does not depend on the type of pressure, but only on the magnitude of the pressure and the capability of the community to recover after the pressure and deterioration has stopped. The recovery time is defined as years needed for recovery to a pre-impact state, after complete or near-complete removal or destruction of the community. This also means that recovery time is less relevant when the communities are exposed to a lower magnitude of pressure. This is taken care of when intersecting recovery time and intolerance to get the final sensitivity towards a given pressure (see section 3.5.3).

3.5.3 Sensitivity

The overall sensitivity of a community is the combination of recovery time and intolerance. This combination is made using a matrix that maps the four categories of the two aspects of sensitivity into the four sensitivity categories minor, medium, high and very high (Table 3.8).

Table 3.8 *Sensitivity as a function of intolerance and recovery time.*

		intolerance			
	Sensitivity	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

There is no linear relationship between intolerance and recovery time under increasing magnitude of pressure. With a low magnitude of pressure, the intolerance is the major aspect governing sensitivity of a benthic community. If the magnitude of pressure is high enough, mortality gets an increasing influence and recovery time starts to play a role, because the population starts to die. This intrinsic relationship between magnitude of pressure and sensitivity is reflected in the matrix. The resulting sensitivity is weighted towards lower magnitudes of pressure, because these are dominating for all pressures assessed in the EIA. This means that the factor intolerance has a higher weight than the factor recovery time.

3.6 Assessment criteria

The following Table 3.9 summarizes the principal assessment criteria used for the assessment of the individual pressures presented in section 2.2. The pressures are described in details in sections 1 and 1. The listed criteria have been discussed and agreed upon with the relevant German authorities. In Table 3.9 the column "Possible impact" is equivalent to the degree of impairment as defined in section 3.7 and for loss of function this column corresponds to "severity of loss" as defined in section 3.8. The column "Magnitude of pressure" has the same meaning as what is described in sections 3.4 and 1.

Table 3.9 *Assessment criteria for the assessment of pressures (see text for further information).*

Phase	**Pressure**	**Possible impact**	**Magnitude of pressure**
Construction	Suspended sediments	Very high change of viability and food availability, high mortality	very high
		High change of viability and food availability, low mortality	high
		Minor to medium change of viability and food availability	medium
		Minor change of viability and food availability	minor
Construction	Sedimentation	Very high change of viability and food availability, high mortality	very high
		High change of viability and food availability, low	high

Phase	Pressure	Possible impact	Magnitude of pressure
		mortality	
		Minor to medium change of viability and food availability	medium
		Minor change of viability and food availability	minor
Construction	Toxic substances	Case-specific criteria	case-specific
Construction	Construction vessels and imported material	Case-specific criteria	case-specific
Structure	Footprint	Habitat loss. The criteria correspond to the importance of the communities	very high
Structure	Solid substrate	Case-specific criteria based on - the amount on existing solid substrate in a specific distance from the structure - water depth - local change of currents suitability of the solid substrate - potential for non-indigenous species	case-specific
Structure	Seabed and coastal morphology	Habitat loss. The criteria correspond to the importance of the communities	case-specific
Structure	Hydrographic regime and water quality	case-specific criteria: - baseline situation of communities - predicted changes in salinity, temperature, oxygen and currents - sensitivity of the communities against changes in these parameters	
Structure	Drainage	case-specific	case-specific

3.7 *Assessment of degree of impairment*

The degree of impairment is derived as function of the magnitude of pressure and the sensitivity according to the linking matrix (Table 3.10) given in the scoping report (Femern and LBV-SH-Lübeck 2010), except for the blue mussel assessment for the pressure suspended sediments, where degree of impairment is the output of a numerical model (see section 3.7.1 below). The very high magnitude of pressure results in a loss of function of the environmental component, which is regarded as loss and therefore assessed as severity of loss, taking the importance of the benthic fauna communities into account (see section 3.8).

Table 3.10 *Degree of impairment as function of sensitivity and magnitude of pressure. Very high magnitude of pressure is treated as loss of function (see section 3.8).*

	Degree of impairment	Sensitivity			
		very high	high	medium	minor
magnitude of pressure	very high	treated as loss of function			
	high	very high	high	high	medium
	medium	high	high	medium	minor
	minor	medium	medium	minor	minor

Thus, the degree of impairment describes the dimension of the biological reaction of the communities towards a pressure with a given magnitude depending on the sensitivity of that community. The sensitivity is defined and scaled such that the degree of impairment corresponds to the "Possible impact" as outlined in section 3.6 (see also sections 3.5 and 1).

3.7.1 Blue mussel population

The impact on the population of blue mussels due to suspended sediments during the construction phase is estimated using a numerical population model embedded in an ecological model (so-called FEMA model). The mussel model equations are fully integrated in the FEMA model, meaning that all feedbacks such as filtration of phytoplankton and release of nutrients are accounted for. The mussel model is described in more detail in Appendix B. The output of the model is the estimated change of the biomass of the mussel population.

This reduction is used as the degree of impairment of the mussel population. A reduction in biomass of less than 13% is considered to be negligible because it lies within the normal range of variation (Appendix B). Another point on the impairment scale is a reduction in biomass of 33% or larger. Such a level of reduction is likely to affect the size of the eider duck population that can be supported. At biomass reductions larger than 50% it is questionable if even individual eider ducks can find enough food. The resulting scale for the degree of impairment is shown in Table 3.11.

Table 3.11 *Degree of impairment of the blue mussel population in the assessment area as function of the reduction in biomass due to suspended sediments.*

Reduction in mussel biomass	**Degree of impairment**
> 50%	very high
33<50%	high
25<33%	medium
13–<25%	minor

3.8 Assessment of severity of impact

Impacts can be loss (as habitat loss) or impairment (as impairment of function or loss of function). The assessment of severity is done differently for the two impact types.

3.8.1 Severity of loss

The severity of habitat loss is derived as function of the lost area and the importance of the respective area. The intersection is done according to the linking matrix given in the scoping report (Femern and LBV-SH-Lübeck 2010). Since the magnitude of pressure is by definition always "very high" for habitat loss, this means the importance category directly translates into the severity of loss.

3.8.2 Assessment of severity of impairment

The severity of impairment is assessed based on the resulting degree of impairment caused by a specific pressure. This is done individually for each case. Initially, the degree of impairment is directly used as severity of impairment without adjustment. Secondly, the available information on the actual magnitude of pressure, the sensitivity of the affected fauna community and its importance is taken into consideration consequently either confirming the severity classification or changing it accordingly. This procedure does the same as the corresponding common linking matrix between importance and degree of impairment (e.g. FEMA 2013c) in a flexible way.

3.9 Assessment of significance

The last step in the EIA process is the assessment of significance. This step takes the results in terms of severity of impact, then uses the rules listed below and expert judgement to assess whether the derived severity is large enough to be of significant magnitude. Significance in this sense means that the impairment or loss is large enough to harm the ecological functioning of the ecosystem component or sub-component.

Principally, significance is assessed on the community level and the area of the communities is the important measure. The impacted area (loss or impairment) of the community is set in relation to the total area of the community in a zone, which extends to the border of the local zone. This means that the whole Fehmarnbelt including the footprint area and the near zone in a 20 km corridor is used as the comparison zone for the significance calculations (Table 3.12). If the loss or impairment extends beyond that comparison zone, the complete EIA assessment area is taken as comparison zone instead (Table 1.1). The significance assessment is then done in the following maximum three steps:

1. If the impacted community area is below 1% of the community area in the whole comparison zone, the impact is always insignificant (regardless of the duration and recovery time) because the function of a community or the ecosystem will not be affected by loss or impairments in this order of magnitude. The value of 1% is adopted from the proposed practice on the assessment of habitat loss for Natura 2000 sites (Lambrecht and Trautner 2007).
2. If the area is 1% or above, the duration of the impact and recovery time is considered. If the community is recovered within the "construction phase +" (i.e. the recovery is expected no later than two years after end of the construction phase), then the impact is also regarded as insignificant.
3. If the area is 1% or above and the community is recovered later than two years after the construction phase has ended (i.e. operation phases A, B or C) an individual judgement is made taking into consideration:

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

Table 3.12 *Areas (ha) of the predicted benthic fauna communities within the comparison zone (20 km corridor around the alignment) used as comparison for the assessment of significance.*

Community	**Comparison area**
Arctica	18,666
Bathyporeia	1,294
Cerastoderma	1,677
Corbula	7,804
Dendrodoa	243
Gammarus	5,526
Mytilus	6,125
Rissoa	0
Tanaissus	60
Total	41,395

4 MAGNITUDE OF PRESSURE

This section describes how the magnitude of pressure is defined and derived for all relevant nine pressures (see section 2.2). The pressures which are analysed as having a magnitude below a defined threshold (e.g. within natural variability or below a legal threshold value) are rendered negligible and thus not considered further in the assessment since they do not exhibit any threat to the benthic fauna. The actual distribution of the magnitude of pressure for the remaining non-negligible pressures is given in sections 7 and 8.

Table 4.1 gives a short summary of the pressures, which are not negligible in this EIA, together with the pressure indicators and the data input.

Table 4.1 Summary of all pressures on the benthic fauna communities that are treated with a detailed assessment in this EIA.

Phase	Pressure	Pressure indicator	Method and data input
Construction	Suspended sediments	Dilution of suspended food particles Abrasion and/or clogging of filtration organs (mgl^{-1} suspended sediment concentration in the near-bottom layer and days of duration, community-dependent)	GIS analysis Data input: Modelled sediment spill Benthic community map Data on sensitivity
	Sedimentation	Burial by sediment (depth, duration and deposition rate – impact is community dependent)	GIS analysis Data input: Modelled sediment spill Fauna community map Data on sensitivity
Structure	Footprint	Footprint area on top of the present benthic fauna communities	GIS analysis Data input: Footprint map Importance map
	Solid substrate	Increase in solid substrate area available for new colonisation Deposition of organic matter and muddy material on the surrounding soft-bottom communities Solid substrate as vector for non-indigenous species	GIS analysis Qualitative and quantitative analysis Data input: Data on additional solid substrate Fauna community map Data on sensitivity

4.1 Suspended sediments

The magnitude of pressure of suspended sediments is quantified using criteria based on expert judgement (e.g. tunicates being more sensitive than bivalves), existing literature (e.g. Cranford and Gordon 1992, Hygum 1993, Last et al. 2011, Kiørboe and Møhlenberg 1981) and the spill scenario data. The following criteria where used to delineate the classification of the magnitude of pressure:

- Irrespective of suspended sediment concentrations, continuous exposures lasting less than a week will not affect benthic invertebrates because mortality is very unlikely (all species can survive a week without food) and instant mortality has not been reported (Essink 1989, Lisbjerg et al. 2002). Growth rates of individuals may be affected, but as suspension feeders generally have a high growth rate, biomass will be restored quickly after the exposure to suspended sediments has stopped.

- An exposure to suspended sediments lasting between a week and a month leads to medium to very high impacts when the concentration is above 100 mg l^{-1} depending on duration (Purchon 1937). Physiological studies have shown a reduction in growth rates due to starvation and expenditures related to cleaning of filtering apparatus (Navarro and Widdows 1997, Velasco and Navarro 2002). Mortality is not expected at this level.

- At suspended concentrations below 10 mg l^{-1} impacts will be negligible because they mark the naturally occurring concentrations and even the most sensitive organisms (tunicates) do not respond negatively.

The magnitude of pressure is extracted from the concentrations of suspended sediment in the model year 2015. The year 2015 is the worst year with respect to the spill and where the maximum spill is reached. In later years the concentration of suspended sediments is below the threshold limit of 10 mg l^{-1} (FEHY 2013e). For each model grid, concentrations in the near-bed layer from the spill model were averaged over 7, 30 and 100 days using gliding averages. The corresponding magnitude of pressure was then determined according to Table 4.2. The highest corresponding magnitude of pressure found within the year was consequently used as representing a given model grid within the assessment area. Except for areas very close to the dredging activity, high concentrations of suspended sediments in the near-bed layer occur in connection with current- and wave-induced resuspension events, where both natural and spilled sediment are brought into suspension. Depending on the season, resuspension events occur every 1 (autumn) to 3 weeks (summer), each typically lasting 2–4 days (see Figure 5.2). Multiple events of long duration within a short interval are therefore not likely and for simplicity only this highest uninterrupted event is used to define the magnitude of pressure in each model grid.

Table 4.2 Magnitude of pressure for suspended sediments in terms of the concentrations in mg l^{-1} and the duration in days.

		Duration (uninterrupted)		
Magnitude of pressure		≥ 100	30–99	7–29
Concentration	≥ 100	very high	high	medium
	50–99	high	medium	Minor

Magnitude of pressure		Duration (uninterrupted)		
		≥ 100	30–99	7–29
	25–49	medium	minor	minor
	10–24	minor	minor	minor

For the blue mussel population along Lolland and around Fehmarn indirect effects of suspended matter were modelled numerically (see section 3.7.1). These are mediated through a reduction in light that consequently leads to a reduction in phytoplankton production followed by reductions in phytoplankton biomass (which is food for mussels).

The result of the magnitude of the pressure is considered a conservative estimate because the applied sediment spill model does not include the filtration capacity of the mussels (FEHY 2013a). There is a lack of knowledge on precisely how much of the suspended sediment is removed by the mussels and the possible reduced impact derived from this (FEMA 2013c). The suspended sediment is hence most likely over-estimated.

4.2 Sedimentation

The expected amount of the sediment spill during the construction phase is quantified in so-called "spill scenarios" (FEHY 2013e). These are the results of a hydrodynamic model covering the area from Kattegat to the Arkona Sea. Different sediment types are represented in the model and the dispersal of the sediment due to the construction activities is modelled. These results were in turn used to estimate the magnitude of pressure (MOP) for the benthic fauna (Figure 4.1). The MOP used here is defined as the „largest incidental net deposition that remains in place for a given time". Thus, the MOP is dependent on two parameters: the thickness of the sediment layer and the time it remains in place. For simplicity, the single largest sedimentation event found during the whole construction phase is used to define the MOP for a given location. In other words, the highest MOP assigned to a sedimentation event in a bottom-layer grid cell of the sediment spill model output is used as the representing MOP of that model cell. The minimum time for the duration is 2 hours, corresponding to the minimum time step of the output data from the sediment spill model.

Only sedimentation of 3 mm and above is considered, regardless of the time it remains in place and the corresponding sedimentation rate. Benthic fauna can generally cope with such low levels of deposition of natural sediments and remains unaffected due to its burrowing/escaping ability and its ability to selectively reject particles when feeding on e.g. pelagic phytoplankton (Miller et al. 2002, Gibbs and Hewitt 2004). The 3 mm threshold value is documented in Gibbs and Hewitt (2004) for the deposition of terrigenous sediments that are considered synonymous with the clay fraction. The grain size fractions treated in detail by the spill modelling include clay (< 4 µm) and silt (4–63 µm) and the biogeochemical effect of these indigenous sediments on benthic fauna should be weaker. Thus, 3 mm was assumed as a conservative documented threshold value for the present assessment.

According to the feasibility study (COWI-Lahmeyer 1998) the mean natural background sedimentation rate in deeper areas of the assessment area is approximately 1.5 mm a^{-1}, whereas the shallow waters in the Baltic are generally regarded as abrasion/erosion areas where erosion is higher than sedimentation (Bobertz and Harff 2004). The natural variability of sedimentation is somewhat larger depending on the frequency and magnitude of storm events, wind and wave action. The modelled spill will add to this background value. The natural background sedimentation is different for the sheltered shallow areas (Rødsand, Orth Bight), the exposed shallow waters (coastal) and the exposed deeper waters (offshore). The assessment results derived using the current MOP will thus be adjusted for these existing differences in the evaluation of the severity and the interpretation of the significance of the impairment.

The individual areas in the intensity-duration diagram ("envelopes") are delineated by linear relationships between pressure intensity and duration (Figure 4.1). The size and extent of the envelopes have been established according to literature estimates and expert knowledge as operational approximations (the black triangles are data points as encountered in the literature). It was needed to incorporate this biological knowledge in order to ensure a proper scaling of the four MOP categories. A very high and high magnitude of pressure should correspond to an effect on viability and mortality, so it fits into the general definition of sensitivity and the resulting degree of impairment can be interpreted corresponding to the assessment criteria given in section 3.6. A minor magnitude of pressure should likewise correspond to an effect on viability only.

Considering a specific spilled amount, sedimentation events with a short duration in the range of hours and days have a corresponding sedimentation rate that is comparably high and thus the left part of the MOP diagram is related mostly to the deposition height. The longer the duration of an event is (weeks to months), the higher is the probability that the corresponding sedimentation rate is low. Therefore, the magnitude of pressure will not increase for a specific deposition thickness, the longer that deposition remains in place. The fauna will react on the deposited material and slowly recover from the event. The point where the corresponding border between two categories of MOP levels off is dependent on the height of the initial deposition layer. The thicker that layer is (corresponding to a higher MOP and higher sedimentation rate), the later recovery will begin. Thus, for a very high MOP, the levelling starts later than for a minor MOP.

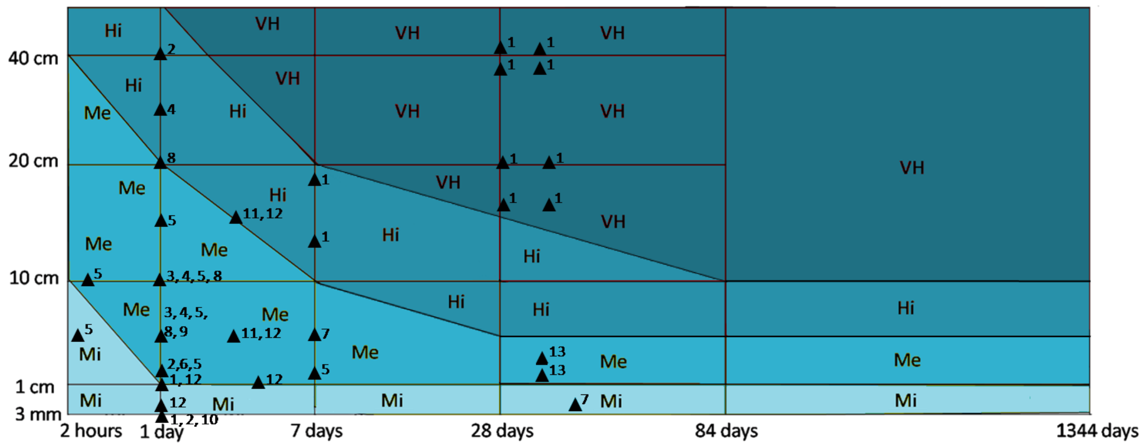


Figure 4.1 *Magnitude of pressure (MOP) of the pressure sedimentation with duration along the horizontal axis and intensity along the vertical axis. The minimum intensity is 3 mm as the lowest level of excess sedimentation with documented negative effect on viability of marine benthic fauna. The minimum duration is 2 hours, which is the minimum time-step of the output data from the sediment spill modelling. The intensity-duration envelopes for the four categories minor (Mi), medium (Me), high (Hi) and very high (VH) are given in different colours. References used in the figure are shown as numbers (see section 1 for full citations): 1 = (Powilleit et al. 2009), 2 = (Essink 1999), 3 = (Maurer et al. 1986), 4 = (Nichols et al. 1978), 5 = (Miller et al. 2002), 6 = (Anderson et al. 2004), 7 = (Montserrat et al. 2010), 8 = (Chang and Levings 1978), 9 = (Chandrasekara and Frid 1998), 10 = (Gibbs and Hewitt 2004), 11 = (Bolam 2011), 12 = (Hinchey et al. 2006), 13 = (Turk and Risk 1981).*

4.3 *Toxic substances*

The baseline study on toxic substances (heavy metals and organic pollutants) showed that the concentrations in the sediment are below existing national and international sediment quality guidelines (FEMA 2013b). A conservative calculation of potential release of toxic substances during dredging showed that water quality standards set by EU will not be exceeded (FEMA 2013d).

Therefore, risk of accumulation and poisoning in benthic invertebrates by toxic substances is negligible.

4.4 *Construction vessels and imported material*

4.4.1 *Potential new non-indigenous species*

The most important *direct vector* for non-indigenous species is ship traffic which may transport and release organisms that settle on the underwater hull. An *indirect vector* is the material imported to the project area (sand, stones etc. of marine origin). Both these vectors can transport new non-indigenous species from regions other than the EIA assessment area.

Figure 4.2 shows the planned production sites and extraction (excavation) areas. These are all located in the same bio-geographical region of the Baltic Sea as the Fixed Link and transport of material and vessels between these sites will follow the already existing ship traffic routes. These waterways also correspond to the main currents and water flow into and out of the Baltic Sea. The Fehmarnbelt area itself is passed by yearly 47,000 ships, most of them using the route through the Great Belt (Femern 2010).

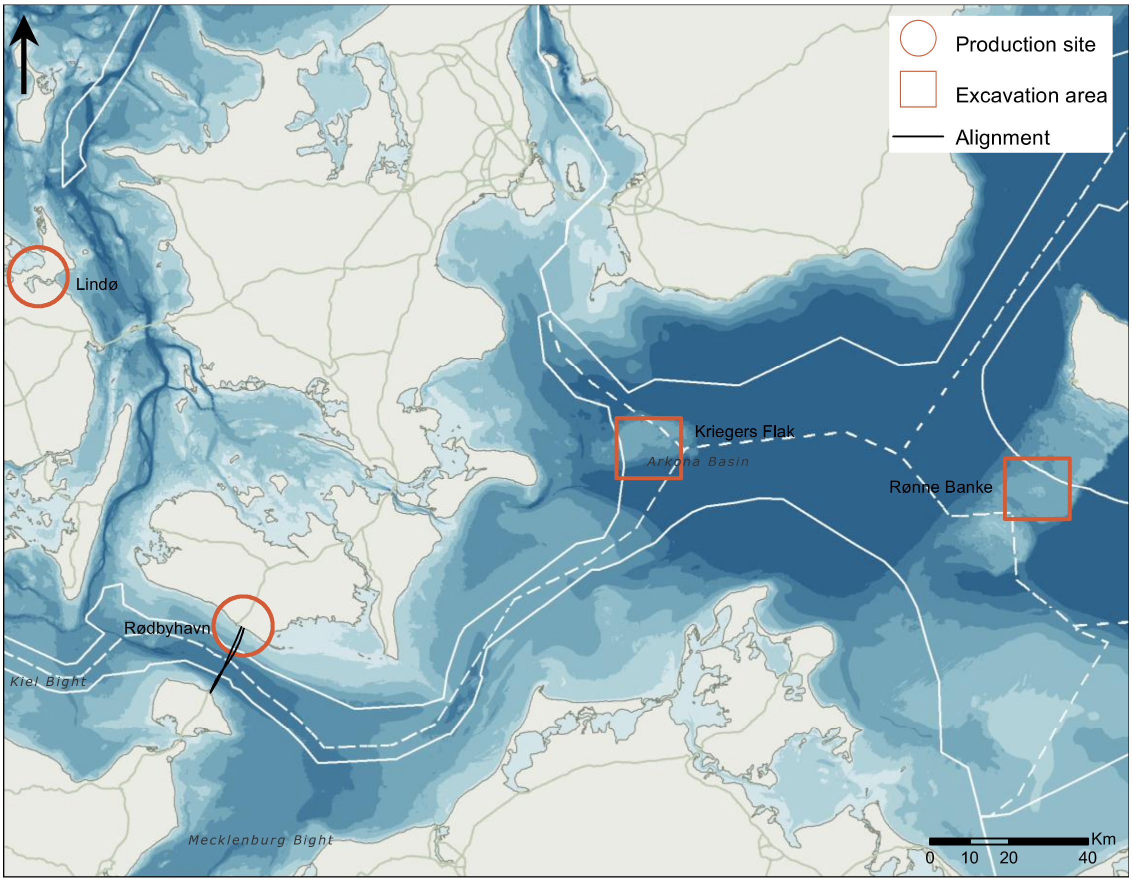


Figure 4.2 Locations of planned production sites and sand excavation areas for the construction phase of the project.

This baseline situation already constitutes a constant risk and potential for new non-indigenous species. The project does not add new vectors that not already exist in nearby places. For certain material (rock, crushed rock and gravel) transportation from Norway, Sweden or Denmark is specified. Exact locations are not yet known, so the risk cannot be assessed. In general, however, increased ship traffic from locations outside the Baltic Sea (Norwegian Sea or Skagerrak) can also increase the risk of introduction of new non-indigenous species.

The risk of introduction of new non-indigenous species and thus the magnitude of pressure is considered as being very low and negligible.

4.4.2 Existing non-indigenous species

In the Kattegat and Belt Sea sub-region of the Baltic Sea, including the Fehmarnbelt, 42 aquatic species are known as being non-indigenous species. 23 of them belong to the benthic fauna. These species are either already established species in the nine benthic fauna communities described for the baseline situation (FEMA 2013a), reproducing and living there for their whole life cycle, or in the process of further spreading and beginning permanent settlement. Most of the species are sessile or have only a low mobility and further distribution takes place via planktonic larvae. Therefore, new habitats created due to the construction works can potentially be colonized within a year after introduction.

All of the 23 known non-indigenous species have a lower potential of increased spreading due to the construction works than their potential to reproduce and spread naturally (see Appendix A for a discussion of each of the 23 species). Most of the species are not established in the EIA assessment area, either because of their marine origin and physiological limitations towards lower salinities in the Baltic Sea or because they are freshwater or genuine brackish water species and tolerate only low (oligohaline or low mesohaline) salinities.

Therefore, the risk of increased spreading of these known non-indigenous species is negligible.

4.5 Footprint

By definition, the magnitude of pressure of footprint is always "very high", since footprint is resulting in a habitat loss and thus a loss of function. The location and extent of the footprint used for the assessment is described in section 7.3.1 for the tunnel and in section 8.3.1 for the bridge solution.

4.6 Solid substrate

4.6.1 Aspect 1

For this aspect of the pressure, i.e. the solid substrate itself, the magnitude is determined by the area of the additional solid substrate. This is given per assessment zone and per community where the additional solid substrate is introduced.

The underwater part of the embankment for the bridge alternative has an average width of 16 m at Fehmarn and Lolland and has a general falling gradient of 1:2. The average water depth is estimated to be 4 m where the embankments are located. It is assumed that the area of the embankments which stretched under water is approximately the same for the bridge and tunnel alternative.

The additional solid substrate from the bridge piers and pillars has been calculated based on the technical drawings of the project structures provided by Femern A/S. The estimated areas of embankments and other structures made of boulders and stones do not account for the three-dimensional structure that is caused by the material itself. Only the projected two-dimensional area that is occupied by the horizontal extent of the structure is considered.

4.6.2 Aspect 2

For this aspect, i.e. the effect of the hard-bottom communities on the surrounding communities, the pressure is a near zone pressure that cannot be detected far from the source. The current regime in the Fehmarnbelt determines the spatial extent of this influence. A theoretical estimate can be done using the sinking speed of faeces and pseudofaeces and the horizontal current speed in the area. Sinking speed varies between 0.3 and 1.8 cm s^{-1} with an estimated average of 1 cm s^{-1} (Callier 2009). The average horizontal current speed is between 35–37.5 cm s^{-1} at the surface in the central Fehmarnbelt (FEHY 2013b). From the surface to the pycnocline at roughly 15 m water depth (depending on the location and the bathymetry) the current speed is decreasing to around 25 cm s^{-1}. This upper water layer shows a net outflow towards the North Sea. Below the pycnocline the current speed is increasing again due to net inflow of saline water into the Baltic Sea and then decreases near the sea floor with typical values of around 10 cm s^{-1} at the bottom (FEHY 2013b). These average numbers are used to estimate the theoretical extent for the pressure using an average westward current in the upper layer of 30 cm s^{-1} and eastward 18 cm s^{-1} in the lower layer. A potential turbulence of the water around the piers and pillars is ignored because its effect on the sedimenting material cannot be quantified.

According to this simple model, the maximal distance from the pillars and piers where faeces can reach the seafloor is 180 m when the water depth is 30 m. At this distance from the solid substrate, a high dilution of the material has occurred resulting in a lower magnitude of pressure. Studies on other underwater structures (Wolfson 1979, Davis 1982) show detectable effects both from sedimenting material and also from foraging fishes to a distance of roughly 50 m. In order to do a conservative assessment without using the maximum theoretical value, a maximum extent of 100 m is assumed for a water depth of 30 m. It is assumed that the extent decreases linearly with water depth to a minimum value of 1 m extent at 1 m water depth. Figure 4.3 shows the total extent of the pressure in relation to the water depth. Investigations from the Darss Rise revealed similar results (Zettler and Pollehne 2008) with a main transport of particles within a 250 m radius.

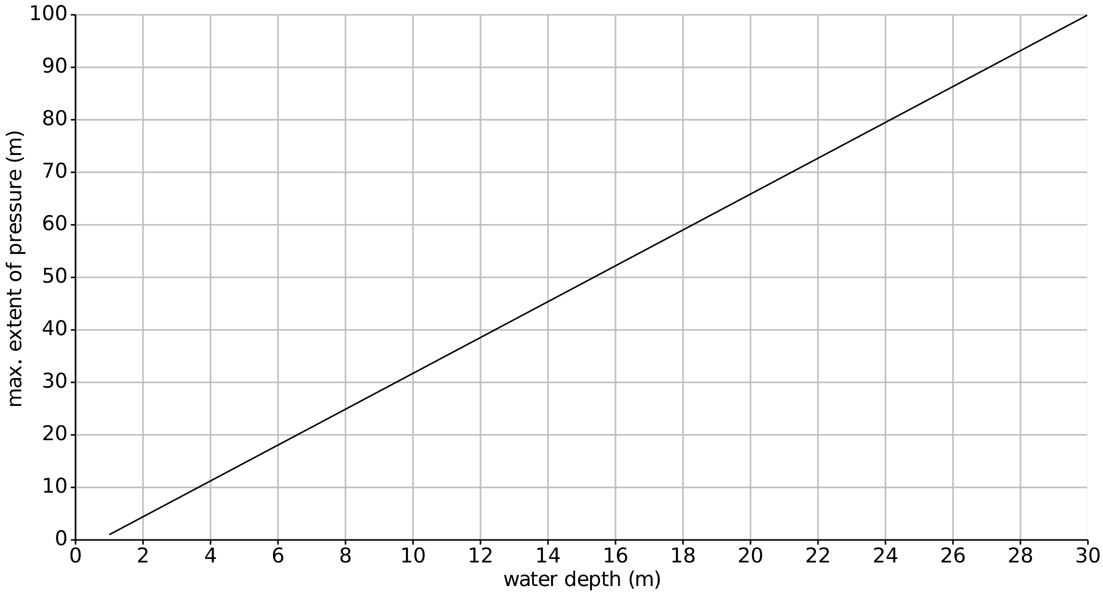


Figure 4.3 Maximum extent of aspect 2 of the pressure solid substrate as a function of water depth.

Faecal material is not the only influence on the surrounding communities. Sedimenting marine organisms, mainly mussels, will accumulate around the piers and pillars and change the community structure of the existing fauna community to a hard-bottom community with high organic content. This effect which is equivalent to the loss of the original community, is restricted to a narrow band around the piers and pillars and estimated to an average extent of 2 m (water depths less than 4 m are not relevant for the bridge, since there are no piers shallower than 4 m). This value defines the spatial extent for the very high magnitude of pressure (Table 4.3).

Table 4.3 Definition of the magnitude of pressure and its spatial extent for the aspect 2 of the pressure solid substrate.

Magnitude of pressure	Definition
very high	The area directly at the introduced solid substrate from 0 to 2 m distance
high	The area from 2 m to a fourth of the total extent of the pressure
medium	The area from a fourth to half the extent of the pressure
minor	The area of half to the full extent of the pressure (see also Figure 4.3)

4.6.3 Aspect 3

Aspect 3 is the influence on non-indigenous species. The magnitude of this aspect of the pressure is determined by the amount of the introduced substrate and the suitability for marine organisms. The amount of solid substrate introduced is large compared to the amount of existing solid substrate in the assessment area (see section 4.6.1). However, similar structures already exist at the Little Belt, Great Belt and Øresund bridges. Together with the existing harbour structures and the ship traffic (see section 4.4) in the region around the Fehmarnbelt, it is estimated that the additional solid substrate does not add new settling possibilities that are not already available elsewhere in the area.

The suitability of the solid substrate for the settlement of marine organisms is strongly dependent on the biological competition and succession patterns happening on the solid substrate. Experiences from other projects show that the upper part of the piers and pillars will be dominated by algae and mussels (down to approx. the pycnocline) and the hard-bottom communities become sparse below (Petersen and Malm 2006, Zettler and Pollehne 2006). Therefore, non-indigenous species will have to compete with the typical local hard-bottom communities in order to successfully use the solid substrate as a vector for further spreading and establishment. This has not been observed in any of the other bridge projects mentioned above. Additionally, none of the known non-indigenous species (see Appendix A) are evaluated to benefit from new solid substrate, either because of physiological limits or because their natural reproduction and spreading potential is high enough in itself to further sustain their populations.

Thus, this aspect of the pressure is regarded as negligible.

4.7 Seabed and coastal morphology

Changes in seabed and coastal morphology due to dredging activities and footprint (e.g. tunnel trench and access channel) are not dealt with in this section, as the pressures from suspended sediments, sedimentation and footprint on the benthic fauna are dealt with separately (see sections 4.1, 4.2 and 4.5). The direct impacts of the project on seabed and coastal morphology are assessed in (FEHY 2013c) and (FEHY 2013d) based on result of hydrographic models.

4.7.1 *Seabed morphology*

Tunnel
The results from the seabed assessment show that there is no direct impact from the tunnel alternative on seabed morphology due to altered current regimes caused by new structures except for the direct loss caused by the footprint (see section 4.5). Therefore, no indirect pressure on the benthic fauna is expected.

Bridge
For the bridge alternative, a new current regime around the bridge pillars creates a permanent impact on the seabed (FEHY 2013c). In the near vicinity of the bridge piers and pillars the existing bedforms in the deep parts of Fehmarnbelt may disappear due to increased turbulence and a large increase in current speed around the structures (> 25% increase). The area is approximately four times the diameter of each pier or pillar. The impacted area covers approximately 128 ha of the areas with bedforms and in total 166 ha of the seabed. Within the local zone there will be a change in current speed between 2.5 and 10%, which increases or decreases sandwave heights by 10–25% (FEHY 2013c). The bedform height will not change abruptly, but develop over 5–10 years for smaller sand waves and 15–20 years for larger sand waves (FEHY 2013c). Furthermore, the increase or decrease in bedform heights does not change the composition of the sand (grain size distribution) and the overall habitat structure of the seabed is not expected to change (FEHY 2013c). Sand waves and other bedforms are by nature dynamic structures that change slowly, even under the existing hydrodynamic conditions of the Fehmarnbelt.

Impacts on the benthic fauna due to changes in seabed structures are not likely to occur. The benthic fauna is widely distributed across areas with and without bedforms, hence the distribution on a large scale is independent of bedforms. Furthermore, the communities are adapted to slow changes in bedforms and the habitat type is not likely to change. The expected magnitude of pressure on the benthic fauna due to changes in seabed morphology is therefore negligible.

4.7.2 *Coastal morphology*

Direct impacts on coastal morphology are caused by reclamation areas for the tunnel alternative and marine ramps for the bridge alternative, which block sediment transport and change wave action patterns (FEHY 2013d).

Tunnel
The assessment of the direct impacts from the tunnel alternative on coastal morphology concludes that there will be a minor impact west of the reclamation area at Lolland. This area will become a deposition site where sand will accumulate and in a period of 30 years a new beach will develop. The seabed and hence the benthic fauna in this area will be lost. The area has a size of *approximately* 32 ha (FEHY 2013d), corresponding to 0.08% of the total comparison zone. This magnitude of pressure is regarded as negligible.

It has been predicted that the coast east of the reclamation area at Lolland will erode and the seabed be deepened (FEHY 2013d). On a short time scale (<20-25 years) the coastline immediately east of the reclamation (1,100 m) will retreat up to 3-5 m a^{-1}. The erodible (loose) seabed material in the coastal profile will erode and change the seabed structure towards a (semi-)hard bottom of moraine clay. The erosion area covers up to 0.3-0.5 ha a^{-1} (3-5 m a-1 x 1,100 m). On a longer time scale (>20-25 to 120 years), erosion will spread further east (1,100-4,100 m east of reclamation). Average coastline retreat rates of about 0.5-1 m a^{-1} will change the seabed structure of about 0.15-0.33 ha a-1 (0.5-1 m x 3000 m).Due to the small area, this pressure on the benthic fauna is regarded as negligible.

On the Fehmarn side, the tunnel alternative has a potential impact on erosion of the seabed between the groins and in front of the seawall protecting Ohlenborgs Huk (FEHY 2013d). The pressure results in an erosion of the coast and will not affect the benthic fauna on the Fehmarn side.

Bridge
The direct impact from the bridge alternative is potentially caused by the marine ramps (including the new beaches), piers and pillars (FEHY 2013d). There will be an impact of increased coastal erosion of the coastal profile/seabed along the section 0-1,100 m east of the marine ramp at Lolland. The erosion is caused by the effect of the ramp blocking the sediment transport along the coast. The seabed along this section is however already starved from loose seabed material due to the impact from Rødbyhavn, which also blocks the sediment transport. The character of the seabed is therefore not expected to change significantly from the baseline situation.Hence there will not be an impact on the benthic fauna.

A sand formation is located west of the marine ramp at Fehmarn off "Grüner Brink". The formation migrates approximately 10 m a^{-1} (FEHY 2013d). The bridge piers and pylons will lead to a net increase in sediment transport of 15–20% along the main part of this sand formation, increasing the migration rate to approximately 12 m a^{-1} (FEHY 2013d). This indirect pressure on the benthic fauna is estimated to be negligible, because species in this area are adapted to high migration rates (FEMA 2013a).

East of Fehmarn there will also be a potential increased erosion of the coast, which can deepen the seabed slightly. The bridge may have a potential impact on erosion of the seabed between the groins and in front of the seawall protecting Ohlenborgs Huk. Minor coastline retreat (estimated to 0-0.5 m a-1) is expected along the beach section 0-2,165 m south of Ohlenborgs Huk. The coastline in the area is presently stable, and the magnitude of this pressure on the benthic fauna (~0.05 ha a^{-1}) is regarded as negligible.

In conclusion, none of the direct impacts from the bridge alternative on the coastal morphology which extend to the seabed (FEHY 2013d) pose an indirect pressure on the benthic fauna.

4.8 Hydrographic regime and water quality

Direct impacts of the project on the hydrographic regime have been assessed in (FEHY 2013a). Furthermore, a biological model has simulated the chlorophyll-a concentration, the primary production and the near-bed oxygen concentration for the tunnel alternative and the impact has been assessed (FEMA 2013d). In connection to the modelling of the seabed morphology, the hydrographic regime around the bridge alternative has also been modelled (FEHY 2013c).

Phytoplankton is a key food source for many benthic organisms. In the Fehmarnbelt and adjacent areas (Great Belt and Western Baltic) the impact on phytoplankton production, measured as surface chlorophyll-a is within the natural variability in the area (FEMA 2013d). Changes are less than ±0.03 µg l^{-1} compared to the baseline conditions and in general nearly zero. Therefore the indirect pressure on the benthic fauna is regarded as negligible.

Tunnel

The assessment of the direct impacts on the hydrographic regime (FEHY 2013a) show that only minor and negligible changes in current speed related to the access channel and reclamation areas are expected (Figure 4.4). This indirect pressure is negligible for the benthic fauna.

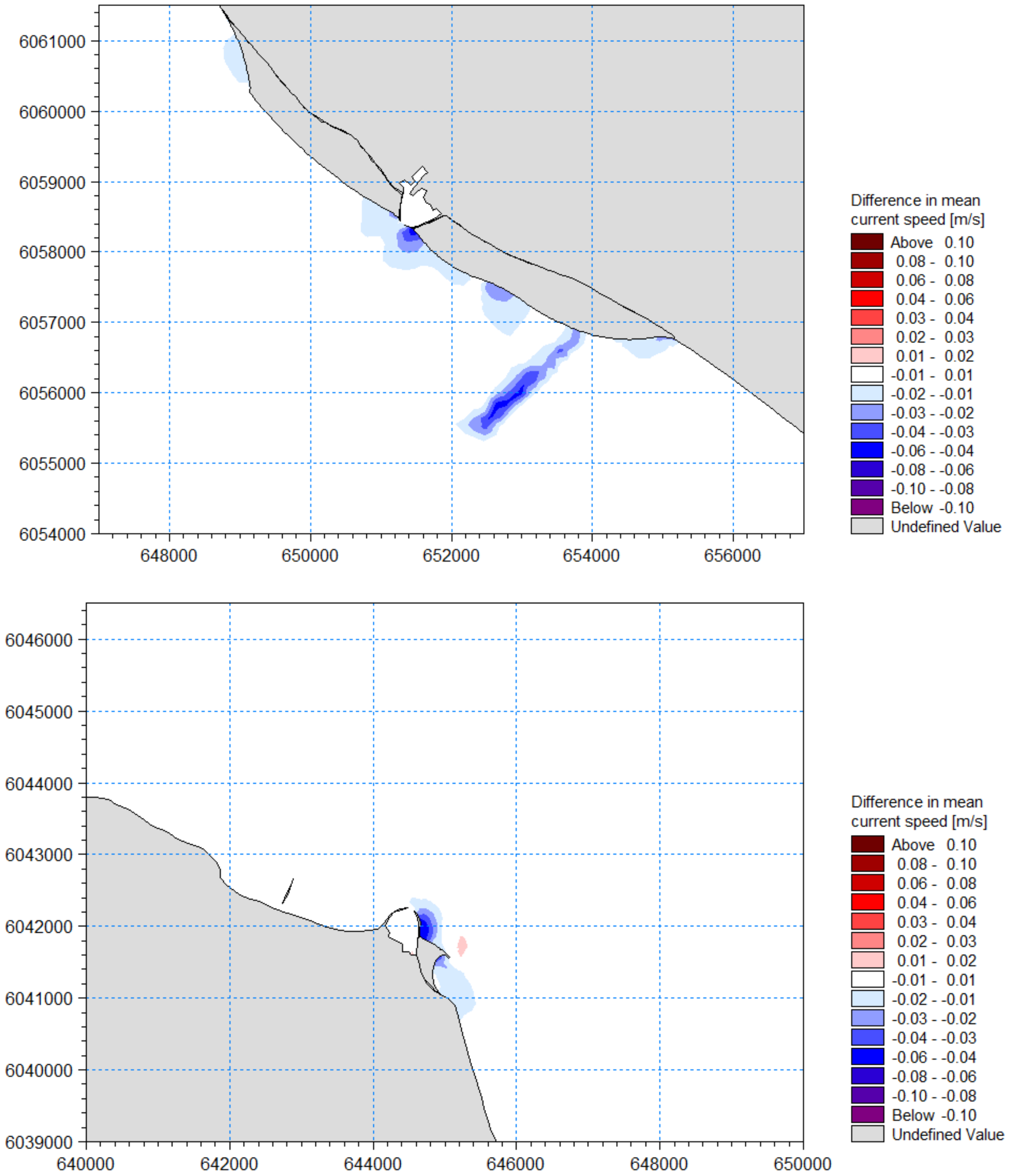
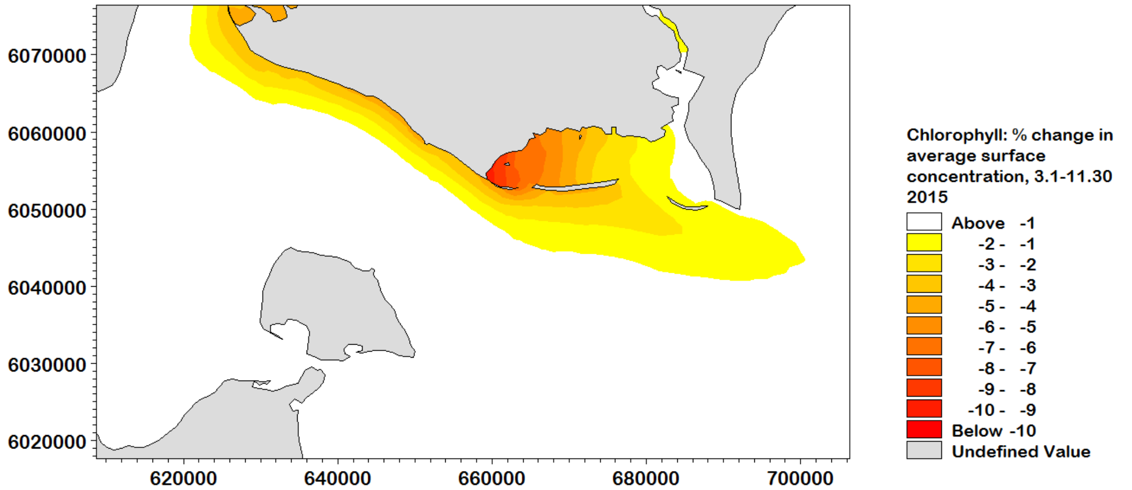


Figure 4.4 Estimated effects on mean bottom current speed (from FEHY 2013a) for the tunnel alternative (August 2011 design) with access channel for the Danish side (upper panel) and German side (lower panel).

The assessment of the results from the water quality and plankton modelling (construction period) (FEMA 2013d) shows that the chlorophyll-a concentration is reduced with maximal 10% and the primary production is reduced with up to 30% locally along the Lolland coast in 2015 due to light attenuation from spilled sediments (Figure 4.5). The very high reductions in the integrated primary production are local and confined to a spot close to the Lolland reclamation area. Such reductions can affect the growth of benthic filter feeders such as mussels. This potential effect is dealt with in the assessment of impact on mussels (see section 7.1). The concentration of near-bed oxygen from June through September 2015 is reduced with up to 8–11% locally along the Lolland coast related to shading from sediment spill (Figure 4.6). The reduction is caused by reduced biomass, growth and production of macroalgae. The largest reduction in oxygen occurs at shallow waters and above the pycnocline where oxygen is close to saturation and the concentration of oxygen does not fall below 5 mg l^{-1}. Therefore, these direct effects are a negligible pressure on the benthic fauna communities.



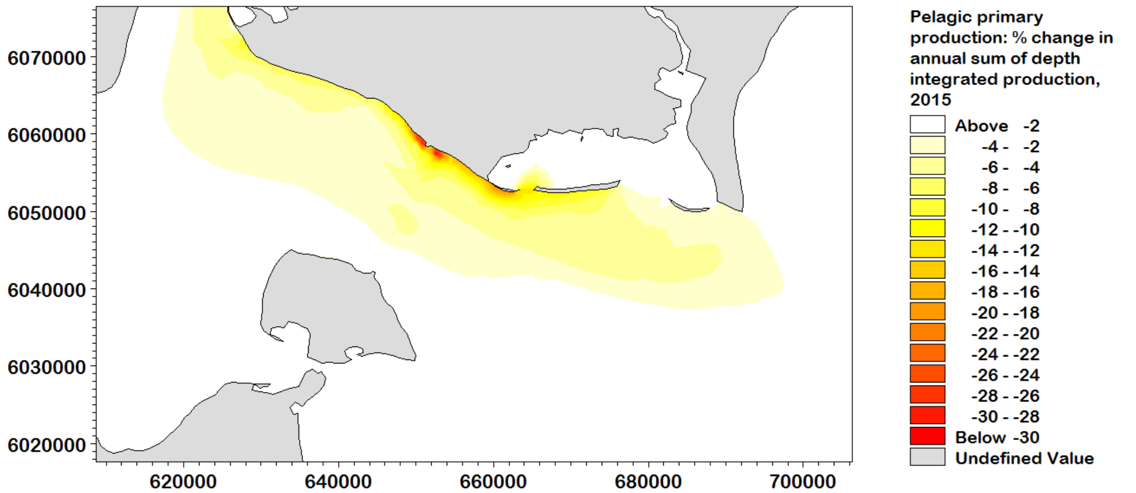


Figure 4.5 Estimated reductions in chlorophyll-a (upper panel) and primary production (lower panel) for the tunnel alternative related to dredging in 2015.

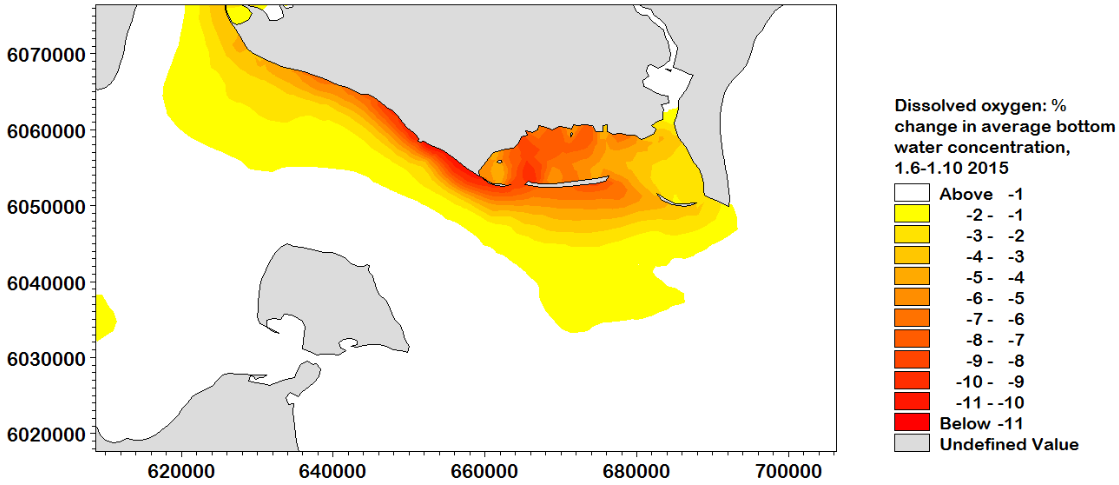


Figure 4.6 Estimated reductions in oxygen concentration for the tunnel alternative related to dredging from 1 June to 1 October 2015.

Bridge

The assessment of the direct impacts on the hydrographic regime (FEHY 2013a) show that only minor and negligible changes in current speed related to the bridge alternative are expected. The change in bottom current speed will be less than 0.005 ms^{-1} outside the near zone of the bridge. This is regarded as no change (FEHY 2013a) and there will thus not be an indirect pressure on the benthic fauna communities in the local zone. In the near zone, the bottom current speed will increase more than 25% within an area of 4 times the diameters of each pillar (FEHY 2013c). The impacted area has a size of 223 ha, which corresponds to 0.08% of the whole assessment area. The average bottom current speed in the alignment area is between 0.05 and 0.15 ms^{-1} (Figure 4.7) and the predicted change in currents will not exceed values that can typically be found in other places in the assessment area. Thus, the pressure on the benthic fauna communities from increased current speed is regarded as negligible.

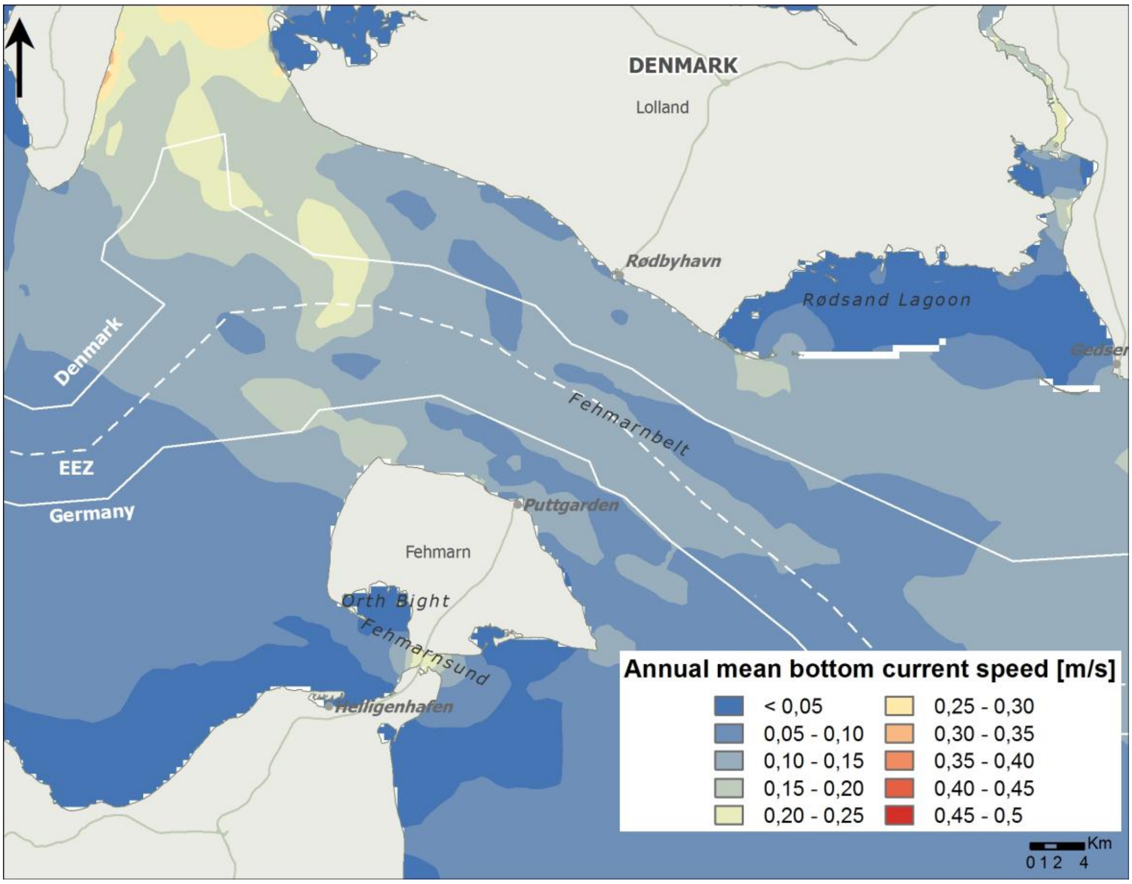


Figure 4.7 Annual mean bottom current speed in 2008 (FEHY 2013b).

Based on modelled results for the bridge alternative (FEHY 2013a), permanent changes show an increase in bottom oxygen concentration in summer, with mean values up to 0.2 mg l^{-1} and a decrease of 0.2 mg l^{-1} in deep parts of Mecklenburg Bight (outside the assessment area). The changes are a result of the larger mixing at the bridge structures and high resilience time of the bottom waters in Mecklenburg Bight. The benthic fauna communities in Fehmarnbelt are subject to natural variations in oxygen concentrations that exceeds the modelled changes (FEHY 2013a). The indirect pressure on the benthic fauna is therefore regarded as negligible.

Phytoplankton concentrations are affected by dredging works with local reductions along the Lolland coast amounting up to 4%. This is within the natural variability and will not pose a pressure to the fauna. Changes in dissolved oxygen and chlorophyll-a are also within the natural variability of the area. There will not be a pressure on the benthic fauna communities due to this.

4.9 Drainage

Drainage water will partly be discharged via the existing water courses, 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, to ensure good mixing with surrounding waters (Femern and LBV-SH-Lübeck 2011). The magnitude of pressure on the benthic fauna is dependent on the amount of drainage water discharged per event, the number and duration of the events and the distance to the outlet area. The first three items (amount, number and duration) are impossible to predict precisely, as they are initiated by natural and random processes (rainfall, washing, accidents).

The area/radius and time scale, in which discharged water will be diluted to a salinity comparable of the surrounding water has been calculated by (FEHY 2013a). The discharge rate is below 1 $m^3 s^{-1}$ with mean speed of about 0.3 $m s^{-1}$. The salinity and temperatures are within normal ranges for freshwater runoff. The effluents have been assessed to having no effect on the salinity and general hydrography close to the source point or on larger scales, taking into account the normal variation in salinity in the affected areas (9–25 psu) and the efficient flushing (FEHY 2013a). Thus, the magnitude of pressure of drainage is negligible.

5 SENSITIVITY ANALYSIS

5.1 Recovery time

The following Table 5.1 shows the classification of the fauna communities into the four different levels of recovery time.

Table 5.1 Recovery time of the benthic fauna communities.

Recovery time category	Definition	Communities
Very high (= very long)	>10 years	Arctica
High (= long)	5–10 years	Dendrodoa Mytilus Rissoa
Medium (= medium)	2–5 years	Cerastoderma Gammarus Tanaissus
Low (= very short)	<2 years	Bathyporeia Corbula

The following paragraphs document the reasoning behind the classification of the nine benthic fauna communities. The recovery time mainly conforms to the typical age of the main species of the corresponding communities.

Very high recovery time (very slow recovery)
The majority of the **Arctica** community is made up of large and old bivalves that are typically up to 30–35 years old. If an impact will lead to loss of long-living individuals of *Arctica islandica* (e.g. due to dredging) the maturity of the recovering community will only reach the pre-disturbance level after the newly settled organisms reach the same age as before. This is estimated as longer than 10 years based on the age structure of a mature *Arctica islandica* population (Zettler et al. 2001). The same is true for the bivalve *Astarte borealis*, which also is a characteristic part of the Arctica community and typically reaches an age of more than 10 years (Zettler 2002).

High recovery time (slow recovery)
The **Dendrodoa** community is typically associated with stable reef habitats (Zettler and Gosselck 2006), of which the constituents generally take 5–10 years to reach stable populations.

Stable **Mytilus** communities consist of several year classes of blue mussels (*Mytilus edulis*), where the oldest year classes are between 5 and 10 years old together with associated epifauna (FEMA 2013a, MarLIN 2010, Schuster 1984).

The recovery time of the **Rissoa** community depends largely on the availability of stable populations of long-living macrophytes, like *Zostera* and *Fucus*. Since these two are coupled and e.g. the *Zostera* vegetation community as the habitat for the Rissoa community has a recovery time of over 10 years, the recovery time of the Rissoa community is also classified into the high category.

Medium recovery time
Adult **Cerastoderma** populations consist of several year classes, where the oldest specimens are approx. 5 years old (Anger 1975, Stotz 1986).

The characteristic amphipods of the **Gammarus** community depend largely on the availability of algae as their living habitat. Perennial algae have a recovery time of about two to ten years and the typical *Gammarus* species reach an age of approx. 2–5 years (Kolding 1981).

The **Tanaissus** community occurs in dynamic, sandy environments, where the intrinsic recovery time is relatively low (FEMA 2013a, Elliott et al. 1998).

Low recovery time (fast recovery)
The **Bathyporeia** community occurs in dynamic, sandy environments and is intrinsically low in total species number, abundance and biomass. The typical constituents are early succession species. Bathyporeia species are typically 1–2 years old (Köhn and Gosselck 1989, MarLIN 2010).

As a highly variable transition community, the recovery of the **Corbula** community will be relatively fast. The life span of *Corbula gibba* individuals is 1–2 years (MarLIN 2010).

5.2 Sensitivity

5.2.1 Suspended sediments

Intolerance to suspended sediments
The composition of the suspended sediments is important for the intolerance of benthic communities towards this pressure. Suspended sediments with a high content (e.g. > 5%) of organic matter can provide additional food to filter feeding bivalves and inorganic matter in low concentrations (10–15 mg l^{-1}) can improve utilization of ingested phytoplankton. It is not known how the composition (such as the fraction of living and dead organic material) of suspended sediments affects benthic invertebrates that do not sort the particulate material prior to ingestion (e.g. tunicates).

Energy expenditure and need for food increases with temperature. During winter at low temperatures (< 3 °C) the activity of most filter feeders is low and accordingly, intolerance to suspended sediments is lower than during higher temperatures.

Table 5.2 shows the relative definitions and estimated intolerance of benthic fauna communities for the pressure suspended sediments. The categories and definitions must be seen as a relative ranking and cannot be directly compared to e.g. "sedimentation". Resuspension is a natural phenomenon in shallow waters of the Fehmarnbelt and sediment concentrations up to 50–100 mg l^{-1} are regularly recorded in the Rødsand Lagoon (FEHY 2013e). Elevated concentrations (but not the level as in Rødsand) occur also along the coasts at depths less than 5–8 m.

Table 5.2 Intolerance classification of the benthic fauna communities for the pressure suspended sediments.

Intolerance category	Definition	Communities
Very high	Periods with very high concentration of suspended sediments reduce the viability of the community such that from around half and up to the whole community population is destroyed.	-

Intolerance category	Definition	Communities
High	Periods with high concentration of suspended sediments reduce the viability of the community such that up to around half of the indicator population is destroyed.	Dendrodoa
Medium	Periods with very high concentrations of suspended sediments reduce the viability of the community markedly, but survival is not affected.	Mytilus Rissoa
Minor	Periods with very high concentration of suspended sediments have a low effect on the viability of the community. Survival is not affected.	Arctica Bathyporeia Cerastoderma Corbula Gammarus Tanaissus

High intolerance
The Dendrodoa epifauna community is characterised by hard substrate (sandy, partially coarse sediments, sometimes accompanied with boulders) in deeper waters (15–25 m). The community is named after the ascidian (sea squirt) *Dendrodoa grossularia* that lives as a filter feeder attached to hard substrate. High concentrations of suspended sediments for prolonged periods affect the indicator species of this community and other tunicates detrimentally, while exposures of shorter duration will be less detrimental affecting a smaller fraction of the population. The community typically occurs below the pycnocline and inhabitants of this community are not adapted to high variability in suspended sediment concentrations, compared to shallow water communities.

During the hydrographic studies concentration of suspended sediment was measured in depth profiles (turbidity data converted to suspended matter). Four examples from MS02 (deep mooring station in alignment) showed increasing concentrations near the seabed, with concentrations ranging between 1 and 2 mg l^{-1} (Figure 5.1). Such low concentrations seem to be representative of the deep near-bed waters below the pycnocline (FEHY 2013f).

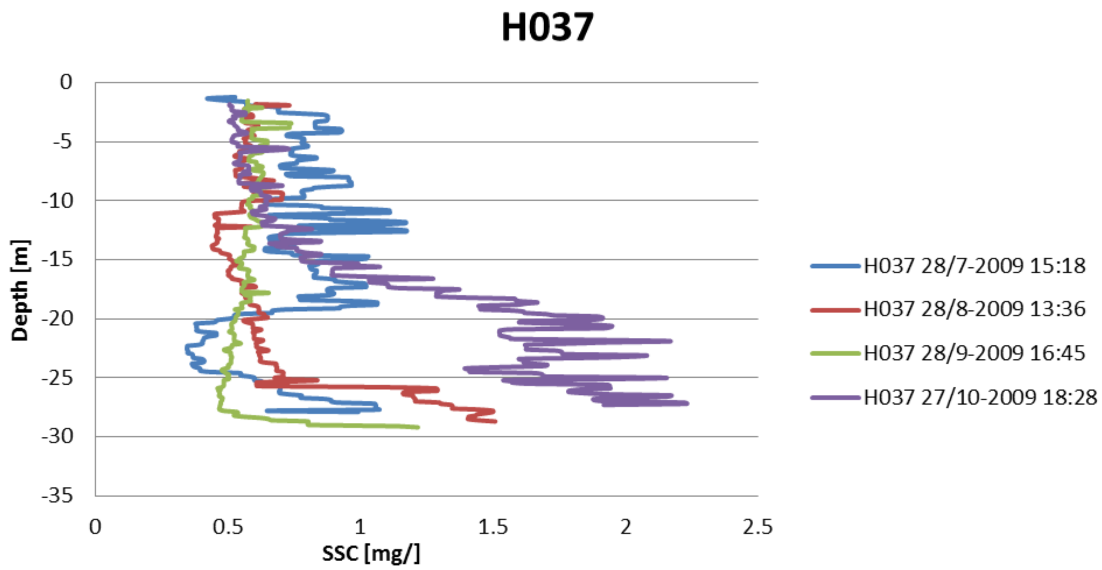


Figure 5.1 Concentration of suspended sediments (SSC) in four depth profiles sampled at station H037. H037 is identical with the monitoring station MS02 located at 28 m depth in the alignment at the German coast. Data taken from (FEHY 2013f).

Medium intolerance

The dominating element in the Mytilus community, the mussel *Mytilus edulis*, is relatively intolerant to suspended sediments, showing reduced growth rates when exposed continuously to suspended sediment concentrations above 30 mg l^{-1}, but without affecting survival. Being so important as a structuring element in the community, reductions in viability such as growth will affect the entire community. Mussels attain high biomass along the Lolland coast at depths between 3 and 12 m (Figure 5.1). Benthic invertebrates living in this community are regularly exposed to high concentrations of suspended sediment due to wave induced resuspension. Continuous measurements of suspended sediment concentrations (converted from NTU measurements) showed regularly elevated concentrations and in few instances concentrations exceeding 150 mg l^{-1} 3–5 m above the seabed during periods with strong winds (Figure 5.2). Near-bed concentrations were not measured but surely will be higher as shown in Rødsand Lagoon (FEHY 2013f).

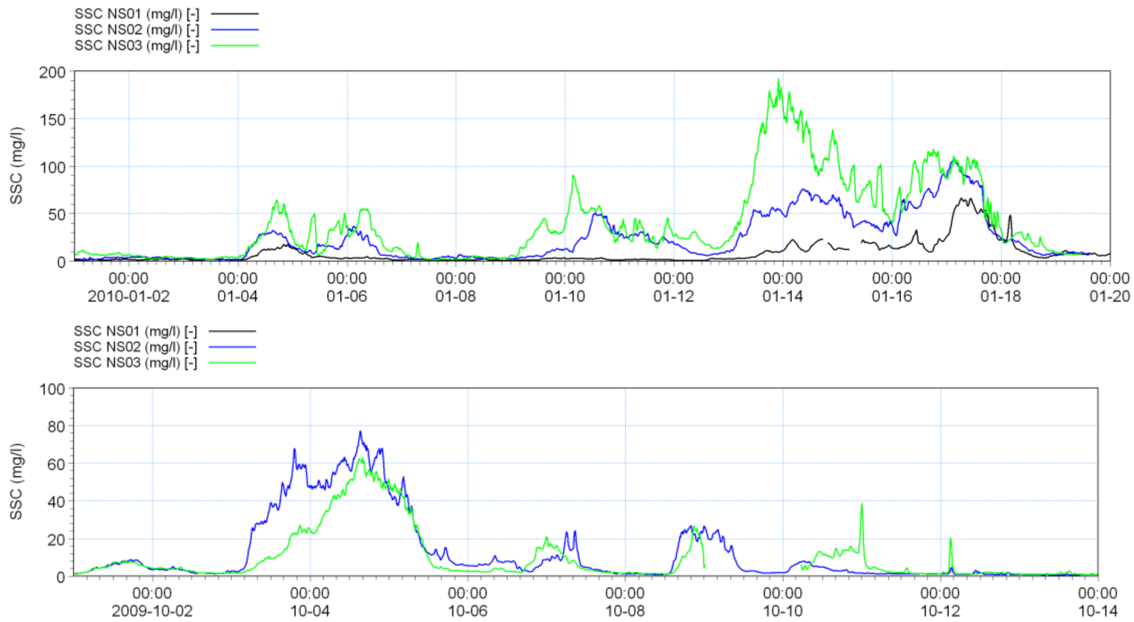


Figure 5.2 *Variation in concentration of suspended sediment in midwater (approx. 3–5 m) at 3 coastal stations along the Lolland coast. NS01: Albue Bank; NS02: 8 km west of Rødby; NS04: 5 km east of Rødby. Data taken from (FEHY 2013f).*

The Rissoa community is dependent on a healthy eelgrass community where the leaves serve as substrate for *Rissoa* and other epifauna. At high concentrations of suspended sediments light availability is reduced and eelgrass biomass and coverage are reduced. Such effects will indirectly influence the Rissoa community.

Minor intolerance
Shallow water communities such as the Cerastoderma community are adapted to varying concentrations of suspended sediments as consequences of storms, wind and wave actions.

The Cerastoderma community is characteristic of the eastern non-vegetated part of the Rødsand Lagoon (Figure 1.1), where station NS05 is located. During windy periods the concentration of suspended sediments may increase up to 200 mg l^{-1} (approx. 2 m above the seabed) as a result of wave-induced resuspension (Figure 5.3). The concentration of suspended sediments will be higher nearer to the seabed during resuspension events (FEHY 2013f). Hence, the Cerastoderma community has a minor sensitivity to excess concentrations of suspended sediments.

Other communities even housing suspension feeders such as *Corbula* and *Arctica* are tolerant to high suspended sediment concentrations because they are feeding in the sediment water interface where concentrations of suspended sediments is high naturally and because these suspension feeders are very efficient in sorting out suspended sediments with low food quality before ingestion (Kiørboe and Møhlenberg 1981).

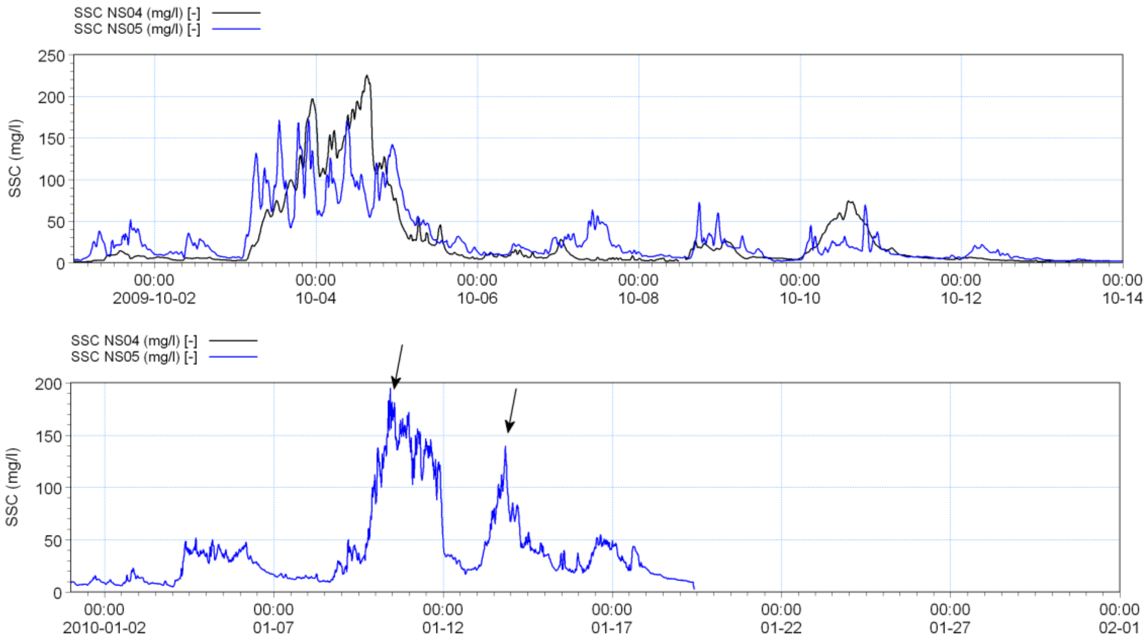


Figure 5.3 Variation in concentration of suspended sediments in midwater (approx. 1–2 m) measured at 2 stations in Rødsand Lagoon. NS04: sheltered location behind the Hyllekrog barrier, area vegetated with eelgrass; NS05: more exposed located in the middle of the entrance to Rødsand Lagoon. Arrows showing peaks when wind speed exceeded 10 ms^{-1}. Data taken from (FEHY 2013f).

The Gammarus, Tanaissus and Bathyporeia communities do not include characteristic and dominating species that are particularly sensitive to suspended sediments. Therefore, they are also classified as having a low intolerance.

Sensitivity as function of recovery time and intolerance

The sensitivity of each benthic fauna community to suspended sediments is determined by intersecting recovery time with intolerance, according to Table 5.3. The recovery time used here is scaled towards the observed magnitude of pressure where no mortality is expected (see section 4.1). It expresses thus the time it takes to re-establish the biomass that possibly was reduced due to lower food availability.

Table 5.3 Sensitivity of the nine benthic fauna communities to suspended sediments.

	Sensitivity	Intolerance			
		very high	high	medium	minor
recovery time	very high	very high	very high	high	medium: **Arctica**
	high	very high	high: **Dendrodoa**	medium: **Rissoa** **Mytilus**	minor
	medium	medium	medium	medium:	minor: **Cerasto-derma** **Gammarus** **Tanaissus**
	minor	minor	minor	minor	minor: **Bathyporeia** **Corbula**

The sensitivity to suspended sediments is high for the Dendrodoa community because of a high intolerance to suspended sediments and also a high recovery time. Three communities are categorised as being medium sensitive to suspended sediments. Although the species of the Rissoa community are not particularly intolerant to suspended sediments or have a high recovery time, the community is fundamentally dependent on eelgrass to provide the habitat. Eelgrass is highly intolerant to reduction in light availability and depending on the concentrations, suspended sediments increase light reduction. Moreover, the recovery time of lost areas is long. Because of this additional indirect nature of the pressure, the sensitivity is categorised as medium. The Mytilus community has a medium sensitivity to suspended sediments determined by a medium intolerance and a medium recovery time. The Arctica community is categorised as medium sensitive to suspended sediments, because of a very long (decades) recovery time if individuals are eliminated.

The recovery of the mussel population after reduction in biomass caused by reduced availability of food is included in the numerical model sued to predict the impacts on fauna biomasses.

5.2.2 Sedimentation

There is limited information available in the literature on the sensitivity of prolonged periods of increased sedimentation on benthic organisms. Most literature deals with acute dumping events and effects of dredging. The assessment of the sensitivity of the benthic fauna communities is therefore primarily an expert judgement based in general knowledge and this limited literature.

Intolerance to sedimentation

In general, additional sedimentation will influence viability, growth and survival of benthic organisms. Survival rates depend on a variety of factors including the type and amount of disposed materials, individual's age and size and the lifestyle of the organisms, where sessile species have a disadvantage in terms of mobility. Communities inhabiting regions where gross sedimentation and erosion are naturally higher are adapted to active sediment dynamics. The persistence of the covering sediment layer, its depth, the type of the deposited material and the water temperature are also limiting factors (Essink 1999).

Mobility and deposition thickness

The majority of the mobile infauna have an innate burrowing ability and are able to move through the sediment to regain their preferred position. In contrast, mobile epifauna has generally only a limited burrowing ability. These species are therefore likely to be more sensitive to the consequences of burial (Chandrasekara and Frid 1998). So, mobile species have a better ability to escape from the pressure or adapt to it, where escaping or survival is characterized as "establishing contact with the overlying water" (Powilleit et al. 2009). Naturally, the escape activity is restricted by the mobility of the particular animals. Laboratory studies seem to be more conservative in estimating benthic invertebrate survival rates after burial, possibly due to spatial constraints, i.e. fauna has only "one way out" in test cores and oxygenation in microcosm experimental setups is lower than in the field. Conservative values derived from laboratory studies are therefore conservative with respect to benthic fauna impact evaluations in the field.

The critical deposition thickness differs from species to species. In general, bivalves are good burrowers by nature. For example, *Cerastoderma edule* can survive burial up to 8–12 cm of sediment. In laboratory experiments the bivalves *Arctica islandica*, *Macoma balthica* and *Mya arenaria* showed high escaping potentials as they successfully moved through the deposited sediment with a covering layer of 32–41 cm (Powilleit et al. 2009). In the Baltic Sea, *Macoma balthica* is among the most resistant species. However, deposition of 10 cm of fine sediment does have clear negative effects on some bivalves, such as *Mytilus edulis* and *Mya arenaria* (Essink 1999).

Also some polychaetes are good burrowers. *Hediste diversicolor* is one of the most resistant species in the Baltic Sea. *Nephthys hombergii* showed high escaping potential moving through a covering layer of 32–41 cm (Powilleit et al. 2009). Under overburden stress of > 5 cm and up to 24 cm survival of *Streblospio benedicti* was significantly reduced (Hinchey et al. 2006). In contrast, the tube-building *Lagis koreni* showed low burrowing velocities (0.29–0.57 cm d^{-1}) and only has the ability to excavate itself if lightly buried (Powilleit et al. 2009). Because the sedimentation rates of this project are within this range, the polychaete will still be able to borrow through the sediment. *Pygospio elegans* is among the most sensitive species.

The mobile snails and the other animal groups exhibit different behaviour. The proportion of *Hydrobia ulvae* surviving burial in natural sediment to 5 cm depth decreased significantly with increasing duration of burial and increasing temperature (Chandrasekara & Frid, 1998). The epibenthic gastropod *Littorina littorea* was unable to survive more than 24 h burial in natural sediment. A clear negative effect was seen on the anthozoan *Sagartia* spp. and on some starfish species deposited in 10 cm of fine sediment (Essink 1999). The tunicate *Molgula manhattensis* suffered significant mortality due to both complete and partial burial under 1 cm of sediment (Hinchey et al. 2006). *Corophium volutator* is among the most sensitive species in the Baltic Sea (Essink 1999).

Environmental factors

Environmental factors like salinity and temperature are important in determining possible outcomes of burial of benthic species. There is a negative correlation between temperature and invertebrate tolerance to burial (Essink 1999). In brackish waters, the fatal burial depth is generally found to be higher (i.e. animals withstand thicker layer) than under saltwater conditions. As contaminated sediment negatively influences physiological condition and thus animal burrowing velocity, levels of sediment-adsorbed contaminants (metals, PCBs, PAHs etc.) should be taken into consideration when assessing possible effects on the benthic community. However, for the present assessment it has been documented that the deposited sediments do not pose a risk with respect to toxic substances (see section 4.3).

Sediment type

The type of accreting material is very important in predicting overall survival of the benthic community. Rapid, incident deposition of coarse or mixed dredging material (spill dump) may directly damage surficial epifauna by mechanical impact, but is likely to impose lower hypoxia stress. Relatively slowly accreting fine sediment (diffuser dumping, spoil mud plume) will allow fauna to undertake (successful) escaping activities. The time for compaction in mud is expected to be an order of magnitude longer, because of the lower density and higher porosity of the material. Accreted fine sediment will therefore be more prone to resuspension. However, the finer the accreting sediment, the more likely hypoxic events will occur in both the overlying water as well as in the sediment. Disposal sites (for either spill plumes or direct disposal) with low numbers of hypoxia-tolerant species are therefore more vulnerable to burial under fine, muddy sediment. In general, sediment matching, i.e. high similarity between allochtonous accreting sediment and sediment at the disposal site, decreases negative impact on the particular benthic communities.

As some of the accreting material from dredge plumes will consist of fine muddy material, the main impact on the seabed will not be mechanical, but rather biogeochemical. Accreting mud has several consequences: amongst others it will increase organic carbon (OC) concentrations and decrease hydraulic conductivity (sediment porosity) and will therefore decrease oxygen penetration depth. Also, the surface-to-volume ratio of mud particles is higher than that of sand, meaning that mud is characterized by higher bacterial activity. Microbial degradation rates will therefore increase non-linearly in muddy sediment. The resulting decrease in oxygen (hypoxia) due to microbial OC degradation may amount to highly sulphidic conditions, which are toxic to many species. However, benthic invertebrates display very species-specific tolerance levels to sulphidic conditions (e.g. Bagarinao 1992, Gamenick et al. 1996).

Intolerance assessment
Based on the background knowledge discussed above and the available literature, the relative definitions and estimated intolerance of the nine benthic fauna communities towards the pressure sedimentation are derived (Table 5.4). The given categories and definitions are relative, because they need to fit with the scale used for MOP categories (see section 4.2). The intolerance of a community to sedimentation depends on the magnitude of the pressure: if the pressure is high enough, all communities will have a very high intolerance and die, e.g. there is no doubt that 1 m of deposition in just one day will be exterminatory (Miller et al. 2002). Thus, intolerance must be assigned such that it reflects the expected magnitude of pressure. The definitions in Table 5.4 serve as an aid to rank the nine communities accordingly. The scale should not be interpreted as having a fixed reference point. Argumentation for the intolerance classification of the fauna communities are given below.

Table 5.4 Intolerance classification of the nine benthic fauna communities for the pressure sedimentation.

Intolerance category	**Definition**	**Communities**
Very high	The pressure reduces the viability of the community such that from around half and up to the whole community population is destroyed.	-
High	The pressure reduces the viability of the community such that up to around half of the community population is destroyed.	Dendrodoa
Medium	The pressure reduces the viability of the community markedly, but survival is not affected.	Rissoa Mytilus Gammarus Cerastoderma Corbula Tanaissus
Minor	The pressure has a low detectable effect on the viability of the community.	Bathyporeia Arctica

Very high intolerance
The highest amount of spilled sediment is predicted in the immediate proximity to dredging locations (alignment area) and in the Rødsand Lagoon due to currents dynamics. In the central Fehmarnbelt the modelled maximum accumulation (that corresponds to the tunnel alternative) approaches 1–2 cm outside the alignment, up to 6–8 cm close to the alignment. In the sheltered Rødsand area modelled accumulation of spilled sediment varies between 0 and a maximum of 8 cm. The accumulation of spilled sediments takes place over several months. Using the data on mod-

elled sediment accumulation at 3 positions in the Rødsand Lagoon, a maximum rate of sediment accumulation less than 0.4 mm d^{-1} was calculated. With respect to these expected levels of sedimentation no community was assigned to the "very high" intolerance category.

High intolerance

The Dendrodoa epifauna community is characterised by hard substrate (sandy, partially coarse sediments, sometimes accompanied by boulders) in deeper waters (15–25 m). The community is named after the ascidian (sea squirt) *Dendrodoa grossularia* that lives as a filter feeder attached to hard substrate. Sedimentation affects the indicator species of this community. Limited mobility of member-species of this community will hinder them from avoiding the pressure. Complex structure of this community is indicated by the constantly high species richness. It typically occurs below halocline and thus inhabitants of this community are not adapted to high variability in sedimentation, compared to shallow water communities that are more accustomed to active sediment transport as consequences of storms, wind and wave actions.

Medium intolerance

The Rissoa community is strongly associated with long-living macrophytes, such as *Zostera sp.* and *Fucus sp.*. The longevity of the macrophytes creates a stable habitat in which these epiphytic species can grow. Sedimentation affects the indicator species of this community as well as the macrophytes on which they grow negatively. However active natural sediment resuspension and bed-load transport observed in the habitat occupied by the community, suggests some degree of adaptation to sediment dynamics.

Most of the Mytilus community-associated organisms are limited in their mobility and therefore intolerant to increased sedimentation. The structuring elements (the *Mytilus* sp. themselves), however, can withstand a certain degree of sedimentation without being too much affected.

The Gammarus community is, just as the Mytilus community, a typical epifauna community and very much dependent on the growth of macroalgae. Numerous epifauna taxa feed on anything from algae and seaweeds to detritus. Many of taxa hide in the algae plants (that might be affected by sedimentation) but can also swim freely in the water column to migrate to other localities. Some can actively avoid sedimentation by burrowing to the surface, if the order of magnitude of the deposition rate does not exceed their burrowing speed. However, the community is also associated with a large number of filter feeding taxa with limited mobility. The intolerance of the Gammarus community is therefore classified as "medium".

Intolerance has been assessed to be intermediate for the three communities Cerastoderma, Corbula and Tanaissus communities, because they occur in environments which are temporally instable and subject to sedimentation.

Minor intolerance

The data from literature indicates that some ecosystem engineering species, involved in the structuring of the Arctica community (*A. islandica*, *Nephtys* sp.) appear to have the highest known escaping potentials and are able to successfully move through the deposited sediment with a covering layer of 32–41 cm (Graf 1992). In contrast, the tube-building polychaete *Lagis koreni* shows low burrowing velocities (0.29–0.57 cm d^{-1}) and has the ability to excavate itself only if slightly buried.

The Bathyporeia community occurs in hydrodynamically highly energetic environments, where incident erosion and deposition are highly variable. Most of the community's constituents are highly mobile and consist of early-succession species.

Disturbance caused by increased deposition can be partly comparable with effects of decreased concentrations of dissolved oxygen, but is also associated with mechanical influence on individuals. Even though mature adults of the long-living species of the community are most tolerant to this impact, it cannot be ruled out that part of their population, i.e. younger generations and smaller individuals, will also be lost, thereby changing the community structure on short, middle and even long time scales.

Sensitivity as function of recovery time and intolerance
The sensitivity of each benthic fauna community to suspended sediments are determined by intersecting the recoverability with the intolerance, according to Table 5.5. The following arguments are taken into consideration:

- The very high sensitivity is only exhibited, when the pressure is high enough and only then the recovery time plays a major role.
- Under the low pressure, when the low intolerance secures that no animals die, but escape the pressure, only the viability is affected, not the survival.
- Since according to the spill scenario the communities are mostly exhibited to lower magnitudes of pressure, the influence of the intolerance factor to sensitivity is strengthen by downgrading the sensitivity for cases with high or very high recovery time but medium or low intolerance.

Table 5.5 Linking matrix to assess sensitivity of benthic fauna communities towards sedimentation.

		Intolerance			
	Sensitivity	very high	high	medium	minor
recovery time	very high	very high	very high	high	medium: **Arctica**
	high	very high	high: **Dendrodoa**	medium: **Rissoa** **Mytilus**	minor
	medium	medium	medium	medium: **Gammarus** **Cerastoderma** **Tanaissus**	minor
	minor	minor	minor	minor: **Corbula**	minor: **Bathyporeia**

5.3 Footprint

Sensitivity is not a relevant factor of footprint assessment, since the sensitivity to habitat loss cannot be defined.

5.4 Solid substrate

5.4.1 Aspect 1

This aspect results in the potential emergence of a hard-bottom community on project structures in the assessment area. The term sensitivity does not make sense in this case. The introduction of a hard-bottom community into a given present benthic fauna community means a local community change, because an artificial substrate becomes part of the habitat and has not been there before. The assessment can only be made by looking at the amount (in terms of area) of the introduced habitat in relation to the original community area in a defined region.

5.4.2 Aspect 2

The sensitivity regarding *aspect 2*, where the surrounding communities are potentially affected, is derived from the general sensitivity assessment (section 3.5). Recovery as a factor of sensitivity does not apply here, since no general habitat loss is involved and increased mortality does not occur. Only intolerance or resilience can to be considered in this case. There are no quantitative data available describing the reaction or resilience of different soft-bottom benthic communities to introduced solid substrate. Resorting to expert judgement is the only way to currently define the sensitivity of the nine benthic communities in terms of their reaction to introduced hard-bottom communities. Three of the nine fauna communities are themselves hard-bottom communities. These are the Dendrodoa, Gammarus and Mytilus community. It is judged that they are not affected by the introduction of additional solid substrate and the associated hard-bottom communities, because they already consist of comparable hard-bottom communities. The following Table 5.6 lists the sensitivity assignments for the six soft-bottom communities that can be affected by the second aspect of the pressure (mainly input of faecal pellets and dead mussels).

Table 5.6 Sensitivity classification of the six soft-bottom communities towards aspect two of the pressure additional solid substrate.

Sensitivity category	**Reasoning**	**Soft-bottom fauna communities**
very high	It is expected that a loss of the original communities will only occur in a 2 m band around the structures. This is assessed separately as loss and sensitivity does not apply in this case.	-
high	Soft-bottom communities that are not adapted to increased input of mud particles or organic matter from dead *Mytilus edulis* and other marine organisms	Bathyporeia Rissoa
medium	Communities tolerant against increased input of mud particles and organic matter to a certain degree, often occurring under varying conditions	Arctica Cerastoderma Corbula Tanaissus
minor	Communities that only change in abundance, since the additional solid substrate will provide more available habitat and has a similar composition and function.	-

5.5 Confidence

The confidence in the assessment and its results depends on the quality and robustness of the baseline data, the available evidence for the effect of a pressure on a species or community, the validity of the applied assessment method and the confidence of the sediment spill model that is the basis for the pressures sedimentation and suspended sediments.

The baseline investigations for benthic fauna conducted in 2008–2010 provided good quality and robust background data for all assessments. The scientific evidence of possible impacts from the assessed pressures has been documented via references to published papers.

The assessment method used is simplified in order to provide a comprehensive and consistent assessment that is still understandable to non-expert readers. Therefore, simplifications were needed that do not account for all the specific biological characteristics of each species/community. Still, the assessment reflects the biological reaction of the communities towards the pressures to a level that corresponds well to the predicted environmental changes.

The sediment spill model itself does not include a confidence assessment by e.g. stochastic methods like Monte-Carlo-Simulations or difference plots by assessing changes in the predicted spill when specific parameters of the model input are changed. Since the pressures sedimentation and suspended sediments are dependent on the spill model, the confidence rating of these two pressures lack some information.

The confidence of the assessment results for the nine pressures on the benthic fauna communities is classified into three levels:

- **high**: Relationships of the pressure indicator to the function of the community in general are well understood and documented. The impact is assessed without the need of major extrapolations of comparable pressures or related species.
- **moderate**: Relationships of the pressure indicator to the function of the community in general are documented. The impact needs extrapolations of comparable pressures or related species.
- **low**: The assessment is inferred from general information on biological relationships to pressures. No specific knowledge on the relation to the functioning of the community is available.

The resulting confidence rating is listed together with short comments in the reasoning (table Table 5.7 below).

Table 5.7 Confidence rating of the assessment results for the nine pressures on the benthic fauna communites.

Pressure	Confidence	Comments
Suspended sediments	moderate	Sensitivity extrapolated from knowledge on few species
Sedimentation	moderate	Sensitivity extrapolated from knowledge on few species
Toxic substances	high	Physiological reactions well-documented and apply largely in general
Nutrients	high	Well-documented that pressure is not relevant in the predicted magnitude
Construction vessels and imported material	moderate	Sensitivity extrapolated from knowledge on few species

Pressure	Confidence	Comments
Footprint	high	Recovery of communities is well-documented and life cycles and reproduction/dispersal well-known for many species
Solid substrate	moderate	Sensitivity extrapolated from knowledge on few species
Seabed and coastal morphology	moderate	Reaction on habitat change well understood in general, but extrapolation needed from species to communities
Hydrographic regime and water quality	moderate	Reaction on habitat change well understood in general, but extrapolation needed from species to communities
Drainage	high	Response to salinity changes well-documented

6 ASSESSMENT OF 0-ALTERNATIVE

All impacts from the construction phase are compared to the baseline conditions without forecasting as described in (FEMA 2013a). Impacts from the operation phase are assessed as projected into the years 2025 and 2030. This projection is e.g. relevant for the assessment of traffic, noise, air quality and other factors connected to these.

Issues affecting the benthic fauna baseline conditions are the realisation of the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD). Achieving the goals of the WFD will mean a significant improvement of the ecological status of the marine waters. It is, however, not possible to determine the future state of the marine environment as a result of the WFD with the necessary level of certainty to use it for the impact assessment.

The MSFD is currently in the implementation phase. No assessment systems have yet been developed to quantify and classify the current environmental status and the descriptions of the final good environmental status are currently not finished. Thus, the effect on the environmental status is currently unknown. Therefore, neither the WFD nor the MSFD realisation is included in the marine benthic fauna 0-alternative.

As a consequence, a projection into the years 2025 and 2030 is not done for the marine benthic fauna and the baseline conditions serve as the 0-alternative. The impacts from the operation phase on the marine benthic fauna are assessed by comparison with the baseline conditions (FEMA 2013a).

7 ASSESSMENT OF IMPACTS OF MAIN TUNNEL ALTERNATIVE

7.1 Suspended sediments

7.1.1 Magnitude of pressure

Figure 7.1 illustrates the estimated magnitude of pressure of excess suspended sediments from the dredging spill for the first dredging year 2015 when the pressure peaks. The pressure is primarily due to a resuspension of the deposited sediments, not due to the primary spill. Therefore the highest magnitudes are not at the source of the sediment spill but rather in the shallow waters where resuspension is largest. The suspended sediment concentration has been modelled for the whole construction phase. The results show that there is only impact for the year 2015. The data for 2016 and later only show magnitudes of pressure that are below the set thresholds and thus are within the range of natural variability. Consequently, the assessment is done for the year 2015 only.

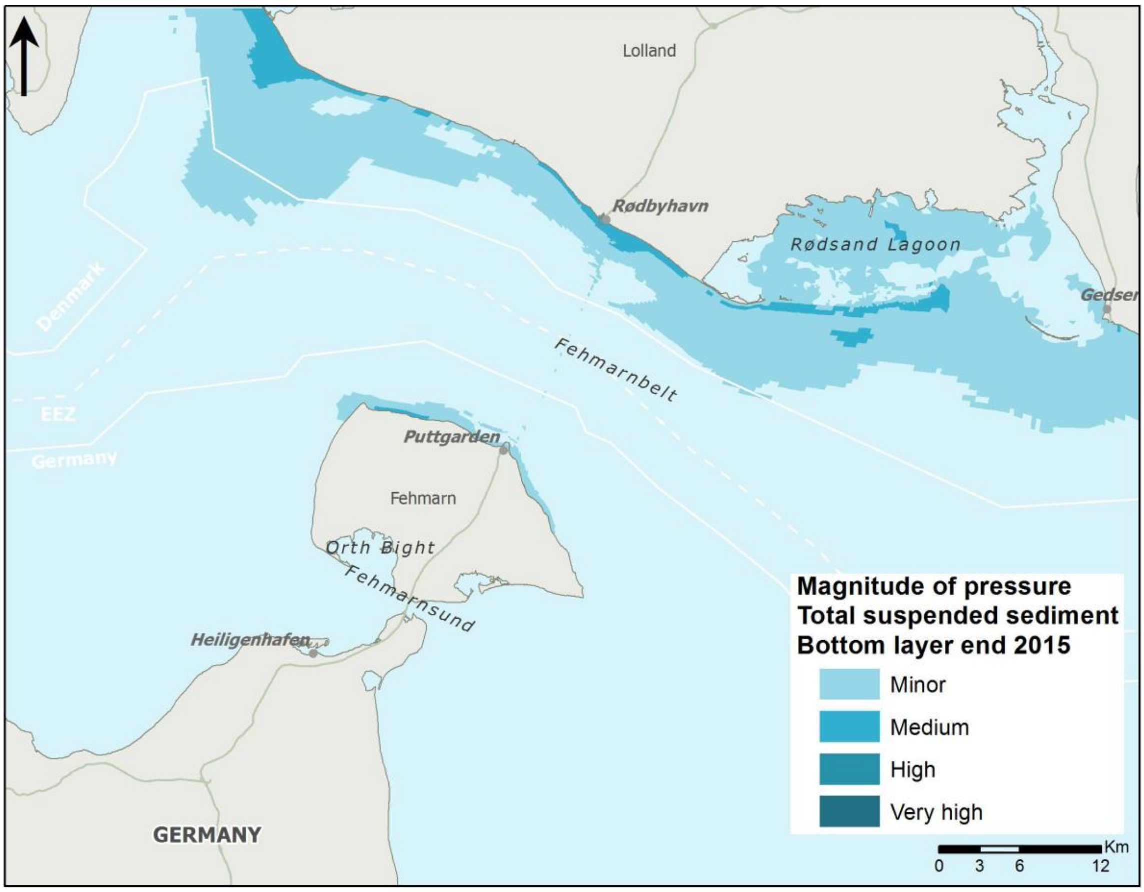


Figure 7.1 Magnitude of pressure for suspended sediments in the near-bed layer for the dredging period October 2014 to end 2015 of the tunnel construction (upper panel). The magnitude is minor in most areas where the pressure occurs.

Very high or high magnitude of pressure is not observed in the assessment area. Medium magnitude of pressure is along the coast of Lolland and in a small area along Fehmarn, west of Puttgarden. The minor magnitudes are distributed along the coast of Lolland, and past Gedser to the east. A comparably narrow band of minor magnitude is distributed along the northern coast of Fehmarn and a trace of minor magnitude of pressure is also predicted for the alignment.

West of the alignment the impact extends into the Great Belt and thus reaches beyond the defined assessment area. The complete extent of the pressure can be seen in (FEHY 2013a). The concentrations of suspended sediments within the assessment area result in a minor magnitude of pressure already near the alignment. It is expected that the concentrations gradually decrease with distance from the alignment. Thus, the impact on the benthic fauna communities outside the assessment area is predicted to be negligible.

7.1.2 Degree of impairment

Benthic fauna communities
The assessment of the degree of impairment is done by intersecting the sensitivity of the benthic fauna communities to suspended sediments with the magnitude of pressure according to the linking matrix given in section 3.7.

In total 57,941 ha of benthic fauna is impaired by increased suspended sediment concentrations (Figure 7.2). Most of the impairment has a minor degree, while 3652 ha is categorised with a medium degree of impairment, observed in the Dendrodoa, Mytilus and Rissoa communities. Most of the impairment is located in the shallow waters along Lolland and extending beyond the local zone, with parts extending into the Danish EEZ. Smaller areas of minor degree of impairment are also observed close to the north coast of Fehmarn. Table 7.1 and Table 7.2 list the results of degree of impairment for the administrative zones and the benthic fauna communities, respectively.

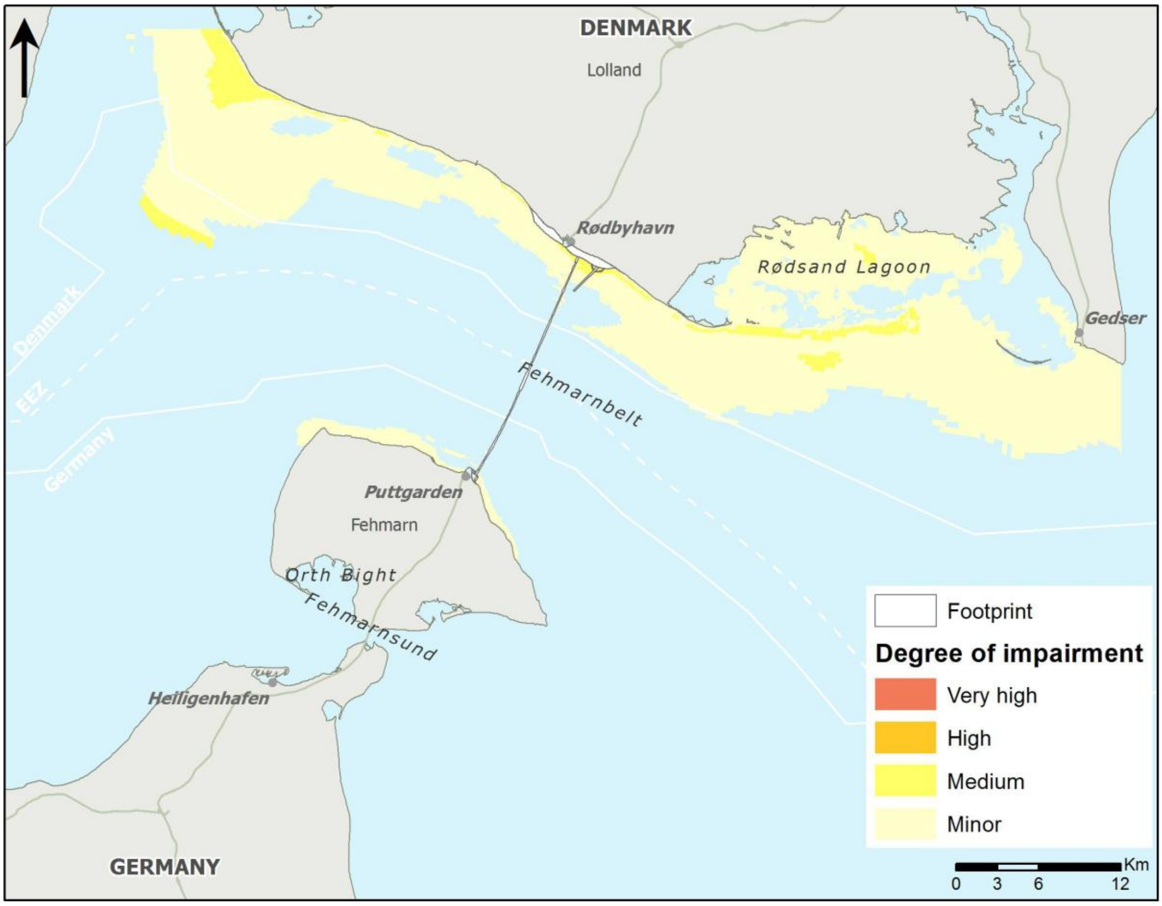


Figure 7.2 Degree of impairment of the pressure suspended sediments for the tunnel alternative by end 2015.

Table 7.1 Degree of impairment due to the pressure suspended sediments caused by tunnel construction for different areal zones.

Pressure:	**Suspended sediments (fauna communities)**					
	degree of impairment – area impaired (ha)					
	Total area	near zone	Local zone	DK	DE national	DE EEZ
Very high	0	0	0	0	0	0
High	0	0	0	0	0	0
Medium	3,652	214	134	3,652	0	0
Minor	54,289	630	6,676	52,709	1,576	4
Total	57,941	844	6,810	56,361	1,576	4

Table 7.2 Degree of impairment for the nine benthic fauna communities due to the pressure suspended sediment for the tunnel alternative.

Pressure:	**Suspended sediments (fauna communities)**	
	Total (ha)	*degree of impairment – area impaired (ha)*
Very high	0	0
High	0	0
Medium	3,652	Dendrodoa - 530 Mytilus – 2,913 Rissoa - 209
Minor	54,289	Arctica - 6 Bathyporeia - 8,803 Cerastoderma - 3,029 Corbula - 910 Gammarus - 12,593 Mytilus – 21,126 Rissoa – 7,799 Tanaissus - 23
Total	57,941	Arctica - 6 Bathyporeia - 8,803 Cerastoderma - 3,029 Corbula - 910 Dendrodoa - 530 Gammarus - 12,593 Mytilus – 24,039 Rissoa - 8,008 Tanaissus - 23

Mussel population

The degree of impairment for the mussel population is modelled and given as the average change in biomass compared to the modelled baseline. Based on predictions using the FEMA model (FEMA 2013c) phytoplankton concentrations along the Lolland coast will be up to 10% lower in 2015 due to sediment spill, associated with reductions in light and a lower plankton growth rate (Figure 4.5). The mussel population model responds with a reduction in biomass after the growth season in 2015. Locally, reductions amount to 5–6 g m^{-2} (AFDW) at Albue Bank (Figure 7.3). The reason for the local peaks in reductions of modelled baseline biomass is due to high local concentrations of the blue mussels, which are sensitive to reductions in food because of intra-specific competition. In most of the impacted areas the reduction in biomass is less than 2.5 g m^{-2}.

In 2016 and later, the biomass of mussels returns to the levels seen in the baseline situation (FEMA 2013a). Since the maximum reduction in mussel biomass is below 10% and thus within the expected natural year-to-year variation (± 13%), impairment is not expected (see section 3.7.1).

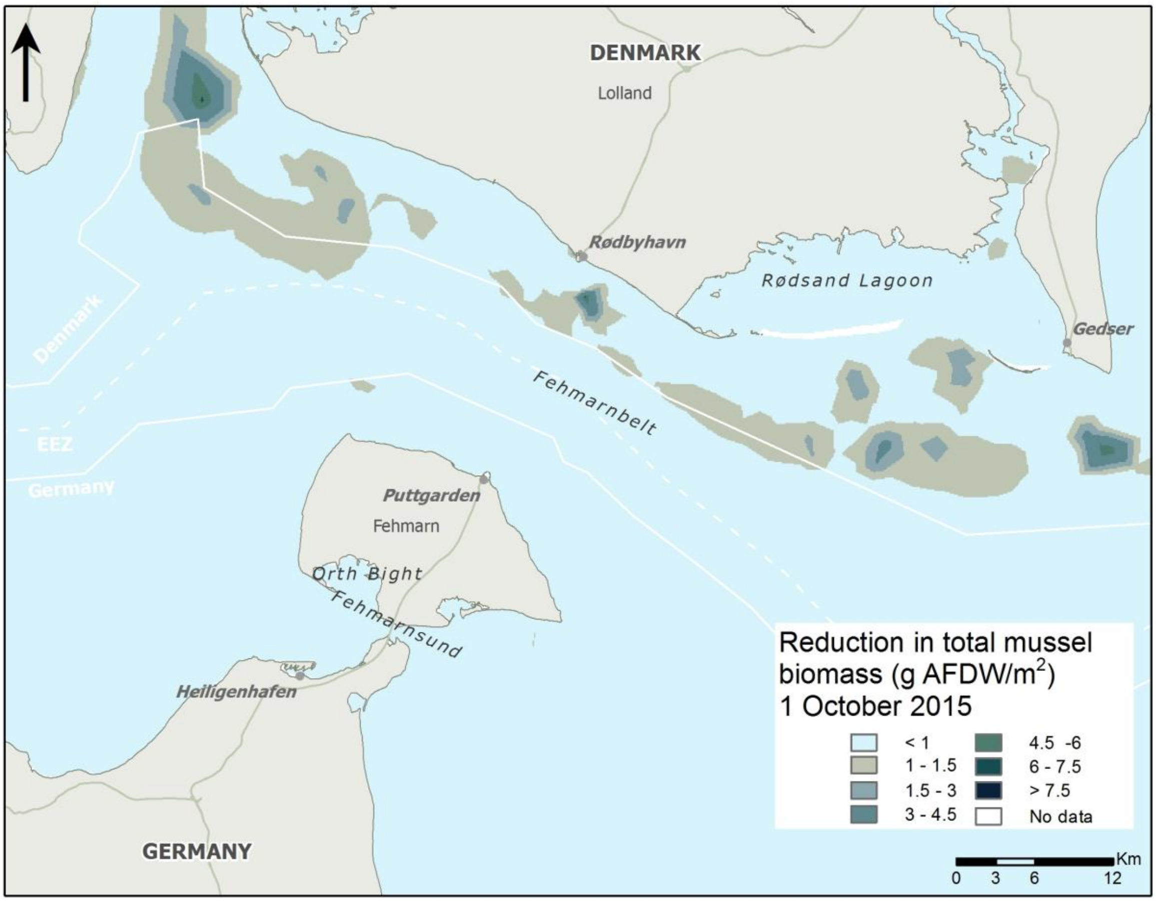


Figure 7.3 Change in total mussel biomass (absolute values of AFDW, g m^{-2}) in Fehmarnbelt caused indirectly by the increased concentration of suspended sediments for the tunnel alternative.

7.1.3 *Severity of impact*

The assessment of the severity of impact is based on the predicted degree of impairment described in the previous section, together with the modelled suspended sediments from the sediment spill scenario.

Benthic fauna communities

The severity of impairment takes the degree of impairment, the importance of the fauna communities and the sensitivity stated for each community into account, where relevant. Most of the impairment is in the minor category and only a small area of Mytilus, Rissoa and Dendrodoa communities are impaired with a medium degree. The areas of medium impact for Dendrodoa and Rissoa are 530 and 209 ha, respectively, and the populations and their ecological functions will not be impaired. For the Mytilus community the impacted area are of 2,913 ha, which is approximately 1/10 of the total Mytilus community. The magnitude of pressure does not distinguish between a high concentration of suspended sediments for a short duration or a low concentration for a long duration.

If a minor magnitude of pressure is due to 10 mg l^{-1} for more than 7 days, this impact will only be relevant for the Dendrodoa community because the other communities are largely insensitive to these concentrations. The concentration of suspended sediments in the bottom layers for the year 2015 (worst year for sediment spill) show that a large part of the plume contains suspended sediments in concentrations lower than 1 mg l^{-1} (Figure 7.4). This indicates that the severity of the impact is actually much smaller than the degree of the impairment, as the Dendrodoa community for which this lower limit is set, only occurs in the western part of the assessment area (Table 1.1). To be conservative, minor degrees of impairment which are predominant for this pressure are directly used as minor severity of impact. Consequently, also the medium degree of impairment is transferred unchanged to medium severity of impact. The areas given in the severity of impairment are therefore identical to the degree of impairment shown in Table 7.1 and Table 7.2.

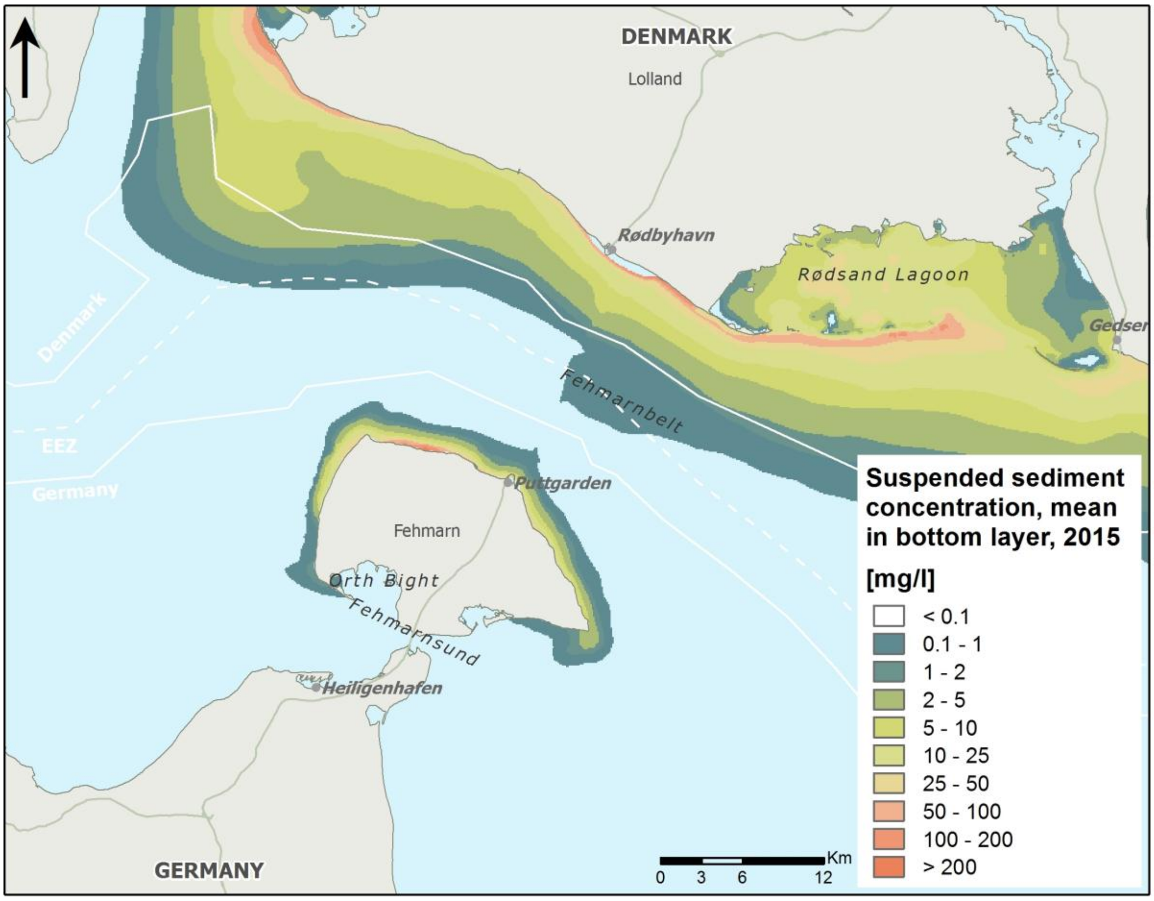


Figure 7.4 Average suspended sediment concentrations (mg l^{-1}) in the bottom layer by end 2015. 2015 is considered to be the year with the highest sediment spill (i.e. worst case).

As stated in section 4.1 an impairment with minor and medium magnitude of pressure does not have an effect on mortality of the benthic fauna species, but may decrease the viability of the species.

Mussel population

The reduction in biomass of the Mytilus community is due to reduced food availability. The mussels are not killed, but a reduction of maximum 10% in biomass occurs locally. Since recovery time is short (within a couple of months) and there is no impact in the later years, the severity of impact is regarded as minor.

7.1.4 Impact significance

Benthic fauna communities

To evaluate the significance of the impact, the complete EIA assessment area is taken as the comparison zone because the impact extends beyond the local zone (20 km corridor around the alignment) (see section 3.9). The impacted area inhabited by each benthic community in relation to the respective total area (in %) in the complete assessment area is summarised in Table 7.3.

Table 7.3 Areas (ha) impacted due to the pressure suspended sediment caused by tunnel alternative in relation to the total area of the community in the complete EIA assessment area given in %.

Community	medium severity		minor severity	
	ha	%	ha	%
Arctica			6	0
Bathyporeia			8,803	56
Cerastoderma			3,029	27
Corbula			910	7
Dendrodoa	530	2	-	
Gammarus			12,593	17
Mytilus	2,913	9	21,126	68
Rissoa	209	2	7,799	67
Tanaissus			23	1

As stated earlier the minor and medium severity of impairment reduces the viability, but does not increase the mortality of any of the communities. Recovery from a reduced viability of the medium and minor impaired fauna is expected to take place within a couple of months after the pressure has ended. The fast recovery of the blue mussel shown in Figure App. B.14.1 in Appendix B confirms that minor and medium severity of impact for the Mytilus community is considered as insignificant. The 2% for the Dendrodoa community is also insignificant since recovery will be fast.

In summary, the impact from suspended sediments will be insignificant for the benthic invertebrate communities.

Mussel population

The reduction in mussel biomass is locally up to 10% and caused by the reduction in food availability (phytoplankton as food for mussels). The recovery time after a decrease in biomass of blue mussels is relatively short (Figure App. B.14.1 in Appendix B) and recovery will occur within a couple of months after the pressure has stopped. This is regarded as an insignificant impact.

7.2 Sedimentation

7.2.1 Magnitude of pressure

The spill causing the sedimentation was modelled assuming that sand and coarser fractions settle quickly close (< 600 m) to the dredging location and only the finer silt/clay particles are carried away by the ambient currents. Thus, the fauna sedimentation assessment is based on these results and outside the 1200 m band around the alignment the data primarily represent the deposited silt/clay material

(FEHY 2013e). The modelling shows that some immediate deposition takes place in the near-shore zone (below 6 m). Here, the material is resuspended by wave action and currents together with the sediment of local origin. From most places the additional spilled sediment is transported to deeper waters outside the assessment area, where it deposits over a large spatial range in a thin layer below 1 mm thickness. Some of the sediment stays in sheltered shallow areas like the Rødsand Lagoon. At the alignment within 200–600 m from the dredging operations, sedimentation is highest and originates from the coarser part of the spill (sand fraction) that is less mobile.

Figure 7.5 illustrates the estimated magnitude of pressure (MOP) of sedimentation for the whole assessment area for the entire period of tunnel construction.

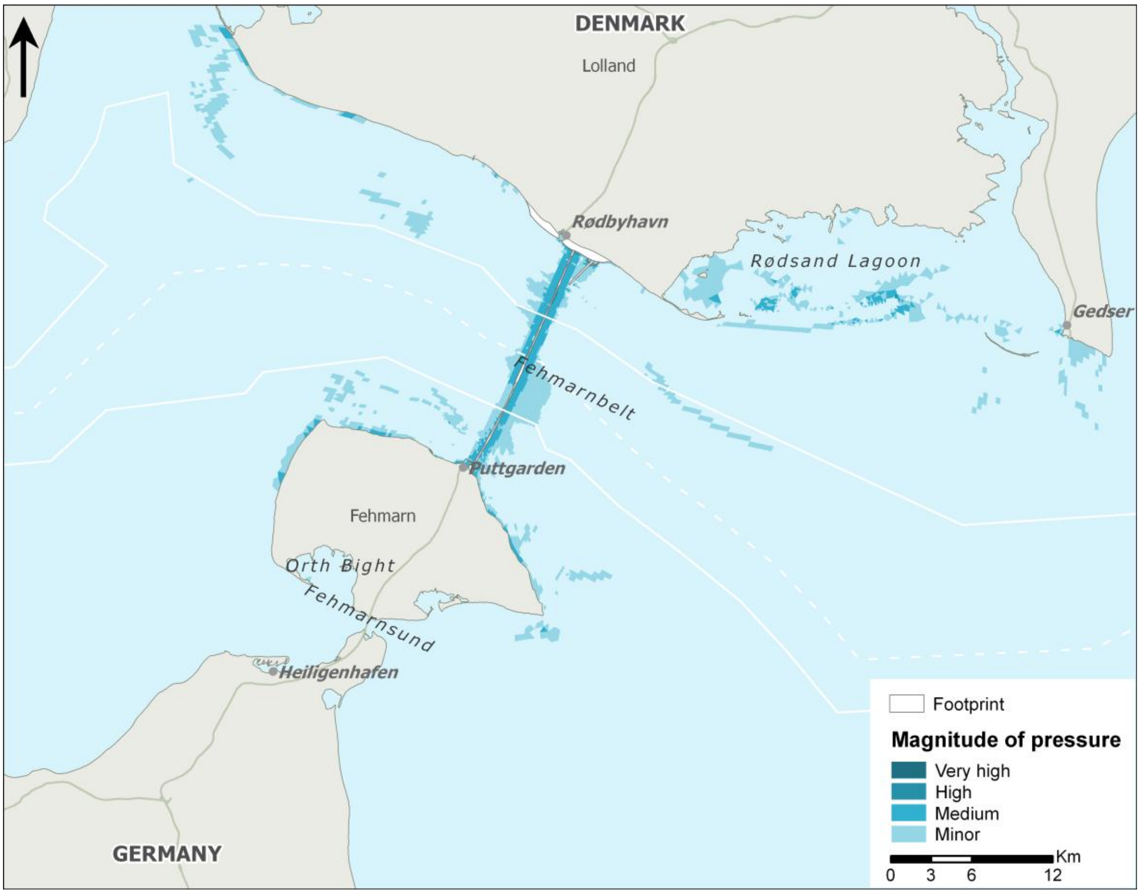


Figure 7.5 The estimated magnitude of pressure for sedimentation for the entire dredging period during tunnel construction and for the whole assessment area.

No very high magnitude of pressure is predicted due to tunnel construction. In the central part of Fehmarnbelt near the tunnel trench (expanding less than 200 m from the alignment) and in the proximity of the construction harbour on the Lolland coast small areas with high magnitude of pressure occur. The other even smaller spot of high MOP is found in Rødsand Lagoon. Large areas of medium magnitude of pressure are found in the central part of Fehmarnbelt near the tunnel trench (at most locations expanding to approx. 600 m from the alignment, i.e. slightly outside the near zone) due to sand fraction deposition and in the shallow areas in Rødsand Lagoon and on the north-eastern coast of Fehmarn due to transport of fine sediment fractions with currents. Minor magnitude of pressure occurs both west and east of the alignment all over the assessment area with most distant spots forming in shallow waters in relative proximity to the shoreline. In the majority of the offshore area in the Fehmarnbelt away from the alignment little or no sedimentation is expected.

The maximum sedimentation caused by tunnel alternative is located near the alignment and in Rødsand Lagoon (Figure 7.6 and Figure 7.7). Along the tunnel trench sedimentation is generally seen to be up to 0.5–1.5 cm (except for few small locations with higher values) in a band of about 600 m on each side of the alignment centre line. This sedimentation originates from the coarser part of the spill (the sand). Deposition is also seen in the sheltered part of the Rødsand Lagoon with typical values up to 1 cm.

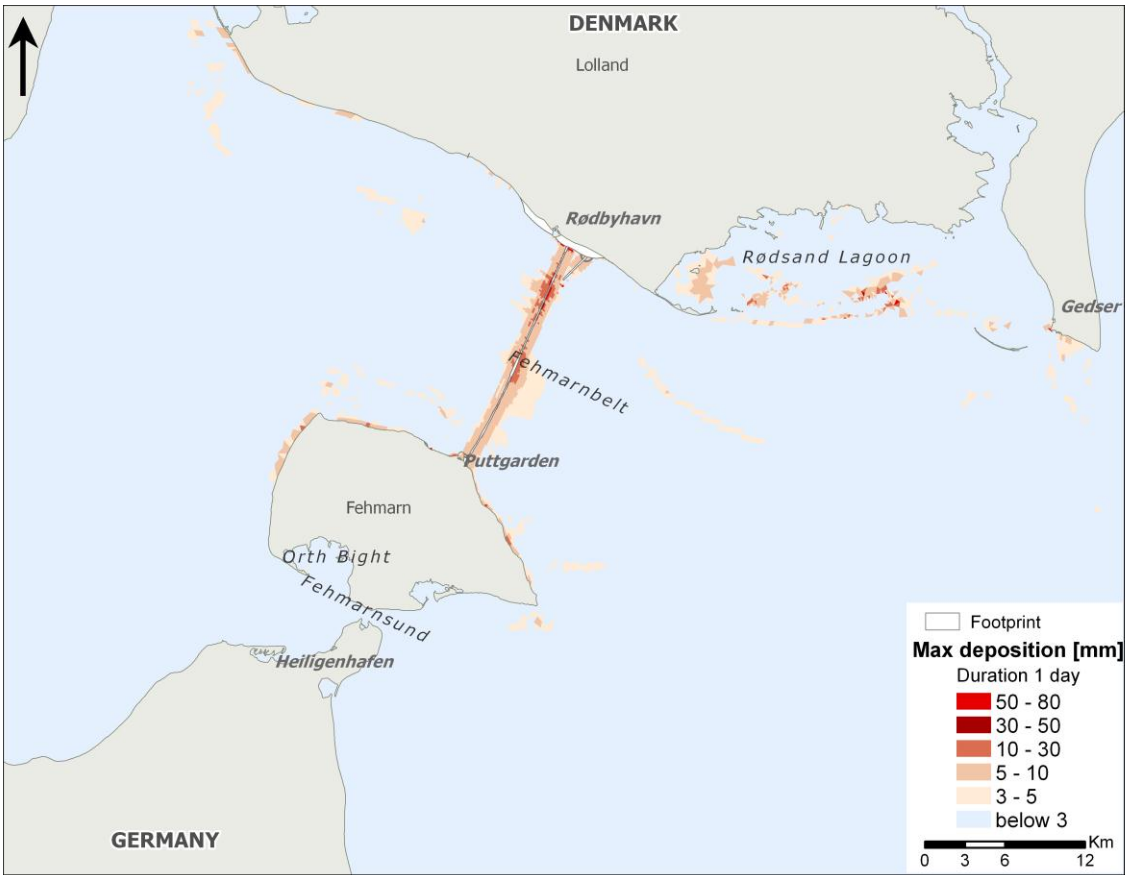


Figure 7.6 Predicted sedimentation in the assessment area caused by the tunnel alternative. The map shows the maximum deposition thickness (mm) that remains in place for more than 1 day within the modelled period (Oct 2014 – Jan 2020). The maximum deposition is 80 mm.

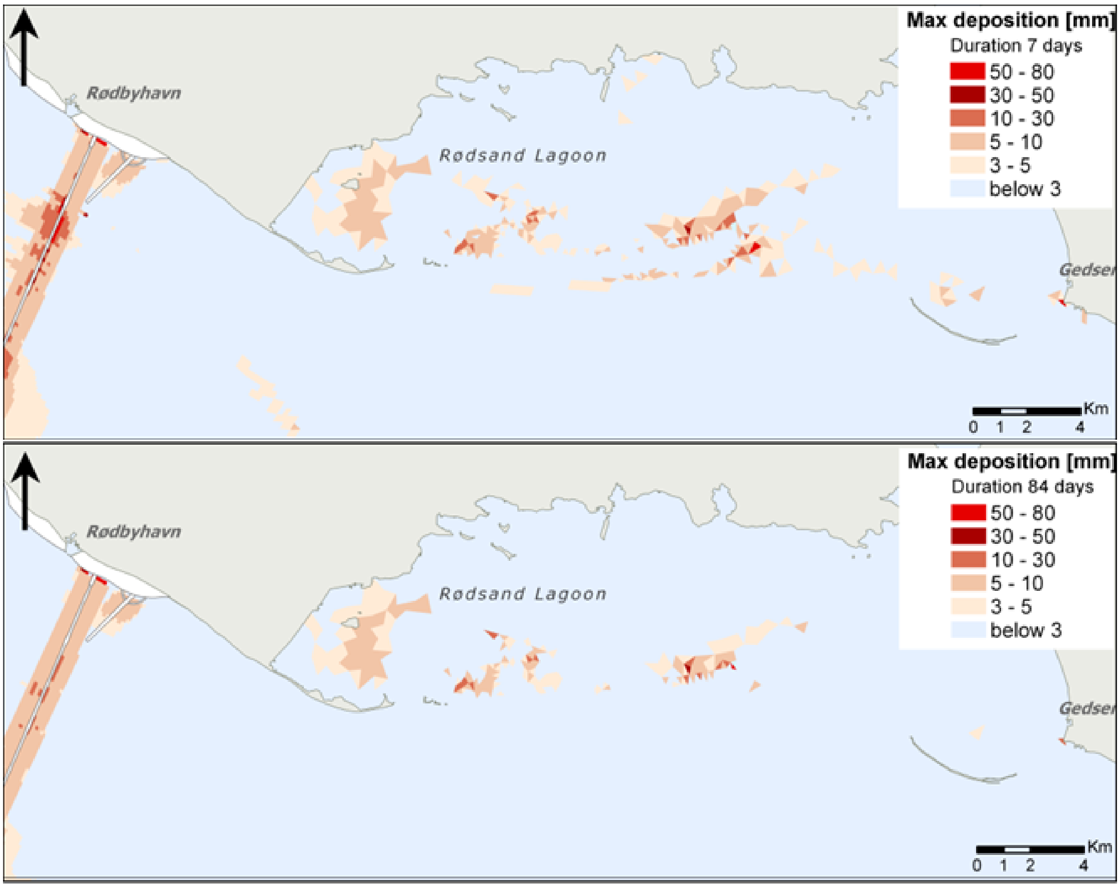


Figure 7.7 Predicted duration of sedimentation caused by the tunnel alternative in the most affected regions. The maps show the maximum deposition thickness (mm) that remains in place for more than 7 (upper panel) and 84 days (lower panel) within the modelled period (Oct 2014 – Jan 2020). The maximum deposition is 80 mm for both periods.

7.2.2 Degree of impairment

The assessment of the degree of impairment is done by intersecting the sensitivity of the benthic fauna communities to sedimentation (defined in section 0) with the magnitude of pressure described in the previous section (according to the linking matrix given in section 3.7).

Figure 7.8 illustrates the predicted degree of impairment levels for benthic fauna communities caused by the pressure sedimentation due to tunnel construction. Table 7.4 lists the results of the assessment for the different degrees of impairments.

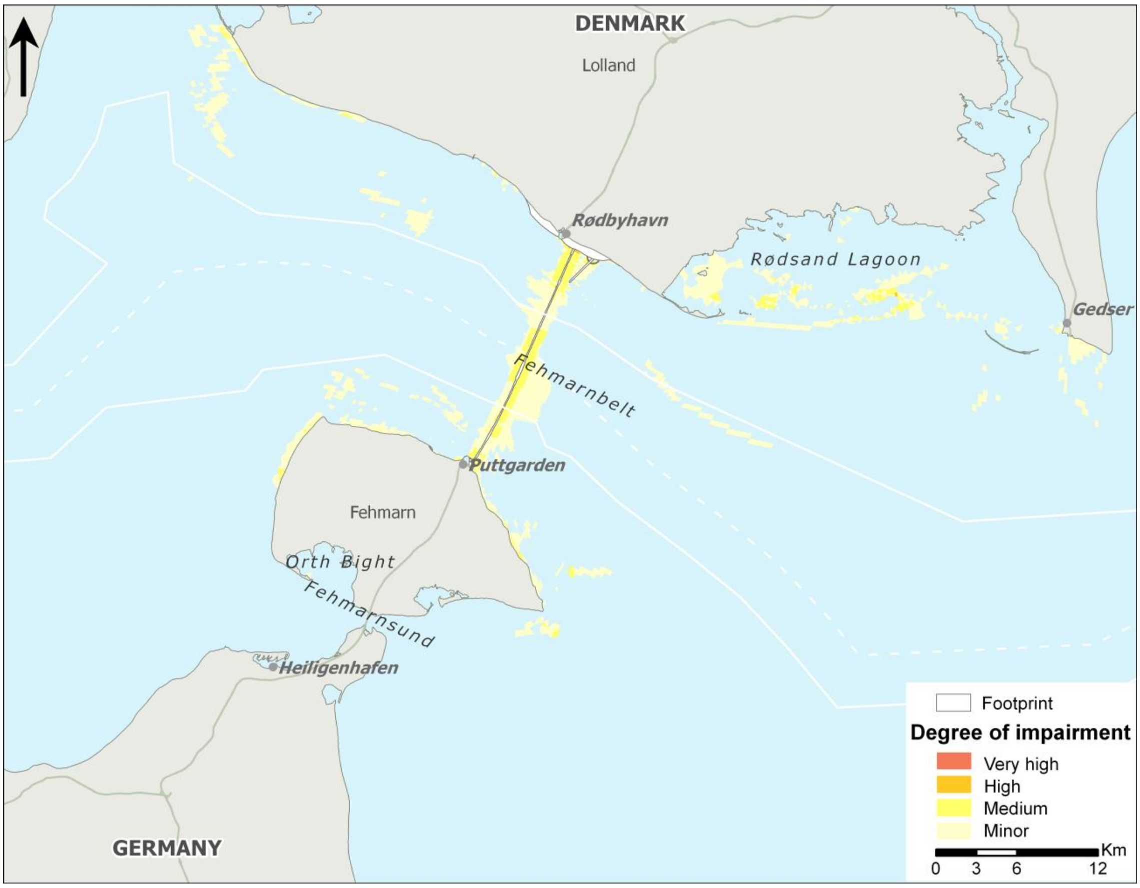


Figure 7.8 *The expected degree of impairment levels for the whole study area resulting from the overlay of sensitivity with maximum magnitude of pressure levels determined for the entire dredging/backfilling period of tunnel construction.*

Table 7.4 *The results of assessment of degree of impairment due to the pressure sedimentation caused by tunnel construction for different areal zones.*

Pressure: **Sedimentation**						
	degree of impairment – area impaired (ha)					
	total	near zone	local zone	DK	DE national	DE EEZ
Very high	0	0	0	0	0	0
High	16	10	0	15	0	0.5
Medium	1,737	1,077	608	1,022	362	353
Minor	10,119	966	2,560	6,481	2,683	955
Total	11,872	2,053	3,168	7,518	3,045	1,309

Table 7.5 *The impact and results of assessment of degree of impairment for the nine benthic fauna communities due to the pressure sedimentation.*

Pressure:	**Sedimentation**	
	total	*degree of impairment – area impaired, ha*
Very high	0	0
High	16	Arctica - 0.45 Cerastoderma - 0.17 Gammarus - 1.7 Mytilus - 7.97 Rissoa - 5.57
Medium	1,737	Arctica - 680.24 Cerastoderma - 126.16 Corbula - 13.25 Dendrodoa - 49.72 Gammarus - 267.19 Mytilus - 352.63 Rissoa - 246.09 Tanaissus - 1.3
Minor	10,119	Arctica - 1,628.48 Bathyporeia - 1,187.01 Cerastoderma - 724.68 Corbula - 1,880.32 Gammarus - 1,703.37 Mytilus - 1,638.38 Rissoa - 1,354.45 Tanaissus - 2
Total	11,872	Arctica – 2,309.17 Bathyporeia – 1,187.01 Cerastoderma – 851.01 Corbula – 1,893.57 Dendrodoa – 49.72 Gammarus – 1,972.26 Mytilus – 1,998.98 Rissoa – 1,606.11 Tanaissus – 3.3

Overall 11,872 ha inhabited by benthic fauna are impaired due to sedimentation (Figure 7.8, Table 7.5), predominantly by minor degree of impairment. No areas with very high degree of impairment are predicted. High degree of impairment affects different communities. Small areas of the Arctica community are impaired in the near zone in central Fehmarnbelt (German EEZ). Approximately 8 and 1.7 ha of Mytilus and Gammarus communities in the near zone in the proximity of the alignment close to the Lolland coast are affected. A small area of the Rissoa and Cerastoderma communities (5.57 and 0.17 ha, respectively) is impaired in Rødsand Lagoon where highest observed deposition of fine spilled sediment fractions occurs due to currents patterns.

Medium degree of impairment occurs mainly in the Arctica community along the tunnel trench (680 ha, with over half of that area being in the German EEZ) and in the Mytilus (mostly close to the reclamation area and access channel at Lolland) and Gammarus communities. 140 ha are impaired in the near zone in Danish and German coastal waters and many smaller areas are impacted in the local zone comprising another 63 ha, mainly along the coast of Fehmarn. 65 ha are impaired outside the 20 km corridor, mainly in Rødsand Lagoon, along the south-western coast of Lolland and the northern coast of Fehmarn. All the medium degree of impairment of the Rissoa community and most impairment on the Cerastoderma community occurs in Rødsand Lagoon.

Possible biomass reductions from the predicted impairment of benthic communities will correspond qualitatively to the degree of impairment determined for the communities. In case of medium to minor degree of impairment, the possible reductions are only due to e.g. lower reproduction, feeding and growth rates, but not due to mortality. These estimates should be considered as being conservative and expected only during the construction phase. Experience from other projects and studies indicate that the effects will be short with quick re-establishment of the natural deposition patterns. Subsequently, the condition of organisms and the population will return to a pre-impact level.

7.2.3 *Severity of impact*

The assessment of the severity of impact is based on the predicted degree of impairment described in the previous section and considers additionally the information on rates and frequencies of the pressure, sensitivity and importance of the community. As no very high magnitude of pressure is predicted due to sedimentation caused by the construction of tunnel alternative, no loss and no very high severity of impact of benthic fauna is expected.

The patterns of sedimentation in areas with most severe sedimentation impact, i.e. exposed to high and medium degree of impairment, are illustrated in details in Figure 7.9 at Lolland and in Figure 7.10 in Rødsand Lagoon.

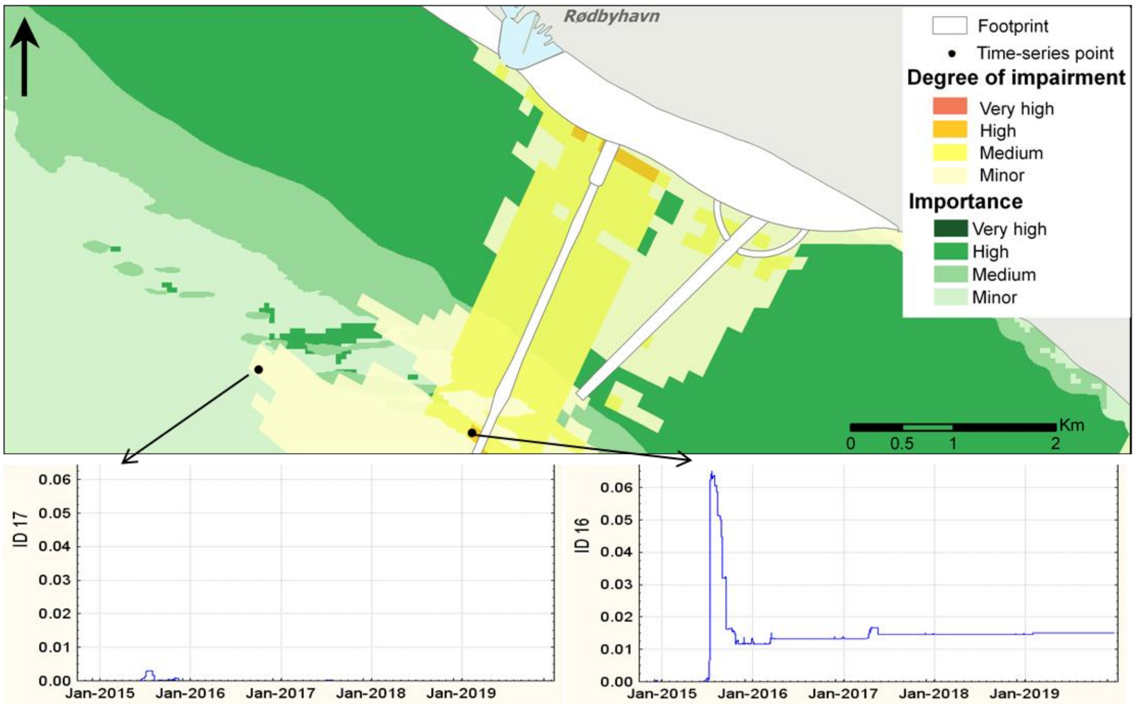


Figure 7.9 Degree of impairment from sedimentation caused by the tunnel alternative at Lolland (upper part). Time series plots (lower part) are shown for selected locations. x axis: time from Oct 2014 to Jan 2020; y axis: deposition thickness in m (0–0.06) with captured 2 hours time steps. Importance of the fauna communities is indicated.

The modelled maximum accumulation near the tunnel trench and near the reclamation area at Lolland (Figure 7.9) is 7 cm. These areas are inhabited by the Gammarus (medium importance) and Mytilus (high importance) communities, respectively. Near the tunnel trench sedimentation takes place due to the dredging within

5 days in July 2015 characterised by a rate of 16 mm per day. After that the deposition sharply drops down. Due to the proximity to the coast slow resuspension (washout) of fine mobile fractions by waves and currents begins. Within 3 month only the most coarse sediments (sand) remain in an approximately 1.5 cm layer that stays in place until the end of the construction phase. Thus, the predicted high degree of impairment resulted from a single (incidental) deposition event characterised by a high rate of sediment accumulation (over an order of magnitude above the background values) with a relatively short duration of the deposition itself (5 days), but with the accumulated layer remaining on the seabed for well over a month. In Essink (1999) such conditions of enhanced sedimentation are described as harmful for characteristic sessile species of the Mytilus community (including *Mytilus edulis*) and the Mytilus community is also classified as having a high importance. Thus, high degree of impairment should be directly interpreted as high severity of impact. However, the affected areas are very small and recovery is expected within two years after the construction phase has ended. The gradual reduction of the degree of impact with increasing distance from the dredging works is seen in most regions. Many areas with minor degree of impairment are predicted due to slow gradual accumulation from a single sedimentation event exceeding 3 mm for 5 days with a maximum deposition rate of 1 mm per day. At these locations the recovery after only a slightly impacted viability of most sensitive species in the community will be quick.

The area with a modelled maximum sedimentation in Rødsand Lagoon (Figure 7.10) is inhabited by the Rissoa community (very high importance), together with negligibly small locations of the Cerastoderma community (medium importance). The gradual accumulation there takes place over months, with a typical rate of 0.35 mm per day (July through December 2015) and a couple of days in July and October, each with rates of 0.5–1.1 cm per day. On the other hand the maximum natural background concentrations of suspended sediments in the Rødsand Lagoon are about 5–10 times higher than the additional concentrations of suspended sediments resulting from the spill, implying that short term natural sedimentation and erosion will be 5–10 times higher than the sedimentation of the sediment spill. Benthic communities in Rødsand Lagoon are adjusted to enhanced sedimentation, which was considered in the definitions of sensitivity for the respective communities, i.e. in the previous steps of the assessment. Therefore, also for the Rødsand Lagoon the predicted degree of impairment is directly used as severity of impact.

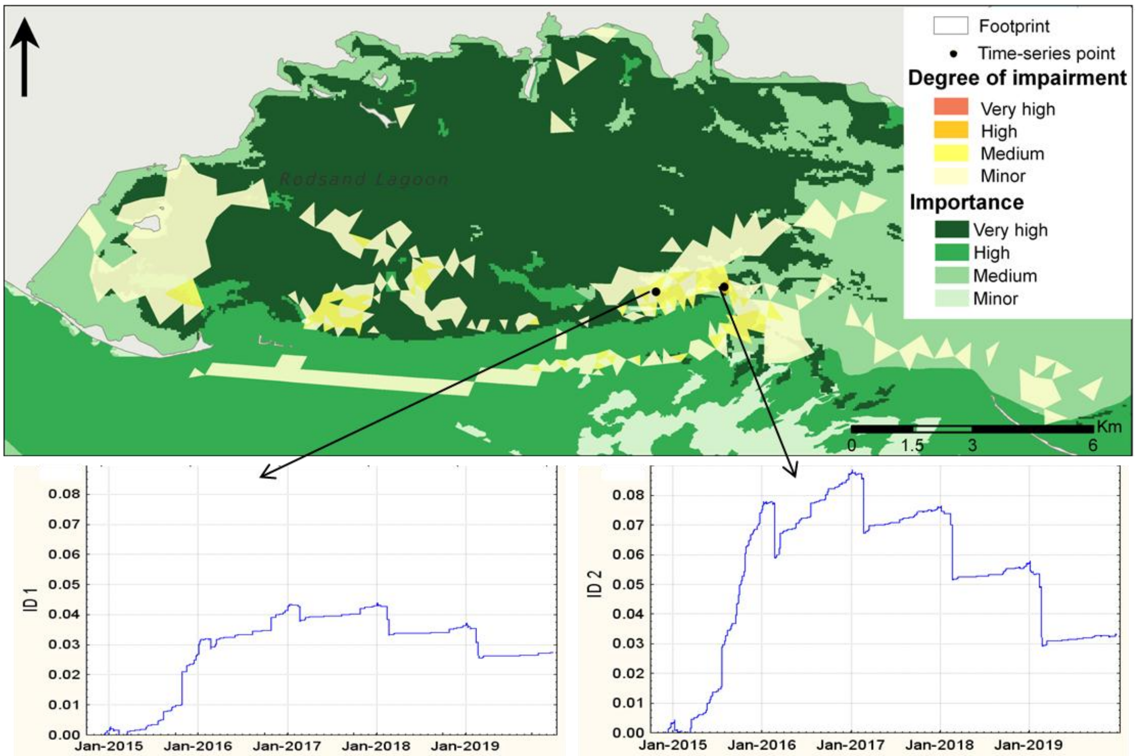


Figure 7.10 Degree of impairment from sedimentation caused by the tunnel alternative in Rødsand Lagoon. Importance and time series plots are shown for selected locations. x axis: time from Oct 2014 to Jan 2020; y axis: deposition thickness in m (0–0.09) with captured 2 hours time steps. The location with high degree of impairment is under the time series point with ID2.

The recovery patterns and recovery time of the communities are site-specific depending on the degree of the disturbance. (Norrko et al. 2010) give an example of recovery in shallow waters habitats. After severe local disturbance (defaunation by hypoxia on plots from 1–16 m^2) at a sheltered sandy site at 5 m depth, benthic macrofauna responded with an increase in the population of the opportunistic Hydrobiidae. This increase occurred due to increased food availability because of rapid growth of microphytobenthos and lasted over a year. This effect gradually disappeared towards exposed sites, indicating a shift in the relative importance of smaller scale biological factors to broader scale physical factors from sheltered to more exposed habitats. The study documented that the recovery of Oligochaeta was clearly delayed compared with epifaunal Hydrobiidae with an abundance below the control values until 1 year after disturbance. This information on the recovery of small, totally defaunated areas can be translated to rather large areas with only viability being impaired. Thus, also here recovery within two years after construction phase has ended is expected.

Within the near zone, large areas of medium degree of impairment are also translated to medium severity of impact. This affects 640 ha of Arctica community, 236 ha of Mytilus community, 140 ha of Gammarus community and 48 ha of Cerastoderma community.

Long time-series observations at the HELCOM monitoring station 010 located at the deep central part of the Fehmarnbelt (within the Arctica community, very high importance) near the alignment suggest that the community shows evidence of beginning recovery after some 2–3 years after aperiodic disturbance events caused by oxygen depletion (Wasmund et al. 2009). This is in consistence with Pearson and Rosenberg's (1978) model of succession. Only the most tolerant species are able to survive severe hypoxia events and are found in the area directly after the disturbance, whereas some rare and sensitive species do not seem to settle in the area for 5 or more years after the event.

The biochemical effects of increased deposition from the construction works are partly comparable to effects of oxygen depletion. Under medium and minor degree of impairment from sedimentation similar effects prevail and may lead to a reduction of feeding activity/efficiency and tissue growth. On the other hand, the mechanical influence of the sedimenting particles on the fauna is low and stops when the sediment is deposited. Therefore no mortality is expected. Short-term changes in the condition of some highly sensitive organisms (e.g. suspension feeders with limited mobility, such as the polychaete *Lagis koreni,* epifaunal *Littorina littorea* or *Hydrobia ulvae*) might occur, but these will not remain for a longer time. Mature adults of some long-living species characteristic for the Arctica community (e.g. the bivalve *Arctica islandica* and the polychaete *Nephthys ciliata*) are most tolerant to deposition and the impact on them is small compared e.g. to variability caused by natural hypoxia disturbance.

In summary, the degree of impairment can be directly interpreted as severity of impact. The largest impact takes place within the near zone and in Rødsand Lagoon and will be characterised by minor to medium severity of impact on all affected communities.

7.2.4 Impact significance

The impairment extends beyond the Fehmarnbelt comparison zone (20 km corridor around the alignment), therefore the complete EIA assessment area is taken as a comparison zone instead (see section 3.9). The impacted areas inhabited by each benthic community in relation to the respective total area is summarised in Table 7.6.

Table 7.6 Areas (ha) impacted due to the pressure sedimentation caused by tunnel alternative in relation to the total area of the community in the complete EIA assessment area.

Community	high severity		medium severity		minor severity		total	
	ha	%	ha	%	ha	%	ha	%
Arctica	0.4	0.0	680	0.6	1628	1.5	2309	2.1
Bathyporeia		0.0		0.0	1187	7.6	1187	7.6
Cerastoderma	0.2	0.0	126	1.1	725	6.5	851	7.6
Corbula		0.0	13	0.1	1880	14.2	1894	14.3
Dendrodoa		0.0	50	0.2		0.0	50	0.2
Gammarus	1.7	0.0	267	0.4	1703	2.3	1972	2.7
Mytilus	8.0	0.0	353	1.1	1638	5.3	1999	6.5
Rissoa	5.6	0.0	246	2.1	1354	11.6	1606	13.8
Tanaissus		0.0	1.3	0.1	2.0	0.1	3	0.1

The impairment of the Arctica community by sedimentation takes place on 2.1% of the total area predicted in the EIA assessment area. This is predominantly due to minor severity of impact and considering all aspects of magnitude of pressure long-lived characteristic species of this community will not be significantly affected, recovery is likely to start within few months. Since only viability is affected, the community is expected to reach pre-disturbance condition within 2 years after the end of the pressure. Based on these arguments, this impact is not significant, also on the scale of the near and local zone, where sedimentation impact is predicted on 11.6% of Arctica community.

The impact on the Bathyporeia and Corbula communities with minor importance is virtually limited to minor severity (7.6% and 14.2% of the total community area within the EIA assessment area, 30% and 18% of its area within the near and local zones, respectively). These communities have the lowest estimated recovery time, (< 2 years) and in reality recovery are expected within less than 1 year, as only low detectable effect on the viability of species is likely to occur under minor severity level. Consequently, these impacts are not significant.

The total impacted area of Cerastoderma community corresponds to 8% of the community area within the 20 km corridor around the alignment and 7.6% of the overall community area. This community has a medium importance and due to predominantly minor level of severity this impact is also not significant. Similar is true for the Gammarus community. The area of 1.7 ha with high severity of impact can be neglected compared to the overall area, but even there the community is likely to recover within 2 years after the cessation of the pressure.

The severity of impact of sedimentation on 1999 ha inhabited by the Mytilus community (high importance) is mainly minor. The area amounts to 6.5% of the total community area within the EIA assessment area and to 8.7% of its area within the combined near and local zone. The impacted areas are found in shallow areas along the south-western shore of Lolland (with hotspot near the reclamation area) and in Rødsand Lagoon. The recovery time of the Mytilus community is estimated to 5–10 years for the case of extended periods of very high levels of pressure. For the predicted minor levels of sedimentation the condition of the community is estimated to restore with 1–2 years. Therefore this impact is insignificant.

The transport of fine sediment fractions from the dredging locations to Rødsand Lagoon results in the impairment of 1606 ha of Rissoa community (very high importance) that corresponds to 13.8% of the total predicted area within the EIA assessment area. This includes 5.6 ha (below 0.05%) subject to high severity of impact, whereas on most of the impacted area impact of minor severity is predicted. The estimated recovery time for that community is 5–10 years. Under the observed conditions of relatively low sedimentation rates and adjustment of the community to naturally enhanced sedimentation, the recovery will be quicker and is estimated to take 2–4 years for the small most impacted area and 1–2 years or less for the remainder of the impacted community area. The severely affected area is small compared to the total area of the community and the remaining unaffected community area or area affected to a minor degree will serve as source of recruitment for the recovery of sensitive species populations and recovery of the community structure. Therefore, this impact can also be regarded as insignificant.

In summary, no irreversible impact on marine benthic fauna is expected due to increased sedimentation related to the construction of the tunnel alternative. The impact on the overall character or functioning of the communities in the area is not significant. Recovery is likely to occur within two years after the construction phase is terminated. The low percentage of the sediment spilled during the dredging works will presumably prevent lethal burial of fauna and significant impairment of function in the assessment area.

7.3 Footprint

7.3.1 Magnitude of pressure

The magnitude of pressure in terms of footprint is defined by the spatial amount of the footprint. In total, 584 ha of footprint are used for the tunnel alternative, divided into the different types of footprint (Table 7.7).

Table 7.8 lists the spatial distribution of the total footprint area into the different types. All footprints are located in the near zone.

Table 7.7 Tunnel footprint structures and corresponding footprint type (according to section 2.2.4) and duration of the impact.

Tunnel footprint structure	Type	Duration
Reclamation areas at Lolland and Fehmarn	structure-related	permanent
Elevated near-coast protection reef	structure-related	permanent
Access channel to Lolland work harbour	construction-related	temporary
Tunnel trench outside Natura 2000 site	construction-related	temporary
Tunnel trench inside Natura 2000 site	construction-related	temporary
Work harbours at Lolland and Fehmarn	construction-related	temporary

Table 7.8 Tunnel footprint types and their size (ha) in the different geographical regions.

Type	Structure	Total/ near zone	DK	DE national	DE EEZ
structure-related	reclamation areas	343	329	14	0
	elevated protection reef	13	7	6	0
construction-related	access channel	32	32	0	0
	tunnel trench outside Natura 2000 site	125	77	48	0
	tunnel trench inside Natura 2000 site	56	0	0	56
	work harbours	15	7	8	0
Total		584	452	76	56

Most of the footprint is used by the reclamation areas, where the reclamation area on Lolland is larger than the one on Fehmarn (Figure 7.12 and Figure 7.13). The tunnel trench is the second-largest footprint structure.

7.3.2 Severity of loss

The footprint assessment for the tunnel is done by intersecting the importance of the benthic fauna communities (FEMA 2013a) with the footprint. The level of importance (minor, medium, high, very high) of the benthic fauna that is present in the different regions of the footprint is identical to the severity of loss (see section 3.8).

All 584 ha of footprint are inhabited by benthic fauna communities. The severity of loss is shown in Figure 7.11 – Figure 7.14. Very high severity of loss is due to the tunnel trench (99 ha) in the Arctica community, the major part being located in the German EEZ (56 ha) (see also Table 7.9). Loss of high severity occurs in the Mytilus community. It is mainly due to the reclamation area at Lolland (175 ha) and the access channel to the work harbour at Lolland (32 ha). Medium severity of loss occurs mainly in the Cerastoderma and Gammarus communities. The main area in this category is due to the reclamation area at Lolland (51 ha), followed by the tunnel trench and work harbour at Fehmarn (14 ha). Minor severity of loss occurs in the Corbula and Bathyporeia communities.

Table 7.9 Severity of loss of the tunnel alternative for the pressure footprint. Areas marked with "c:" are construction-related, areas marked with "s:" are structure-related footprints.

Pressure:	**Footprint**					
	severity of loss – area lost (ha)					
	total	near zone	local zone	DK	DE national	DE EEZ
Very high	c: 99 s: 0	c: 99 s: 0	c: 0 s: 0	c: 18 s: 0	c: 25 s: 0	c: 56 s: 0
High	c: 56 s: 182	c: 56 s: 182	c: 0 s: 0	c: 56 s: 182	c: 0 s: 0	c: 0 s: 0
Medium	c: 23 s: 62	c: 23 s: 62	c: 0 s: 0	c: 9 s: 51	c: 14 s: 11	c: 0 s: 0
Minor	c: 51 s: 111	c: 51 s: 111	c: 0 s: 0	c: 34 s: 102	c: 17 s: 9	c: 0 s: 0
Total	c: 229 s: 355	c: 229 s: 355	c: 0 s: 0	c: 117 s: 335	c: 56 s: 20	c: 56 s: 0

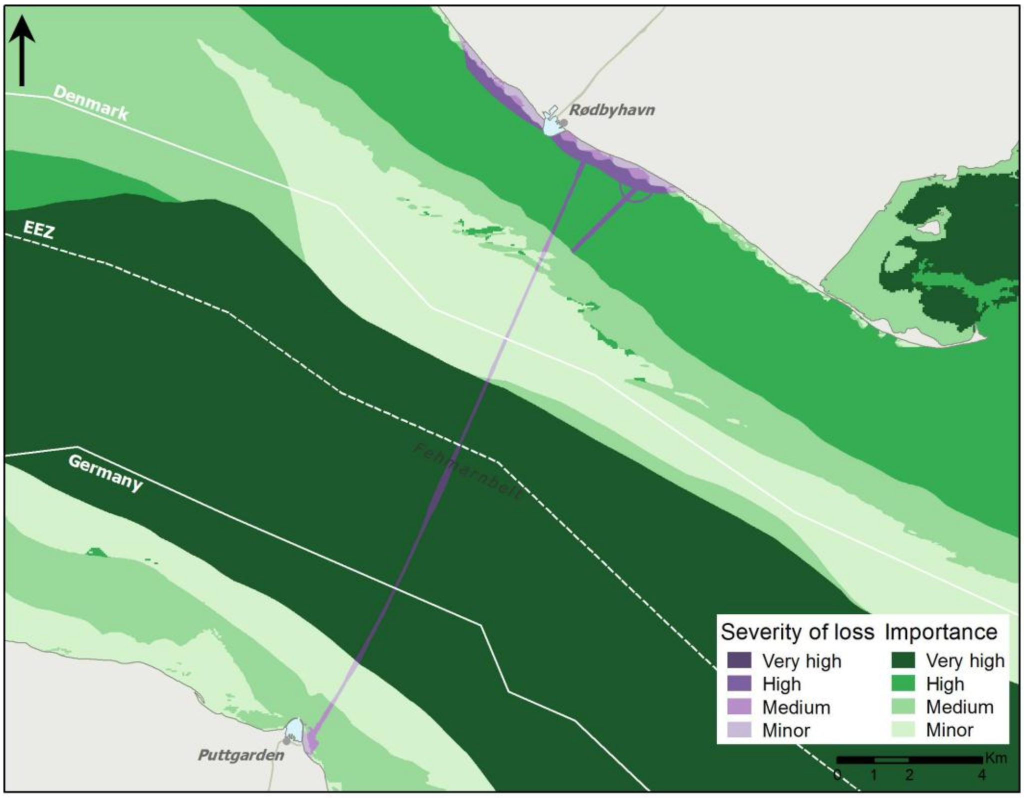


Figure 7.11 Severity of loss (purple) of the tunnel alternative for the pressure footprint.

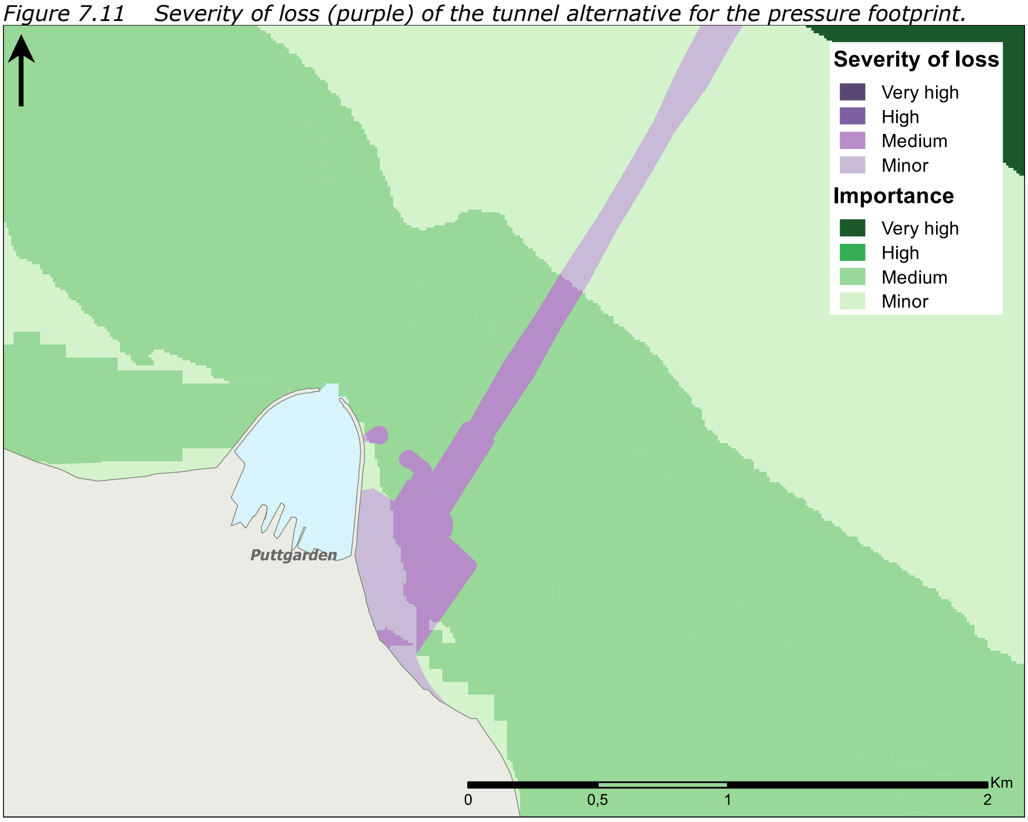


Figure 7.12 Severity of loss (purple) of the tunnel alternative at Fehmarn for the pressure footprint (zoom of Figure 7.11).

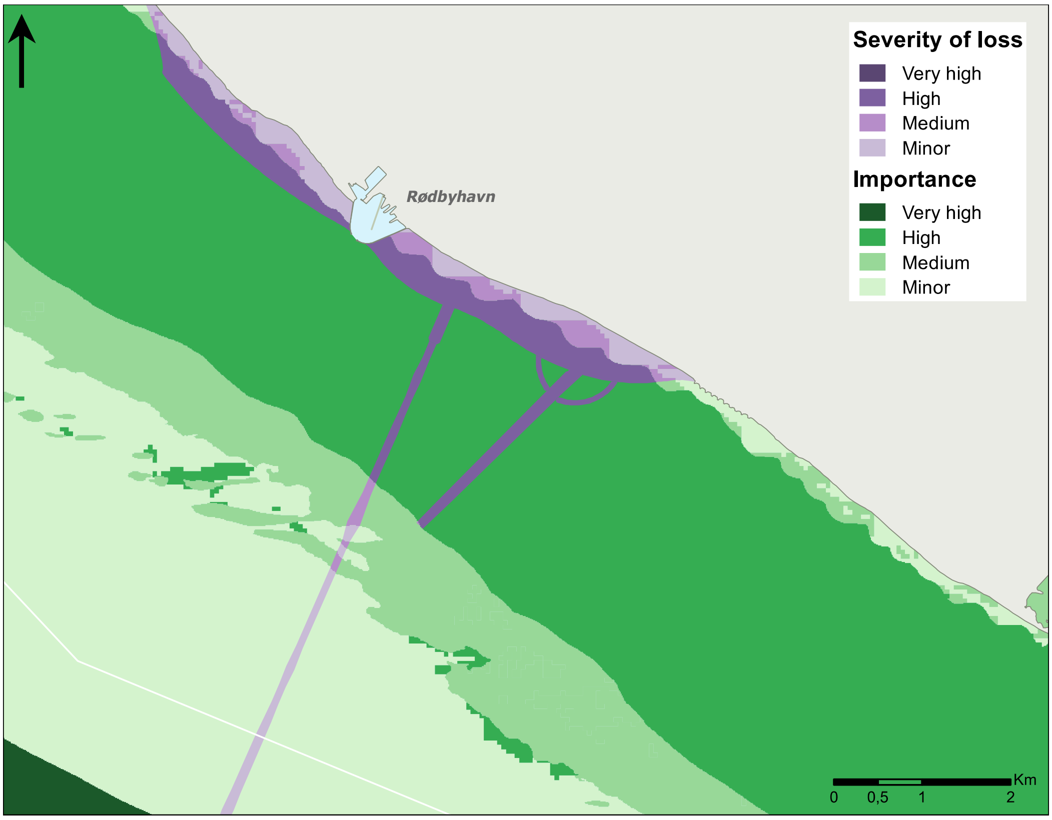


Figure 7.13 Severity of loss (purple) of the tunnel alternative at Lolland for the pressure footprint (zoom of Figure 7.11).

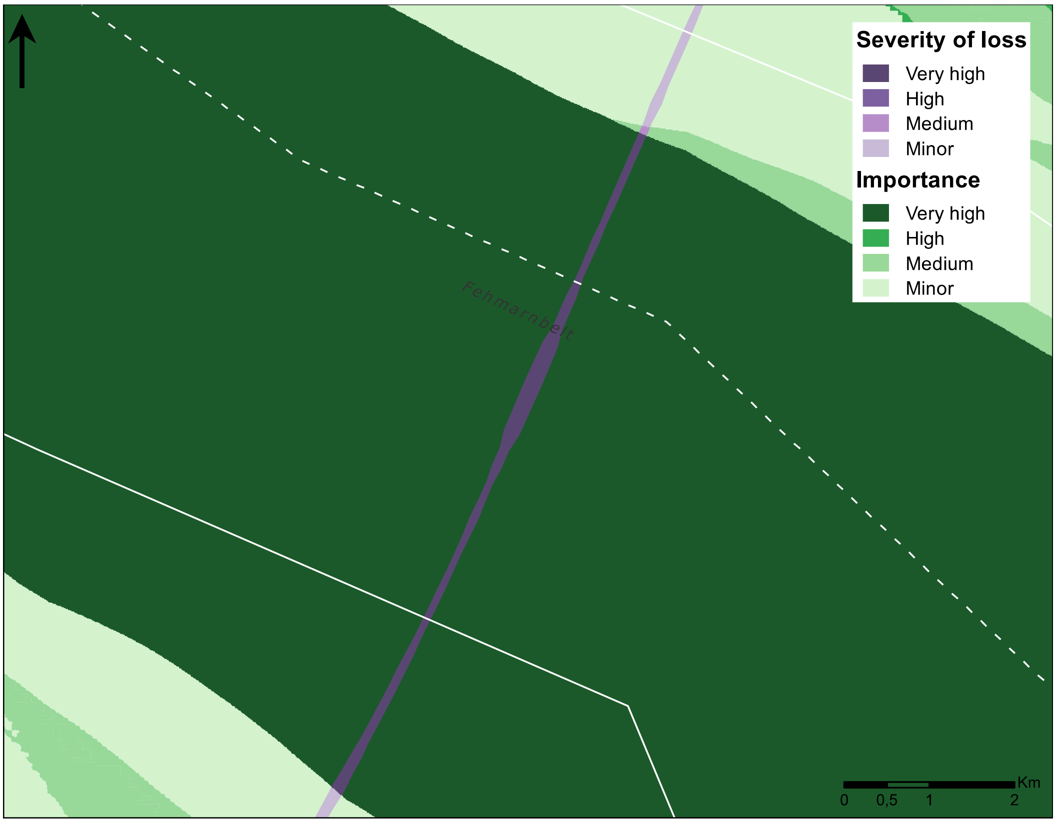


Figure 7.14 Severity of loss (purple) of the tunnel alternative in the central Fehmarnbelt for the pressure footprint (zoom of Figure 7.11).

7.3.3 Impact significance

Six communities in the EIA assessment area are affected by the footprint. These are:

- 238 ha in the Mytilus community (high severity)
- 112 ha in the Bathyporeia community (minor severity)
- 99 ha in the Arctica community (very high severity)
- 66 ha in the Gammarus community (medium severity)
- 49 ha in the Corbula community (minor severity)
- 20 ha in the Cerastoderma community (medium severity)

The 238 ha of Mytilus community are lost at Lolland mainly due to the reclamation area (176 ha) and the access channel (32 ha) and corresponds to 3.9% of the Mytilus community in the comparison zone. The community cannot recover in the major part, because the reclamation area is part of the project structure. Recovery is possible for 55 ha (tunnel trench, access channel, protection reef) within 5–10 years after construction, i.e. in the operation phase A. On the regional scale of the whole EIA assessment area, the impact is equivalent to 0.8% of the areas occupied by the Mytilus community. In terms of the ecological relevance, the impact is thus not significant, because no lasting effect for the community as a whole is expected. Also, the reclamation areas and the protection reef themselves will generate solid substrate (see section 7.4) and thus be new settling grounds for the species of the Mytilus community.

The loss of 112 ha of the Bathyporeia community corresponds to 8.7% of the Bathyporeia community in the comparison zone and is divided into the reclamation areas (111 ha) and the work harbour at Fehmarn (1 ha). Thus, the community cannot recover in the major part of the affected area. On regional scale, this loss is equivalent to 0.7% of the Bathyporeia community in the whole assessment area. Due to this minor loss on the regional scale and the fact that the severity also is minor (minor importance of the Bathyporeia community), the impact is also considered not significant.

The loss of 99 ha Arctica community is part of the construction-related tunnel trench. This corresponds to 0.5% of the Arctica community in the comparison zone (Table 3.12). 65 ha of this footprint are within the Natura 2000 site Fehmarnbelt, meaning that

The bottom of the trench will be approx. 0.7 m below seabed level and have a width of 80–160 m. The seabed in the tunnel trench will recover naturally, with an infill time of 1-28 years depending on the geographical site of the trench. Total recovery of the seabed forms (e.g. sand waves, lunar bed forms) is between 15 and 40 years (FEHY 2013c). In the area where the Arctica community is lost the infill time is estimated to be 2-28 years with a total recovery of bed forms of 15-28 years. The colonisation of the Arctica community can however be expected to commence as soon as the dredging activities are ended. The full recovery time of the Arctica community is estimated to > 10 years (see section 3.5.2). It is expected that the re-colonisation can occur simultaneously with the infilling of the trench, and the re-colonisation time of the Arctica community is therefore estimated to 10-28 years. Based on the sensitivity of the Arctica community and the importance of it, the severity of the loss is assessed as very high. The affected area, however, is below 1% of the total Arctica community in the comparison zone. Therefore, this impact is insignificant.

The major part (51 ha) of the 66 ha impacted Gammarus community is due to the reclamation area at Lolland and cannot recover since it is part of the project structure. The remaining 15 ha are part of the tunnel trench and will recover within the time for the tunnel trench recovery (see above). The area of 66 ha corresponds to 1.2% of the Gammarus community area in the comparison zone. Although this number is above the threshold of 1% and the recovery time will extend into the operation phases, the ecological relevance on the regional scale of the whole assessment area is minor, since the impacted area is 0.1% of the total community area there. Thus, the impact on the Gammarus community is regarded as insignificant.

The 49 ha impacted Corbula community at the tunnel trench corresponds to 0.6% of the community area in the comparison zone and is thus insignificant.

20 ha of Cerastoderma community is impacted due to the reclamation area (5 ha), the work harbour (6 ha), tunnel trench (3 ha) and the protection reef (6 ha). All these areas are at Fehmarn. In total, this corresponds to 1.2% of the community area in the comparison zone. For 9 ha (work harbour and tunnel trench), the seabed can recover within 1–10 years (FEHY 2013c) and with a community recovery time of 2–5 years, it is possible that recovery takes place within two years after the construction phase has ended, but it can potentially also reach into the operation phases. The ecological relevance within the complete assessment area is minor, since the 66 ha Cerastoderma community correspond to 0.6% of the total community area there. Thus, the impact on the community is regarded as insignificant.

In summary, no significant impact is expected due to footprint for the tunnel alternative. The above reductions in area for the communities will result roughly in a similar reduction of biomass for the community corresponding to the above mentioned percentages.

7.4 Solid substrate

Aspect 1 of this pressure is the only relevant aspect of solid substrate for the tunnel alternative. This section therefore gives the assessment of this aspect only.

7.4.1 Aspect 1

Magnitude of pressure
Since sensitivity cannot be applied in this case, the impact can only be quantified from the amount of the solid substrate as the magnitude of pressure as listed in Table 7.10 and Table 7.11.

Table 7.10 Estimated areas (ha) of additional solid substrate for the tunnel alternative divided into the zones where the substrate is introduced.

	total	near zone	local zone	DK	DE national	DE EEZ
Embankment Fehmarn	0.96	0.96	0	0	0.96	0
Embankment Lolland	10	10	0	10	0	0
Protection reef Fehmarn	6	6	0	0	6	0
Protection reef Lolland	6	6	0	6	0	0
Protection layer	181	181	0	77	48	56
Total	204	204	0	93	55	56

Table 7.11 Estimated areas (ha) of additional solid substrate for the tunnel alternative divided into the existing fauna communities where the substrate is introduced. For structures of constant width also the dimensions in terms of 'length x width' are given.

Structure	Benthic fauna community	Area (ha)
Embankment Fehmarn	Cerastoderma	475 m x 16 m = 0.76 ha
	Bathyporeia	125 m x 16 m = 0.2 ha
Embankment Lolland	Mytilus	6100 m x 16 m = 9.76 ha
Protection reef Feh-marn	Gammarus	5.98 ha
Protection reef Lolland	Mytilus	6.26 ha
Protection layer	Cerastoderma	3.69 ha
	Gammarus	4.06 + 0.93 + 8.51 = 13.50 ha
	Corbula	15.16 + 31.33 + 3.10 = 49.59 ha
	Arctica	25.48 + 17.68 = 118.16 ha
	Mytilus	15.85 ha
Total		204 ha

Impact significance

In relation to the predicted community area in the comparison zone, the introduced solid substrate never reaches a significant amount in the affected six fauna communities (Table 7.12). Also, part of the substrate is temporary, since the protection layer on top of the tunnel eventually will be covered by sediment and not be available anymore as solid substrate. Thus, a potential effect of this aspect of the pressure is insignificant for the tunnel alternative.

Table 7.12 *Surface area of additional solid substrate for the tunnel alternative in relation to the total area of the existing community where the substrate is introduced.*

Benthic fauna community	Area (ha)	Percent of comparison zone
Cerastoderma	4	0.27
Bathyporeia	0.2	0.015
Mytilus	32	0.52
Gammarus	20	0.35
Corbula	50	0.64
Arctica	118	0.63
Total	204	0.49

7.5 *Aggregation of impacts*

The results of the assessment for the relevant pressures on the nine benthic fauna communities are presented in Table 7.13. In conclusion none of the pressures have significant effect on the benthic fauna communities.

The pressure suspended sediments causes the largest impact as it has the largest spatial distribution, but most of the area is impacted at minor severity. The pressure sedimentation causes the second-largest extent of impact. Both pressures are restricted to the construction phase. They are caused by material spread with currents and therefore extend beyond the local zone.

It must be emphasized that it is not possible to simply add up the severity of impairment across different pressures for each community because the pressures have been addressed in different ways and without taken the interactions into account. The intolerance, which is an important basis for the assessment, is evaluated for each pressure and community and is given on relative scale for the given pressures. In addition, the severity of impairment for the suspended sediment concentration has been measured for 2015 (only) and the sedimentation for the entire project period. These pressures can hence not be added.

A possible approach to assess cumulative impacts is to identify areas which are impacted by more pressures. It is clear that there are areas where impact from suspended sediment coincides with impact from sedimentation. Areas with coinciding areas with medium-high and medium-medium severity of impairment are less than 0.1 % of the entire investigation area. If there is a cumulative impact from the pressures, this is therefore regarded as insignificant. For areas which are influenced by medium-minor or minor-minor severity of impact, the risk of cumulative impacts is considered very unlikely. Footprint and additional solid substrate are restricted to the near zone. Footprint is not relevant for a discussion of cumulative impacts as these areas are not included in the assessment of impairment (are lost). The amount of solid substrate added is so small that the risk of cumulative impact must be estimated as insignificant.

The tunnel alternative impairs all benthic fauna communities in terms of communities. Most of the communities are impaired with minor severity of impact. Medium severity also occurred in many of the communities but with a small area impacted. Impacted areas are large especially for the pressures suspended sediment and sedimentation and the spatial range of the impacts exceed the local zone for those two pressures. Very high severity only occurs for the pressure footprint (as loss of function, both permanent and temporary) in small areas compared to the above two pressures. High severity is observed for footprint and sedimentation for the Gammarus, Mytilus and Rissoa communities. Only 99 ha of the Arctica community is impacted with very high severity of impact from the pressure footprint. The amount of solid substrate added is small compared to the other three pressures.

The Mytilus community is impacted most, with impairment from suspended sediments in 21,126 ha with minor severity being the largest impact. The second-most impacted communities are the Gammarus, Bathyporeia and Rissoa communities, also exposed to predominantly minor severity and mainly affected by suspended sediments. The remaining communities are affected much less with the Arctica and Corbula communities impacted mostly by sedimentation and the Cerastoderma community impacted mostly by suspended sediments. The Tanaissus community is affected least. This is because the community is located outside the near zone and away from the pressures from footprint and solid substrate.

Even though some of the communities are impacted by two or more pressures, it is unlikely that the impact will be more severe.

Table 7.13 Aggregation of severity of impact (either impairment or loss) for benthic fauna from the tunnel alternative. Numbers indicate the impaired/lost areas (in ha) for the respective communities and the 4 severity classes. For solid substrate the number indicates the area added to the community. Impacts below 1% of the total area are not shown in this table.

	Suspended sediments	**Sedimentation**	**Footprint**	**Solid substrate**
	impairment	**impairment**	**Loss**	**addition**
Arctica				99
Very high			99	
High				
Medium		680		
Minor		1,628		
Bathyporeia				0.2
Very high				
High				
Medium				
Minor	8,803	1,187	112	
Cerastoderma				4
Very high				
High				
Medium		126	20	
Minor	3,029	725		
Corbula				50
Very high				
High				
Medium		13		
Minor	910	1,880	49	
Dendrodoa				-
Very high				
High				
Medium	530	50		
Minor				

	Suspended sediments	Sedimentation	Footprint	Solid substrate
	impairment	impairment	Loss	addition
Gammarus				19
Very high				
High		2		
Medium		267	66	
Minor	12,593	1,703		
Mytilus				32
Very high				
High		8	238	
Medium	2,913	353		
Minor	21,126	1,638		
Rissoa				-
Very high				
High		6		
Medium	209	246		
Minor	7,799	1,354		
Tanaissus				-
Very high				
High				
Medium		2		
Minor		2		
Total*	**57,941**	**11,872**	**584**	**204**
Very high	0	0	99	
High	0	16	238	
Medium	3,652	1,737	86	
Minor	54,289	10,119	161	

*Incl. impairments < 1 %

7.5.1 *Indirect impact due to reduction in eelgrass biomass*

The environmental impact assessment of the benthic flora (FEMA 2013c) has revealed that the increase in suspended sediment will reduce the light availability in some areas with eelgrass, which will reduce the biomass of eelgrass with up to 50 % in some areas of the Rødsand Lagoon. The conclusion in the flora report is that the biomass reduction is temporary and that the biomass can be expected to be restored no later two years after the construction phase has ended. Furthermore the modelled reduction in eelgrass biomass is conservative. As the Rissoa community is closely related to eelgrass there is a potential risk that the community will be impacted by this biomass reduction. However, since the eelgrass is not lost and only reduced in size and biomass, the eelgrass is still present as a habitat for the Rissoa community and the community must therefore be expected to recover (Section 5.2), within the same time frame as the eelgrass.

7.5.2 *Impact on biodiversity*

In connections with large infrastructural projects there is a risk that the biodiversity will be impacted as a result of a decrease in species number caused by the project pressures. As discussed in previous sections the impairment on the benthic fauna communities is assessed to be insignificant for all pressures (individual and aggregated). Only small areas with benthic fauna are lost or are impaired by biomass reduction. In all cases the biomass reduction or loss is only a small percentage of the specific fauna communities. It is therefore not likely that the biodiversity will decrease as a consequence of the tunnel alternative.

7.6 Cumulative impacts

Cumulative impacts are all impacts that add to the project-related impacts and stem from other planned or on-going projects. For a project to be relevant to include, it requires that the project:

- is within the same geographic area
- has some of the same impacts as the fixed link
- affects some of the same environmental conditions, habitats or components
- creates new environmental impacts during the period from the environmental investigations were completed to the fixed link is in operation.

In Table 7.14 projects at sea which are considered relevant to include in the assessment of cumulative impacts are listed. All projects are offshore wind farms. Placement of projects is shown in Figure 7.15 and Figure 7.16.

Table 7.14 Projects which can have cumulative impacts with the fixed link.

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

Rødsand II is specifically included, as this is a project that was under construction while Femern A/S conducted its baseline investigations, whereby a cumulative effect in principle cannot be excluded.

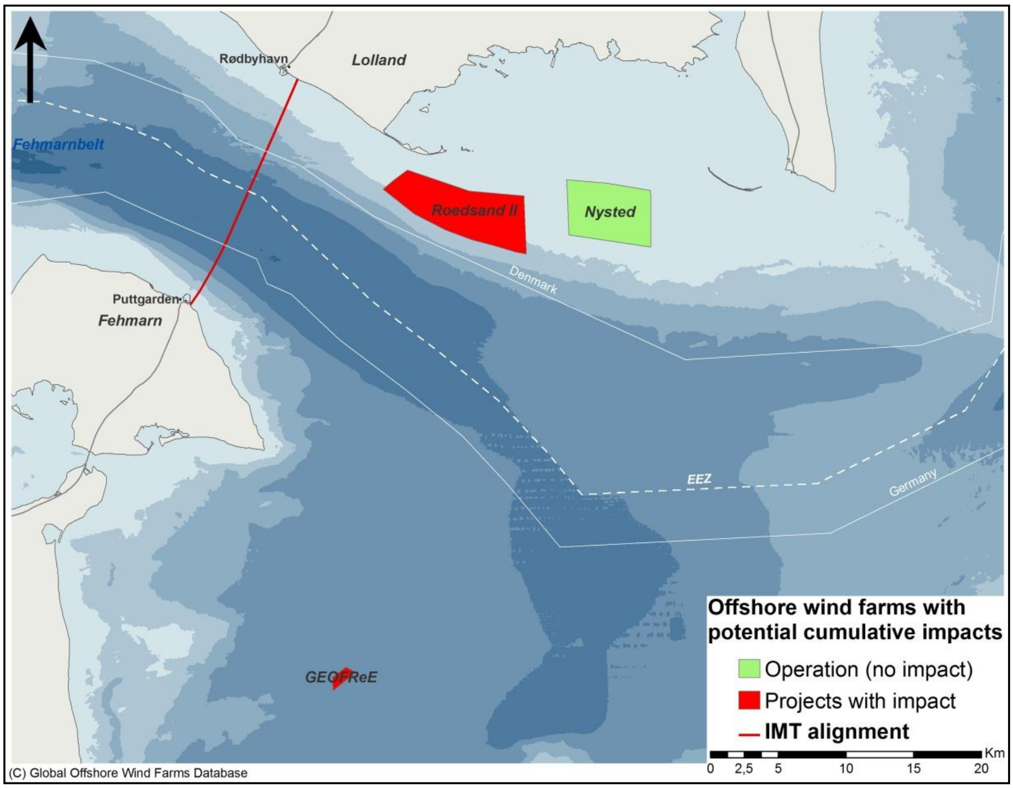


Figure 7.15 Locations of Roedsand II, Nysted and GEOreE

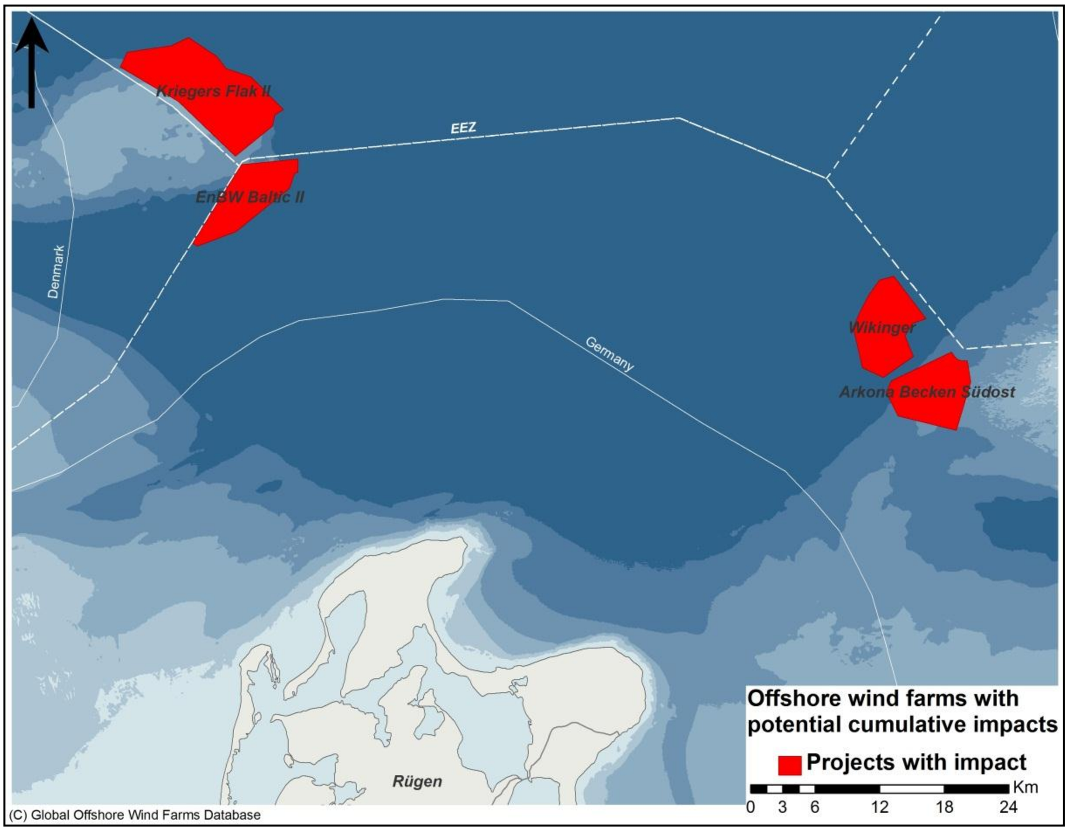


Figure 7.16 Locations of Kriegers Flak, EnBW Baltic II, Wikinger and Akona Becken Südost

In general the impact on the benthic fauna from the wind farms is likely to be local (close to the farm area) (e.g. Energinet.dk 2009, Dong Energy and Vattenfall 2006). As the planned wind farm projects (not Rødsand or Nysted) are all in areas away from the areas impacted by the tunnel alternative (in case of the benthic fauna), a cumulative impact is not likely.

The following section treats the specific projects in detail. There is a risk of cumulative impacts from sediment spill between the installation of the immersed tunnel and the offshore wind farm 'GEOFReE', because sediment spill could overlap in time and space depending on when the project is constructed, which could have a cumulative impact on the benthic fauna. Based on experience from similar projects, it is estimated that the cumulative impacts from sediment spill are not significant. The possibility of cumulative impacts from 'GEOFReE' will definitely be cancelled, if the project is not constructed at the same time as the tunnel.

As for the two offshore wind farms planned east of Rügen, the cumulative impacts will have to be assessed for the relevant components, but no significant impacts are expected because of the relative long distance from Fehmarnbelt, which will have no cumulative impact on the benthic fauna.

Cumulative impacts from raw material extraction and planned wind parks at Krieger's Flak and Rønne Banke are not likely, since there will be approx. 15 km distance between the raw material extraction and wind farms, and it is estimated that the impacts will be of minor extent. Additionally, there are no fixed dates for the establishment of the wind farms, so it is likely that there will not be a coincidence in time between the projects.

The conclusion of the EIA for Rødsand II (Dong Energy 2007) is that the impact on the benthic fauna is either insignificant or very limited. It is therefore not expected that there will be cumulative effects with? this project.

7.7 Transboundary impacts

No transboundary impacts on benthic fauna are predicted for the tunnel alternative.

7.8 Mitigation and compensation measures

This chapter of the report are prepared in co-operation with Femern A/S.

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

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.

As there are no significant impacts on the benthic fauna no mitigation or compensation measures have been suggested.

7.9 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. There is an overall plan for decommissioning of all main elements of the tunnel. This section describes the decommissioning which are in relations to the marine area and hence the benthic fauna.

The overall plan for the marine area is as follows:

Tunnel tubes: The tunnel elements will remain under the seabed. The near shore parts of the tunnel will be filled with inert material from other parts of the decommissioning. The filling will occur from land. There will be no impact on the marine environment and hence the benthic fauna.

Reclamation areas: The reclamation areas are designed to remain in place and will not be decommissioned. There will therefore not be an impact on the marine environment nor the benthic fauna.

As these are the only two elements of the tunnel which are in contact with the marine area, there will be no impact on the marine area due to decommissioning of the tunnel alternative.

8 ASSESSMENT OF IMPACTS OF MAIN BRIDGE ALTERNATIVE

8.1 Suspended sediments

8.1.1 Magnitude of pressure

The spill scenario for the bridge alternative shows that the spill will be approximately 10 times lower than for the tunnel alternative (FEHY 2013e). The concentration of suspended sediments never reaches 10 mg l^{-1} (FEHY 2013e) and is hence below the threshold set for the benthic fauna (Table 4.2). There is no impact and an assessment is not needed.

The mussel population is dependent on primary production (see section 3.7.1) and this is reflected in the mussel modelling. For the bridge alternative, no changes outside the natural variability are estimated (FEMA 2013d) and no effect on the mussel population is expected. An assessment is not needed.

8.2 Sedimentation

8.2.1 Magnitude of pressure

The spill causing the sedimentation was modelled assuming that sand and coarser fractions settle quickly close (< 600 m) to the dredging location and only the finer silt/clay particles are carried away by the ambient currents. Thus, the fauna sedimentation assessment is based on these results and outside the 1200 m band around the alignment the data primarily represent the deposited silt/clay material (FEHY 2013e). The modelling shows that some immediate deposition takes place in the near-shore zone (below 6 m). Here, the material is resuspended by wave action and currents together with the sediment of local origin. From most places the additional spilled sediment is transported to deeper waters outside the assessment area, where it deposits over a large spatial range in a thin layer below 1 mm thickness. Some of the sediment stays in sheltered shallow areas like the Rødsand Lagoon. At the alignment within 200–600 m from the dredging operations, sedimentation is highest and originates from the coarser part of the spill (sand fraction) that is less mobile.

The magnitude of pressure analysis is based on the sediment spill modelling of an earlier bridge version (B-EE, April 2010) which is conservative compared to the final bridge version (variant 2 B-EE, October 2010, see Figure 8.1) by a factor of about 2 (FEHY 2013e). The difference in alignment between the former and final bridge is corrected for by a minor shift of the resulting fields. For the given reasons, the present assessment can be regarded as conservative. Figure 8.2 illustrates the estimated magnitude of pressure (MOP) sedimentation for the whole assessment area for the entire period of the bridge construction.

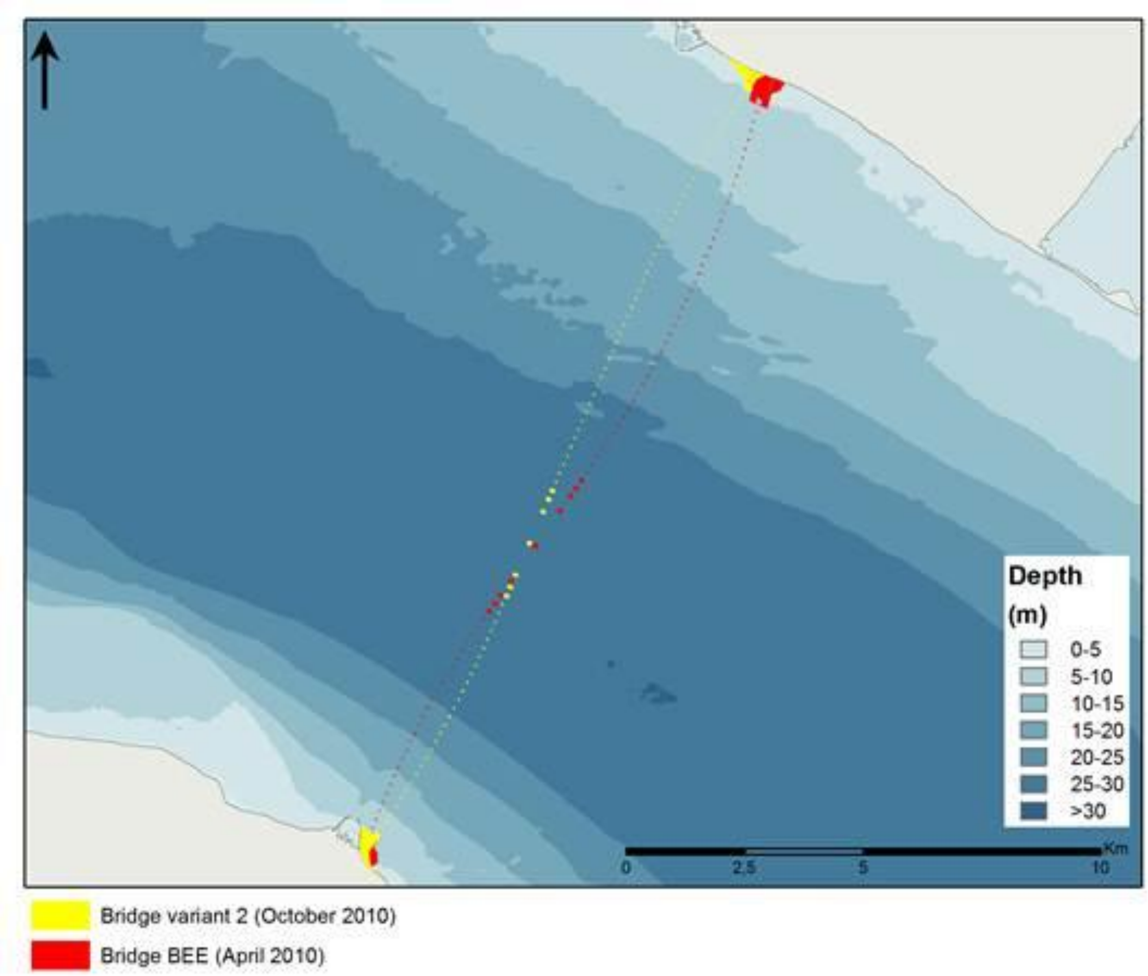


Figure 8.1 Deviation of the alignment of the final main bridge alternative (variant 2 B-EE, October 2010) from the one sediment spill modelling results are based on (B-EE, April 2010).

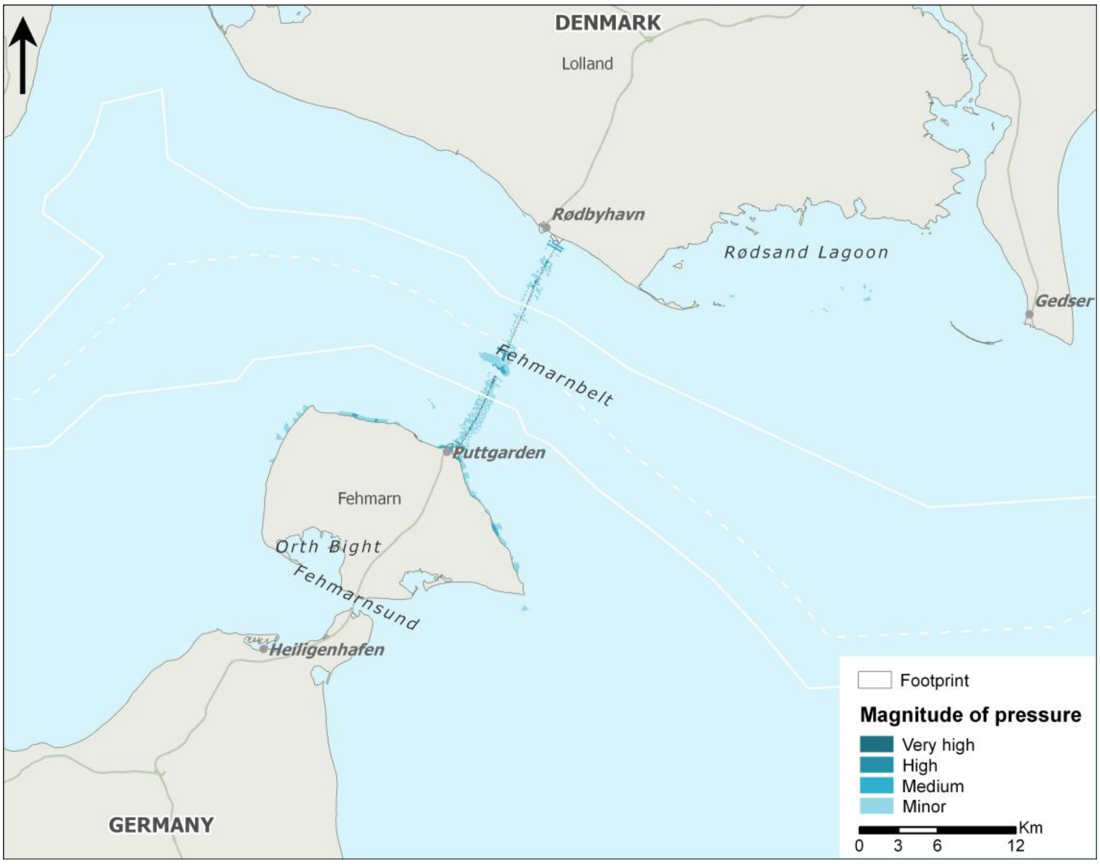


Figure 8.2 The estimated maximum of sedimentation for the whole assessment area for the entire dredging period during bridge construction.

8.2.2 Degree of impairment

The assessment of degree of impairment by sedimentation is done by intersecting the sensitivity of the benthic fauna communities (according to section 5.2.2) with the magnitude of pressure described in the previous section.

Figure 8.3 illustrates the degree of impairment of benthic fauna due to sedimentation, Table 8.1 and Table 8.2 list the results of the assessment for the different degrees of impairments.

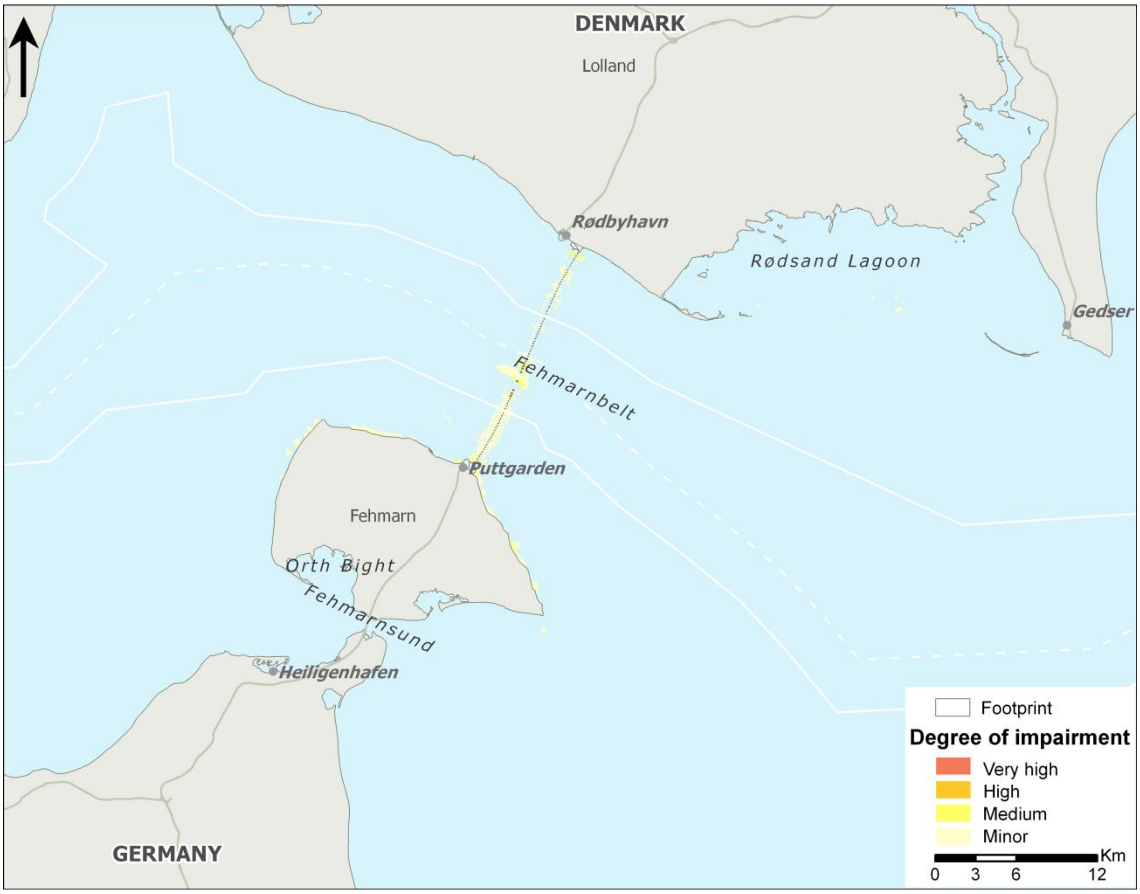


Figure 8.3 *Degree of impairment for the assessment area resulting from the intersection of sensitivity with magnitude of pressure levels determined for the entire dredging period for the bridge alternative.*

Table 8.1 *Degree of impairment for benthic fauna due to the pressure sedimentation caused by the bridge alternative in the different administrative zones.*

Pressure:	**Sedimentation**					
	degree of impairment – area impaired (ha)					
	Total area	near zone	local zone	DK	DE national	DE EEZ
Very high	0	0	0	0	0	0
High	0	0	0	0	0	0
Medium	178	146	32	38	63	78
Minor	1346	689	512	287	770	290
Total	1524	835	544	325	833	368

Table 8.2 Degree of impairment for the nine benthic fauna communities due to pressure sedimentation caused by bridge alternative.

Pressure: **Sedimentation**		
	total	*degree of impairment – area impaired (ha)*
Very high	0	0
High	0	0
Medium	178	Arctica - 92.10 Cerastoderma - 22.89 Gammarus - 25.97 Mytilus - 37.27
Minor	1,346	Arctica - 498.36 Bathyporeia - 241.84 Cerastoderma - 35.96 Corbula - 241.63 Gammarus - 232.29 Mytilus - 72.20 Rissoa - 23.11 Tanaissus - 1.08
Total	1,524	Arctica - 590.46 Bathyporeia - 241.84 Cerastoderma - 58.85 Corbula - 241.63 Gammarus - 258.26 Mytilus - 109.47 Rissoa - 23.11 Tanaissus - 1.08

The sediment spill from the bridge alternative will impact 1524 ha. Nearly 90% of that area is affected by only minor degree of impairment and for the rest of the area a medium degree of impairment is predicted (Table 8.1 and Table 8.2). Most of the medium degree of impairment is within the near zone and only one fifth extends outside it falling into the local zone.

Possible biomass reductions from the predicted impairment of benthic communities will correspond qualitatively to the degree of impairment determined for the communities. In case of medium to minor degree of impairment, the possible reductions are only due to e.g. lower reproduction, feeding and growth rates, but not due to mortality. These estimates should be considered as being conservative and expected only during the construction phase. Experience from other projects and studies indicate that the effects will be short with quick re-establishment of the natural deposition patterns. Subsequently, the condition of organisms and the population will rapidly return to a pre-impact level.

8.2.3 Severity of impact

The assessment of severity of impact is based on the predicted degree of impairment described in the previous section and additionally considers the information on sedimentation rates and frequencies, sensitivity and importance of the communities.

As no loss and no very high or high degree of impairment is predicted, the highest expected level of severity is medium. Four communities are subject to medium degree of impairment: 92 ha of Arctica community (in the central part of Fehmarnbelt, mainly in the German EEZ within the near zone), 37 ha of Mytilus community (at Lolland in the near zone in proximity to reclamation area), 23 ha of Cerastoderma community (within the near zone close to the reclamation area at Puttgarden, with a maximum predicted accumulation of 2 cm remaining for at least 1 day) and 26 ha of Gammarus community (at the coast of Fehmarn around Puttgarden harbour, about one third within the near zone and two third within the local zone). These areas are characterised by a maximum predicted accumulation of 2–5 cm sediment remaining for at least 1 day, rarely over 1 week. The importance of the Arctica community is classified as very high, the Mytilus community as high and the Gammarus and Cerastoderma communities as medium. Considering this situation for these areas, the medium degree of impairment is interpreted as medium severity of impact. A minor severity of impact is predicted for the remaining area affected by sediment deposition. The analysis of deposition time-series show that accumulation takes place over few days to several months. At the same time, the ability of most species to tolerate the predicted low levels of deposition, reworking of the sediment by deposit feeding bioturbators and selective ejection of particles by suspension feeders ensure low impact under the described levels of pressure and fast subsequent recovery (for most location estimated to a few months, rarely more, but not longer than two years).

In summary, the degree of impairment can be directly interpreted as severity of impact. The largest impact takes place within the near zone. The severity of impact on the communities is minor in the largest part of the affected area and only locally medium. Recovery will take place within two years after the construction has ended.

8.2.4 Impact significance

No lethal effects are expected in the assessment area for any of benthic fauna communities due to the pressure sedimentation. The dredging activities during the construction phase only cause disturbance that affects viability with minor and to a limited degree medium severity of impact. The impairment is roughly limited to the extent of the combined near and local zone. Therefore, the comparison zone as defined in section 3.9 is used for the significance assessment. The impacted areas inhabited by each benthic community in relation to the respective total area is summarised in Table 8.3. The affected Rissoa community is located outside the comparison zone in Rødsand Lagoon and assessed separately (see below).

Table 8.3 Areas (ha) impacted due to the pressure sedimentation caused by the bridge alternative in relation to the total area of the community in the comparison zone.

Community	medium severity		minor severity		total	
	ha	%	ha	%	ha	%
Arctica	92	0.5	498	2.7	590	3.2
Bathyporeia			242	18.7	242	18.7
Cerastoderma	23	1.4	36	2.1	59	3.5
Corbula			242	3.1	242	3.1
Dendrodoa						0.0
Gammarus	26	0.5	232	4.2	258	4.7
Mytilus	37	0.6	72	1.2	109	1.8
Rissoa			23		23	
Tanaissus			1.0	1.8	1.0	1.8

The impairment of the Arctica community affects 3.2% of the total of its area predicted in the comparison zone (corresponds to 0.5% of its area within the total EIA assessment area). This is predominantly minor severity of impact and considering all aspects of the magnitude of pressure, long-lived characteristic species of this community with very high importance will not be significantly affected, recovery is likely to start within few months and the viability of the community is expected to reach pre-disturbance condition within few months to 2 years after the end of the pressure. Based on these arguments the impact is not significant.

The impact on the Bathyporeia and Corbula communities (minor importance) is limited to minor severity (18.7% and 3.1% of its area respectively, within the comparison zone, 1.5% and 1.8% of the total community area within the EIA assessment area). Recovery is expected within less than 1 year, as only low detectable effect on the viability of species is likely to occur under minor severity of impact. Therefore, these impacts are not significant.

Total impacted area of the Cerastoderma community corresponds to 3.5% of the community area within the comparison zone and 0.5% of the overall community area within the EIA assessment area. This community has a medium importance and due to mainly minor severity of impact, this is also not considered significant. Similar is true for the Gammarus community. The communities are expected to recover within 1 year after the cessation of the pressure.

The impact on the Mytilus community (high importance) is also mainly minor. The affected area amounts to 1.8% of its area within the comparison zone and to 0.3% of the total community area inside the EIA assessment area. For the predicted minor levels of severity the condition of the community is estimated to restore mostly with 1 year. Therefore this impact is insignificant.

The transport of fine sediment fractions from the dredging locations and into the Rødsand Lagoon results in a minor severity of impact on 23 ha of the Rissoa community (very high importance), corresponding to 0.2% of the total predicted area within the EIA assessment area. The estimated recovery time for that community under the assessed conditions of low sedimentation rates will be maximum 1–2 years. Consequently, this impact is also regarded as insignificant.

In summary, the impact on the overall character and functioning of the communities due to sedimentation in the area caused by the bridge alternative is not significant. Under the final design of the bridge alternative the spill is further reduced compared to the modelled estimates that the present assessment is based on. Therefore the severity of impact will be even lower.

8.3 Footprint

8.3.1 Magnitude of pressure

The magnitude of pressure in terms of footprint is defined by the spatial amount of the footprint. In total, 80 ha of footprint are used for the bridge alternative, divided into the different types of footprint (Table 8.4). Table 8.5 lists the distribution of the total footprint area into the different categories. All footprints are located in the near zone.

Table 8.4 Bridge footprint structures and corresponding footprint types (according to section 2.2.4).

Bridge footprint structure	Type
Reclamation areas at Lolland and Fehmarn	structure-related
Bridge pillars, piers and scour protection	structure-related
Access channels to work harbours	construction-related
Work harbours at Lolland and Fehmarn	construction-related

Table 8.5 Bridge footprint types and their size (ha) in the different geographical regions. The footprint area in the near zone is identical to the total area.

Type	Structure	Total	DK	DE national	DE EEZ
structure-related	reclamation areas	36	16	20	0
	piers and pillars	20	7	4	9
construction-related	work harbours and access channels	24	15	9	0
Total		80	38	33	9

Most of the footprint is used by the reclamation areas, where the reclamation area on Lolland and Fehmarn are roughly equally large (Figure 8.4, Figure 8.5, and Figure 8.6).

8.3.2 Severity of loss

The footprint assessment for the bridge is done by intersecting the importance of the benthic fauna communities (FEMA 2013a) with the footprint. The level of importance (minor, medium, high, very high) that is present in the different regions of the footprint is directly used as the severity of loss (see section 3.8).

All 80 ha of footprint are inhabited by benthic fauna communities. The main impact comes from the footprint of the reclamation areas and the pillars, piers and scour protection (Table 8.6 and Figure 8.4). These are lost, but are small in comparison to the total area the respective communities occupy. Where construction-related footprint is present, the former community can re-establish, when the sediment characteristics do not change. For a smaller part of the Mytilus community that is affected by the temporary work harbours at the Lolland coast, it is assumed that the former hard substrate, if any, will not re-establish. Under these conditions, a community change will occur. In relation to the total Mytilus community area within the assessment area, this change is, however, negligible.

Table 8.6 Severity of loss of the bridge alternative for the pressure footprint.

Pressure: Footprint

	severity of loss – area lost (ha)					
	total	near zone	local zone	DK	DE national	DE EEZ
Very high	13	13	0	2	2	9
High	13	13	0	13	0	0
Medium	27	27	0	9	18	0
Minor	27	27	0	14	13	0
Total	80	80	0	38	33	9

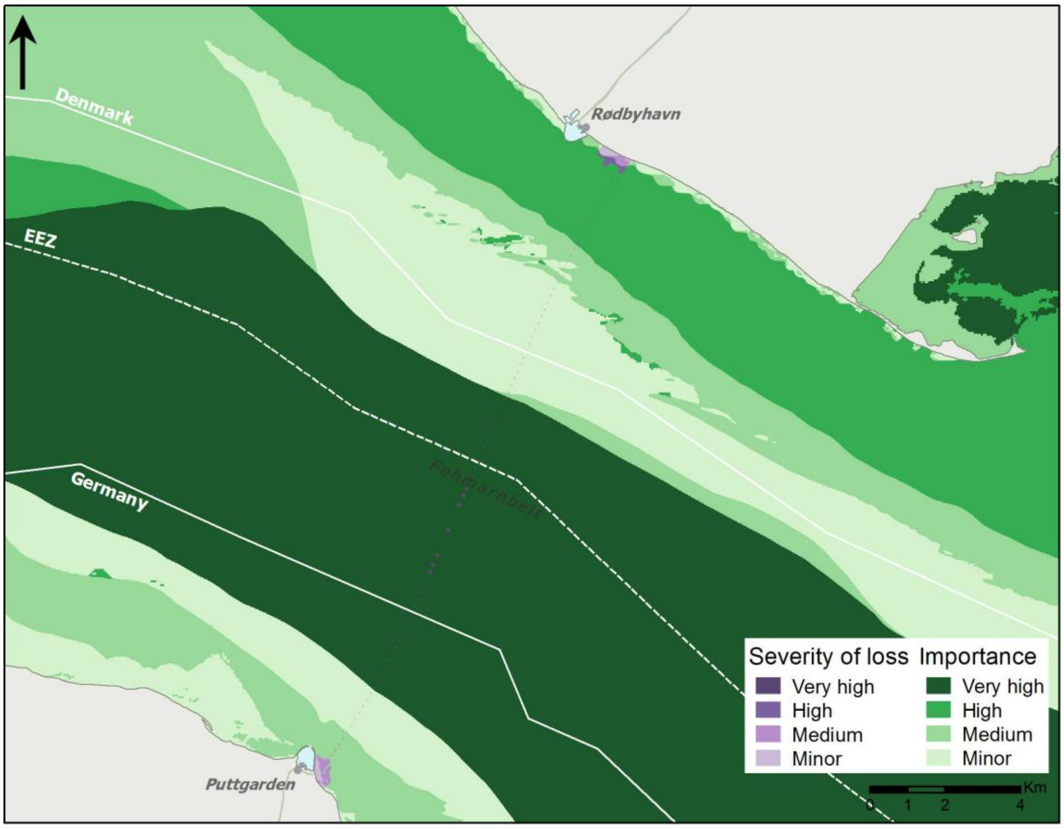


Figure 8.4 Severity of loss (purple) of the bridge alternative for the entire area of the pressure foot-print.

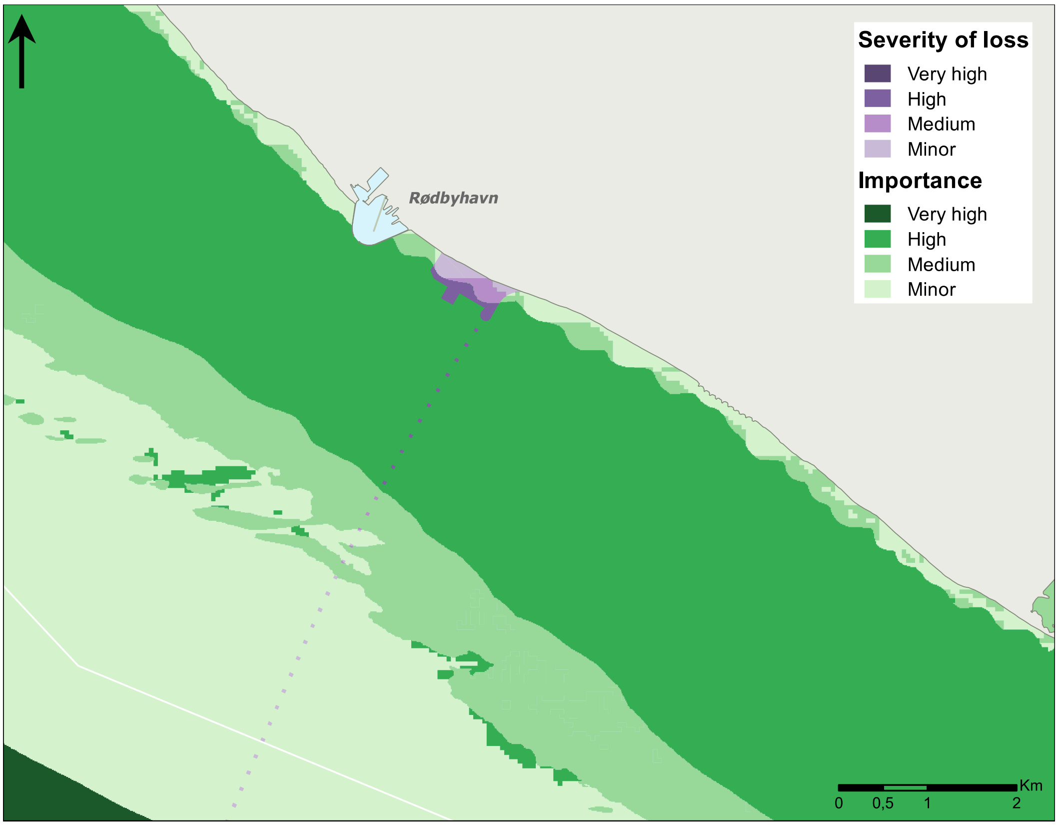


Figure 8.5 Severity of loss (purple) of the bridge alternative at Lolland for the pressure footprint.

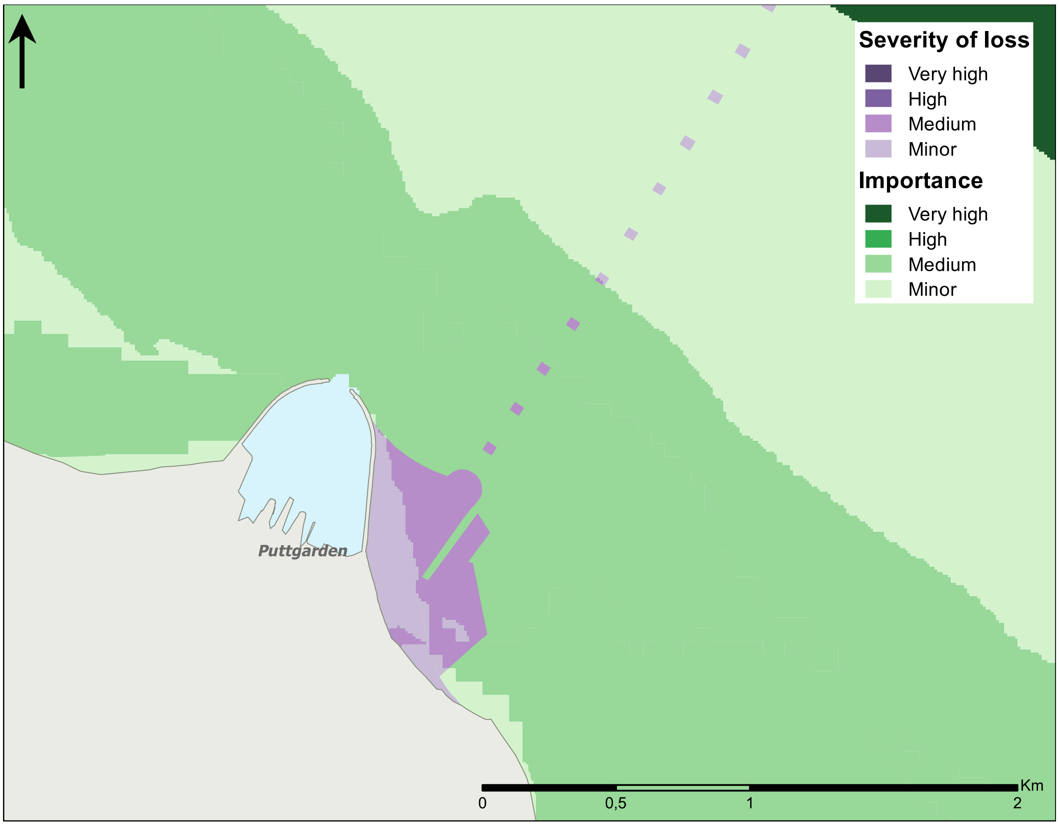


Figure 8.6 Severity of loss (purple) of the bridge alternative at Fehmarn for the pressure footprint.

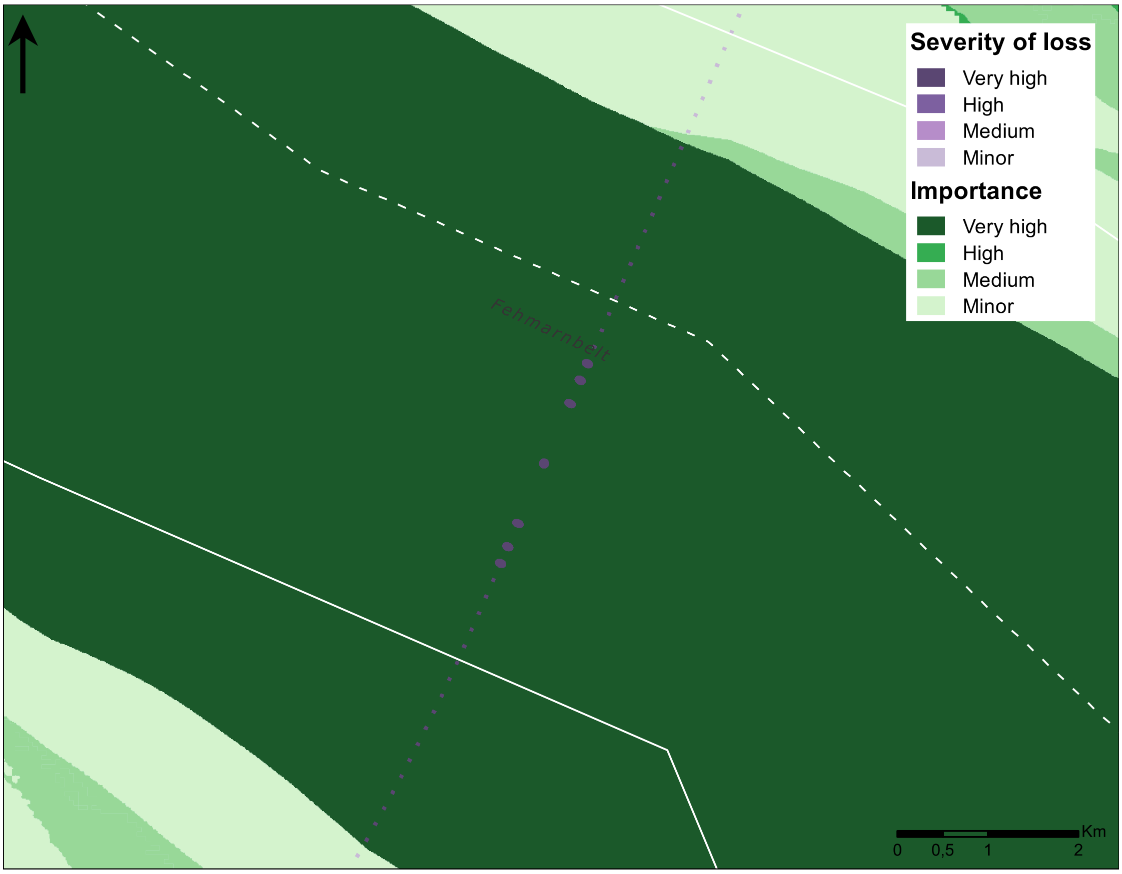


Figure 8.7 Severity of loss (purple) of the bridge alternative in the central Fehmarnbelt for the pressure footprint.

8.3.3 Impact significance

Six benthic fauna communities are affected by the footprint. These are

- 23 ha in the Bathyporeia community (minor severity)
- 15 ha in the Cerastoderma community (medium severity)
- 13 ha in the Mytilus community (high severity)
- 13 ha in the Arctica community (very high severity)
- 11 ha in the Gammarus community (medium severity)
- 5 ha in the Corbula community (minor severity)

The 23 ha of Bathyporeia community lost are due to reclamation areas (17 ha) and work harbours (6 ha). They correspond to 1.8% of the community area in the comparison zone. While the area lost to the reclamation areas cannot recover, the area for the work harbours are expected to recover within two years after the construction phase has ended as the recovery time for the Bathyporeia community is less than 2 years. The permanent loss of 17 ha has minor ecological relevance, since the whole affected area only corresponds to 0.1% of the community area in the whole assessment area. Since the Bathyporeia community has minor importance, the impact is regarded as insignificant.

The other five communities are affected to a degree that always corresponds to less than 1% of the area in the comparison zone. The largest percentage is the impact on the Cerastoderma community with 0.9%. Thus, all remaining five impacted communities show an insignificant impact.

In summary, no significant impact is expected due to footprint for the bridge alternative. The above reductions in area for the communities will result roughly in a similar reduction of biomass for the community corresponding to the above mentioned percentages.

8.4 Solid substrate

8.4.1 Aspect 1

Magnitude of pressure

Since sensitivity cannot be applied in this case, the impact can only be quantified from the amount of the solid substrate as the magnitude of pressure as listed in Table 8.7 and Table 8.8.

Table 8.7 Estimated areas (ha) of additional solid substrate for the bridge alternative divided into the zones where the substrate is introduced.

	total	near zone	local zone	DK	DE national	DE EEZ
Embankment Fehmarn	0.92	0.92	0	0	0.92	0
Embankment Lolland	0.84	0.84	0	0.84	0	0
Piers and pillars	23	23	0	9	5	9
Total	25	25	0	10	6	9

Table 8.8 Estimated areas (ha) of additional solid substrate for the bridge alternative divided into the communities where the substrate occurs. For structures of constant width also the dimensions in terms of 'length x width' are given.

Structure	Benthic fauna community	Area (ha)
Embankment Fehmarn	Cerastoderma	580 m x 16 m = 0.92 ha
Embankment Lolland	Mytilus	523 m x 16 m = 0.84 ha
Piers and pillars	Mytilus	1.32 ha
	Gammarus	0.58 ha
	Corbula	5.58 ha
	Arctica	15.78 ha
	Cerastoderma	0.36 ha
Total		25 ha

Impact significance

In relation to the predicted community area in the comparison zone, the introduced solid substrate never reaches a significant amount in the affected five fauna communities (Table 8.9). The numbers also assume that the complete surface of the piers and pillars is utilized as settling ground. A study from the German Bight (Joschko et al. 2008) shows that only the upper fraction of the structures are covered with dense fauna, while the lower part is only sparsely covered. Experiences from the fixed link across the Øresund and the Great Belt (unpublished reports) showed that *Mytilus* covers the pillars from about 1–2 m depth until the pycnocline at about 10–15 m water depth. Thus, the amount of the utilized additional substrate that accounts for the magnitude of pressure is less than the totally available substrate and must consequently be even lower than the numbers in Table 8.9. Therefore, a potential effect of this aspect of the pressure is insignificant.

Table 8.9 Surface area of additional solid substrate for the bridge alternative in relation to the total area of the existing community where the substrate is introduced.

Benthic fauna community	Area (ha)	Percent of comparison zone
Cerastoderma	1.28	0.076
Mytilus	2.16	0.035
Gammarus	0.58	0.010
Corbula	5.58	0.072
Arctica	15.78	0.085
Total	25	0.061

8.4.2 Aspect 2

This aspect of the pressure is only relevant for the pillars and piers.

Magnitude of pressure

Figure 8.8 shows the spatial distribution of the magnitude of pressure around the piers and pillars.

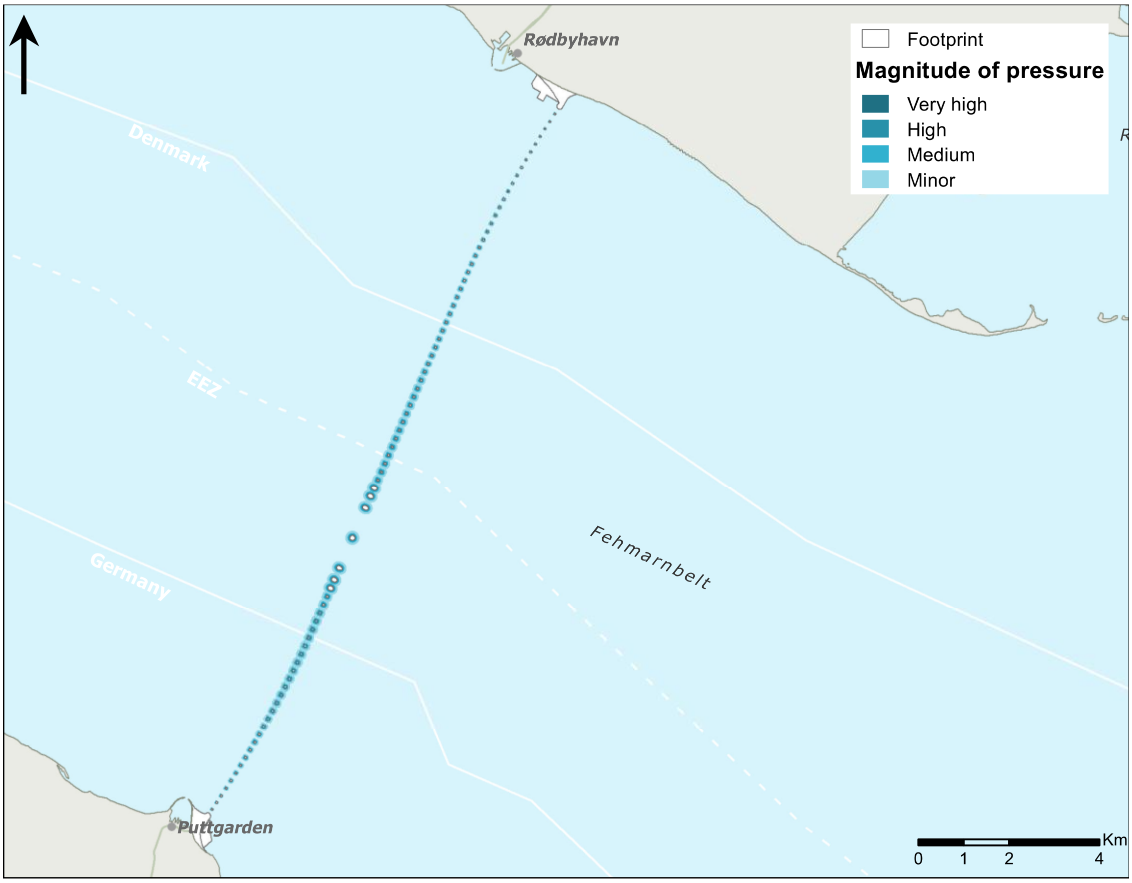


Figure 8.8 Magnitude of pressure for aspect 2 of the pressure solid substrate for the bridge alternative.

Degree of impairment

Impairment is not present in the three hard-bottom communities Dendrodoa, Gammarus and Mytilus (see section 5.4.2). The other six communities show impairments in the near zone depending on the water depth and the sensitivity of the soft-bottom communities. The total amount of the impaired area is estimated to 200.68 ha. More than half of the impaired area has a minor degree of impairment (Table 8.10), approximately a quarter of the impaired area has a medium degree of impairment. The impairments are roughly evenly distributed among the administrative zones, but with the German EEZ having the largest numbers. This is because the largest pillars are located in this zone with the highest water depths (Figure 8.9).

Table 8.10 Degree of impairment of aspect 2 of the pressure solid substrate for the bridge alternative in the different administrative zones.

Pressure:	**Solid substrate – aspect 2**					
	degree of impairment – area impaired (ha)					
	total	near zone	local zone	DK	DE national	DE EEZ
Very high	0	0	0	0	0	0
High	29	29	0	10	8	11
Medium	46	46	0	15	13	18
Minor	126	126	0	44	36	46
Total	201	201	0	69	57	75

Out of the six soft-bottom fauna communities, only three are affected by the pressure. These are the Arctica, Cerastoderma and Corbula community. The remaining communities are either not located in the near zone (Rissoa, Tanaissus) or are too far away from the piers and pillars (Bathyporeia). The main impairment is within the deepest region of the alignment where the Arctica community is located (Table 8.11). The impaired Arctica area amount to roughly 75% of the total impaired area. The remaining impaired area is within the Corbula community and only 1.62 ha are located in the Cerastoderma community.

Table 8.11 Degree of impairment of aspect 2 of the pressure solid substrate for the bridge alternative in the different fauna communities.

Pressure:	**Solid substrate – aspect 2**	
	total	*degree of impairment – area impaired (ha)*
Very high	0	0
High	29	Arctica – 21.94 Cerastoderma – 0.24 Corbula – 6.54
Medium	46	Arctica – 35.32 Cerastoderma – 0.40 Corbula – 10.32
Minor	126	Arctica – 95.28 Cerastoderma – 0.99 Corbula – 29.65
Total	201	Arctica – 152.54 Cerastoderma – 1.63 Corbula – 46.51

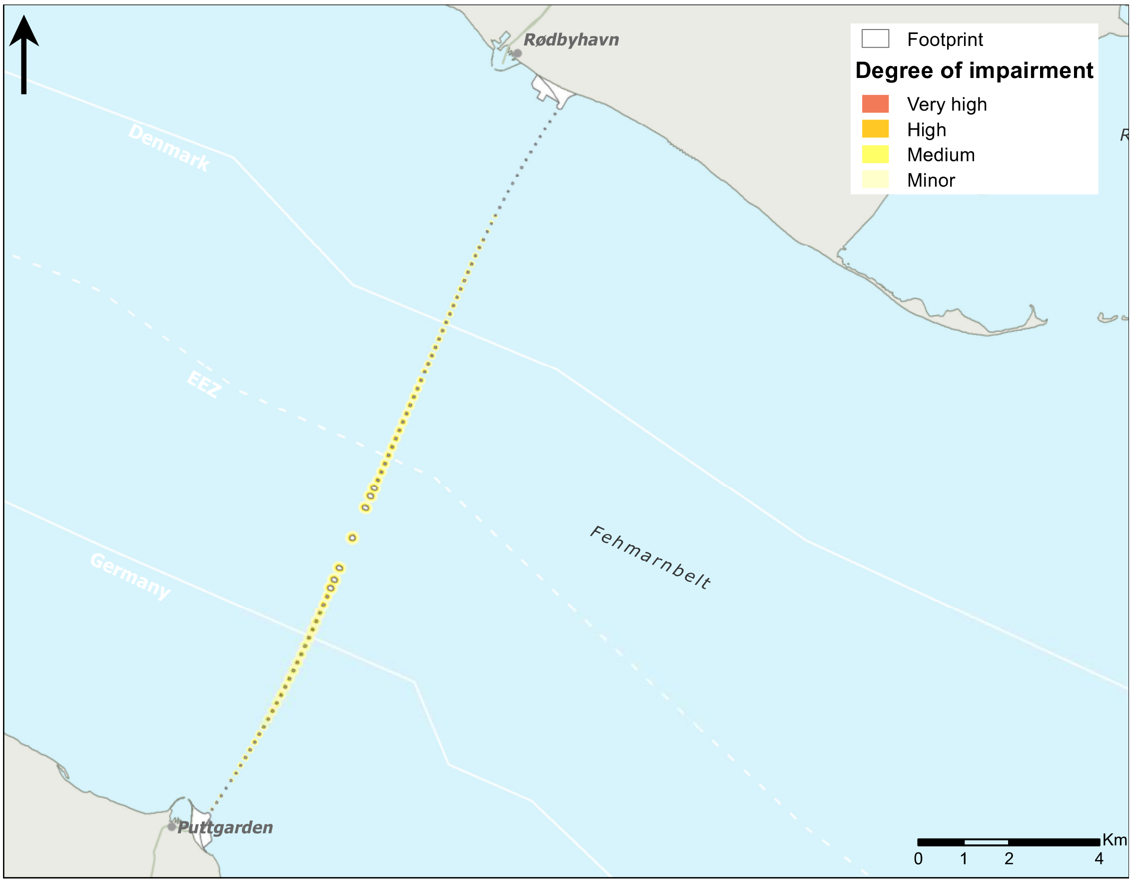


Figure 8.9 Degree of impairment for aspect 2 of the pressure solid substrate for the bridge alternative.

Severity of impact

The 2 m wide area adjacent to the piers and pillars is estimated to be affected to a degree that the function of the existing soft-bottom fauna community is lost. For these areas, the importance is considered (as described in section 3.8) in order to get the severity of loss. The results are not shown on a map, because the areas are too small to be seen properly. The total amount of functional loss is 2.56 ha and only affects certain parts of the assessment area (Table 8.12 and Table 8.13). The Arctica community shows the highest loss with 1.59 ha, mainly in the German EEZ.

Table 8.12 *Severity of loss of function for aspect 2 of the pressure solid substrate for the bridge alternative in the different administrative zones.*

Pressure:	**Solid substrate – aspect 2**					
	severity of loss of function (ha)					
	total	near zone	local zone	DK	DE national	DE EEZ
Very high	1.59	1.59	0	0.36	0.43	0.80
High	0	0	0	0	0	0
Medium	0.09	0.09	0	0	0.09	0
Minor	0.88	0.88	0	0.65	0.23	0
Total	2.56	2.56	0	1.01	0.75	0.80

Table 8.13 *Severity of loss of function for aspect 2 of the pressure solid substrate for the bridge alternative in the different fauna communities.*

Pressure:	**Solid substrate – aspect 2**	
	Total	*Severity of loss of function (ha)*
Very high	1.59	Arctica – 1.59
High	0	0
Medium	0.09	Cerastoderma – 0.09
Minor	0.88	Corbula – 0.88
Total	2.56	Arctica – 1.59 Cerastoderma – 0.10 Corbula – 0.87

The degree of the other impairments is directly used as the severity, since most of the impact already has a minor degree of impairment. The smaller areas of medium and high degree of impairment are mainly in the Arctica community which has a very high importance and thus should also not be downgraded in terms of severity.

Consequently, the severity of the impact (both loss of function and impairment) is predominantly in the Arctica community in deeper water followed by impacts in the Corbula community.

Impact significance

All impacted areas are small and below 1% compared with the comparison zone, which is used to assess the significance of the impact. Thus, all impacts due to aspect 2 of the pressure are insignificant.

8.5 Aggregation of impacts

The results of the assessment for the relevant pressures on the nine benthic fauna communities from the bridge alternative are presented in Table 8.14. In conclusion none of the pressures have significant effect on the benthic fauna communities.The pressure sedimentation causes the largest impact, though mainly with minor severity in terms of area. The second-largest extent is seen for the pressure footprint. The spatial range of the impacts exceeds the local zone only for sedimentation. The other pressures are restricted to the near zone. There is no impact from suspended sediments on the benthic fauna. Very high and high severity of impact (exceeding 1% of their area) does not occur. The predominant impact is of minor severity and occurs due to the pressure sedimentation. The amount of solid substrate added is small.

It must be emphasized that it is not possible to simply add up the severity of impairment across the different pressures for each community because the pressures have been addressed in different ways. The intolerance which is included in the assessment is evaluated for each pressure and community and is therefore relative within the pressures. Furthermore the intolerance is depending on the magnitude of pressure for each pressure. For the bridge alternative the two pressures which causes the largest impact is the sedimentation and the footprint. The pressures cannot be added as the fauna can only be killed once (by the footprint) and there is hence not an overlap in the areas impacted. For the pressure additional solid substrate the severity of impact is so small that a cumulative impact can be considered negligible.

The bridge alternative impairs all benthic fauna communities except the Dendrodoa community. Besides the Cerastoderma community, the communities are impaired with minor severity of impact. Impacted areas are in general small compared to the total assessment area. Medium severity is only observed for sedimentation in the Cerastoderma community. The Arctica community is impacted most, with sedimentation on 498 ha with minor severity being the largest single impact. The next communities are the Bathyporeia, Corbula and Gammarus communities, exposed to only minor severity and mainly affected by sedimentation. The remaining communities are affected much less and by sedimentation only. The Tanaissus community is affected least (1 ha). This is because the community is located outside the near zone and away from the pressures from footprint and solid substrate.

Table 8.14 Aggregation of severity of impact (either impairment or loss) for benthic fauna from the bridge alternative. Number indicate the impaired/lost areas (in ha) for the respective communities and the 4 severity classes. For solid substrate, the numbers indicate the area added to the community. Impacts below 1% of the total area are not shown in this table.

	Suspended sediments	Sedimentation	Footprint	Solid substrate
	no impact	impairment	loss	Addition
Arctica				15.78
Very high				
High				
Medium				
Minor		498		
Bathyporeia				-
Very high				
High				
Medium				
Minor		242	23	
Cerastoderma				1.28
Very high				
High				
Medium		23		
Minor		36		
Corbula				5.58
Very high				
High				
Medium				
Minor		242		
Dendrodoa				-
Very high				
High				
Medium				
Minor				
Gammarus				0.58
Very high				
High				
Medium				
Minor		232		
Mytilus				2.16
Very high				
High				
Medium				
Minor		72		
Rissoa				-
Very high				
High				
Medium				
Minor		23		
Tanaissus				-
Very high				
High				
Medium				
Minor		1		
Total*	**0**	**1,524**	**80**	**25**
Very high		0	13	
High		0	13	
Medium		178	27	
Minor		1,346	27	

*Incl. impairments < 1 %

8.5.1 *Impact on biodiversity*

In connections with large infrastructural projects there is a risk that the biodiversity will be impacted as a result of a decrease in species number caused by the project pressures. As discussed in previous sections the impairment on the benthic fauna communities is assessed to be insignificant for all pressures (individual and aggregated). Only small areas with benthic fauna are lost or are impaired with biomass reduction. In all cases the biomass reduction or loss is only a small percentage of the different fauna communities. It is therefore not likely that the biodiversity will decrease as a consequence of the fixed link.

8.6 *Cumulative impacts*

Cumulative impacts are all impacts that add to the project-related impacts and stem from other planned or on-going projects. For a project to be relevant to include, it requires that the project:

- is within the same geographic area
- has some of the same impacts as the fixed link
- affects some of the same environmental conditions, habitats or components
- creates new environmental impacts during the period from the environmental investigations were completed to the fixed link is in operation.

In Table 8.15 projects at sea which are considered relevant to include in the assessment of cumulative impacts are listed. All projects are offshore wind farms. Placement of projects is shown in Figure 8.10 and Figure 8.11.

Table 8.15 Projects which can have cumulative impacts with the fixed link.

Project	Placement	Phase in which cumulative impact can occur	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 Krieger's Flak	Construction	Sediment spill, habitat displacement, collision risk, , barrier effect
Wikinger	North East of Rügen	Construction	Sediment spill, habitat displacement, collision risk, , barrier effect
Rødsand II	In front of Lolland's southern coast	Operation	Coastal morphology, collision risk, barrier risk
Kriegers Flak II	Kriegers Flak	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
GEOFReE	Lübeck Bay	Construction	Sediment spill, habitat displacement, collision risk

Rødsand II is specifically included, as this is a project that was under construction while Femern A/S conducted its baseline investigations, whereby a cumulative effect in principle cannot be excluded.

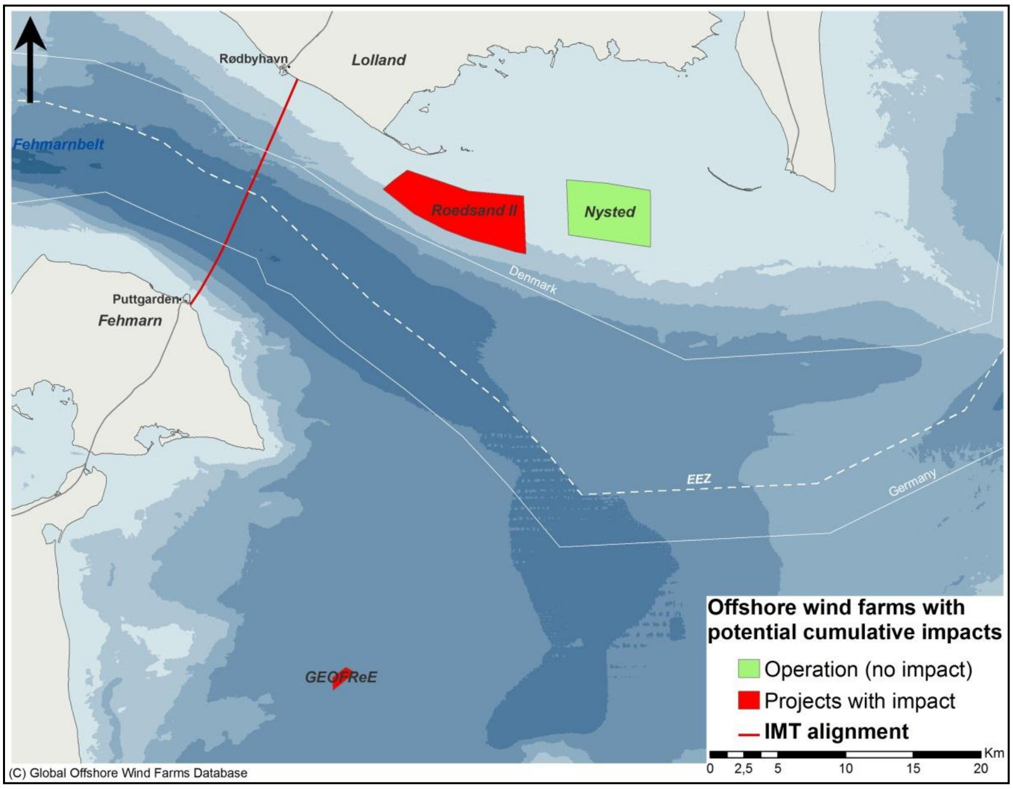


Figure 8.10 Locations of Roedsand II, Nysted and GEOreE

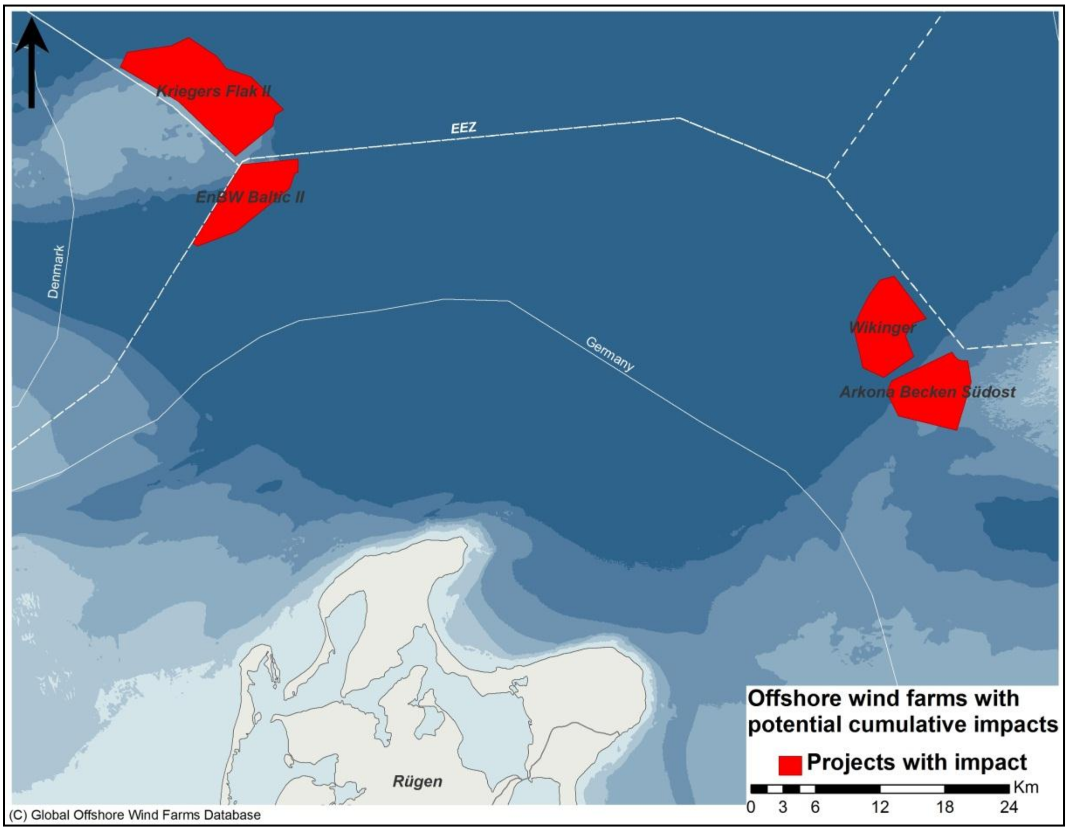


Figure 8.11 Locations of Kriegers Flak, EnBW Baltic II, Wikinger and Akona Becken Südost

In general the impact on the benthic fauna from the wind farms is likely to be local (close to the farm area) (e.g. Energinet.dk 2009, Dong Energy and Vattenfall 2006). As the planned wind farm projects (not Rødsand or Nysted) are all in areas away from the areas impacted by the bridge alternative (in case of the benthic fauna), a cumulative impact is not likely.

In detail, the there is a possibility of cumulative impacts from sediment spill between the installation of the bridge and the offshore wind farm 'GEOFReE', because sediment spill could overlap in time and space depending on when the project is constructed, which could have a cumulative impact on the benthic fauna. Based on experience from similar projects, it is estimated that the cumulative impacts from sediment spill are not significant. The possibility of cumulative impacts from 'GEOFReE' will definitely be cancelled, if the project is not constructed at the same time as the bridge.

There is a risk of cumulative effects between the cable-stayed bridge and Rødsand II offshore wind farm on the coastal morphology of Lolland in the operation phase, as the environmental assessment of Rødsand II shows an effect on erosion and deposition of material along the coast. The cumulative impact of the cable-stayed bridge and Rødsand I and II on the south coast of Lolland from Rødbyhavn to Hyllekrog has been assessed. In some parts of the coast there is a slight increase in impact, while the impacts from the two projects are counteracting on others. However, both individually and collectively, the effects are assessed as non-significant and will have no cumulative impacts on the benthic fauna.

As for the two offshore wind farms planned east of Rügen, the cumulative impacts will have to be assessed for the relevant components, but no significant impacts are expected because of the relative long distance from Fehmarnbelt, which will have no cumulative impact on the benthic fauna.

Cumulative impacts from raw material extraction and planned wind parks at Krieger's Flak and Rønne Banke are not likely, since there will be approx. 15 km distance between the raw material extraction and wind farms, and it is estimated that the impacts will be of minor extent. Additionally, there are no fixed dates for the establishment of the wind farms, so it is likely that there will not be a coincidence in time between the projects.

The conclusion of the EIA for Nysted/Rødsand II (Dong Energy 2007) is that the impact on the benthic fauna is either insignificant or very limited. It is therefore not expected that there is cumulative effects from this project.

8.7 Transboundary impacts

No transboundary impacts on benthic fauna are predicted for the bridge alternative.

8.8 Mitigation and compensation measures

This chapter of the report are prepared in co-operation with Femern A/S.

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

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.

As there are no significant impacts on the benthic fauna no mitigation or compensation measures have been suggested.

8.9 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 the decommissioning of 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 fauna.

Bridge Superstructure: Dismantling of the bridge superstructure will happen at sea and structures will then be transported to the shore.

Pillars and piers: All elements will be cut in-situ into manageable sizes and then transported to shore.

Caissons: The pier and pillar caissons will be removed by in-situ demolition of the plinth, deballasting and de-floating of the caissons. Caissons are transported to shore. 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 protection: Ship collision structures are removed by a reversed construction.

During the decommissioning of the bridge, fauna communities associated with the bridge structures (primarily blue mussels) will be lost. Blue mussels settle at the vertical structures of the bridge, which function as an artificial reef. It is expected that the blue mussel biomass on the reefs will be lost during decommission (see section 4.6). It is emphasized that the mussels must not be dumped at the seabed during decommissioning. If the mussels are dumped, the decomposition of the organic material will most likely create oxygen deficiency and reduced seabed quality in the area. Mussels will/shall be treated as waste.

Reversed construction, in-situ demolition and cutting procedures can have a near zone effect on the benthic fauna in the work areas. It is expected that only the demolition of the plinth can have an actual effect on the seabed and hence the benthic fauna. Here it is expected that the fauna will be disturbed and perhaps destroyed in a small area in the near vicinity of the demolition site. The impact will only occur in the demolition period and will be reversible. The impact is regarded as negligible.

9 COMPARISON OF TUNNEL AND BRIDGE MAIN ALTERNATIVES

The purpose of the main comparison of the tunnel and bridge alternatives is to find the preferred alternative with respect to the environmental impact acting on the benthic fauna communities. The comparison is based on the assessment results of the relevant pressures in terms of the affected areas and the severity of impacts. The significance can be disregarded here, since none of the impacts are significant. A short summary of the results of the impact assessment is shown in Table 9.1.

Table 9.1 Summary of overall impacts from all relevant pressures for the tunnel and bridge alternatives.

Pressure	Description of impact	Tunnel	Bridge
Suspended matter	Severity of loss	-	-
	Severity of impairment	Medium – minor	-
	Range	Complete EIA assessment area	Complete EIA assessment area
	Duration	Spatially and temporally varying	Spatially and temporally varying
	Significance	Not significant	Not significant
Sedimentation	Severity of loss	-	-
	Severity of impairment	High – minor	Medium – minor
	Range	Complete EIA assessment area	Complete EIA assessment area
	Duration	Spatially and temporally varying	Spatially and temporally varying
	Significance	Not significant	Not significant
Footprint	Severity of loss	Very high – minor	Very high – minor
	Severity of impairment	-	-
	Range	Near zone	Near zone
	Duration	Temporary and permanent	Temporary and permanent
	Significance	Not significant	Not significant
Solid substrate	Severity of loss	-	Very high – minor
	Severity of impairment	-	High – minor
	Range	Near zone	Near zone
	Duration	Permanent	Permanent
	Significance	Not significant	Not significant

The main comparison is shown in summary in Table 9.2 stating for each pressure the preferred alternative. For the component benthic fauna, the bridge is consequently the overall preferred alternative in the sense that it causes the least environmental impact.

Table 9.2 *Comparison of alternatives. ++ = clear advantage, + = advantage. See text for further explanations.*

Pressure	**Tunnel**	**Bridge**	**Preferred alternative**
Suspended sediments		+	bridge
Sedimentation		++	bridge
Footprint		++	bridge
Solid substrate	+		tunnel
Summary		**++**	**bridge**

The criteria used for the main comparison are as follows. A clear advantage (++) is given when the impacted areas of an alternative are minimum less than half the size of the other alternative and have a similar severity. When the severity is much different, the difference in area size should be accordingly larger. If the above does not apply, but a difference in severity can be observed with similar area size, an advantage is still present. If one of the alternatives does not result in an impact or in only negligible impacts while the other alternative has an impact that is not negligible, there is also an advantage present.

Suspended sediments
No impact is present for the bridge alternative, since the concentrations of suspended sediments are within the natural variability. For the tunnel alternative, mainly minor severity is present. Thus, the bridge alternative is the preferred one.

Sedimentation
The impacted area for the tunnel alternative is more than twice as large as the impacted area for the bridge alternative. The severities are similar with the tunnel alternative having small areas with high severity while the bridge alternative is maximum causing medium severity. Thus, the bridge alternative is the preferred one with a clear advantage.

Footprint
The impacted area for the tunnel alternative is more than twice as large as the impacted area for the bridge alternative. The severities are similar with the tunnel alternative. Thus, the bridge alternative is the preferred one with a clear advantage.

Solid substrate
The amount of solid substrate added by the project structures is much higher for the tunnel alternative, but most of solid substrate added by the tunnel structures is temporary. The solid substrate of the bridge alternative has a limited influence of the surrounding soft-bottom communities. In terms of severity, no differentiation can be done. Thus, the tunnel alternative is the preferred alternative.

10 PROTECTED SPECIES

Protected species in terms of the EIA are all species protected by national and international legislation. Red list benthic fauna species are only appointed in Germany. Red list species are numerous and widely distributed throughout the assessment area (FEMA 2010a). Protected species, as described here, do not include species on red lists, since red lists do not have a legally binding character

Habitats Directive
The European Habitats Directive (directive 92/43/EEC) contains lists of species of community interest and priority species in Annexes II, IV and V. These Annexes do not list any of the benthic fauna species found in the EIA assessment area during the baseline survey (FEMA 2013a).

German legislation
The German nature protection law (Bundesnaturschutzgesetz) does not specifically list benthic fauna species. These are contained in the corresponding species protection regulation (Bundesartenschutzverordnung). The regulation does not contain any of the benthic fauna species found in the EIA assessment area during the baseline survey (FEMA 2013a).

Danish legislation
The Danish nature protection law (Naturbeskyttelsesloven: LBK nr 933 af 24/09/2009, bekendtgørelse af lov om naturbeskyttelse) lists the protected biotopes in §3. This only includes biotopes on land. The law also includes a list of protected species in Annex 3, derived from the Habitats Directive. It does not contain any of the benthic fauna species found in the EIA assessment area during the baseline survey (FEMA 2013a).

11 CONSEQUENCES IN TERMS OF WFD AND MSFD

11.1 Water Framework Directive (WFD)

The baseline study (FEMA 2013a) includes an assessment of the current ecological status of the water bodies within the assessment area using the official WFD indices. This ecological status can potentially change as a consequence of the project. It is impossible to predict the ecological status quantitatively based on the results of the EIA, since this would involve calculating the corresponding German and Danish WFD indices for each of the impacted water bodies.

The consequences of the project in terms of the WFD is therefore evaluated as a risk assessment, qualitatively assessing the risk that impacted water bodies will show a lower ecological status because of the project. Figure 11.1 shows the water bodies that are covered in this EIA (dark green coloured areas).

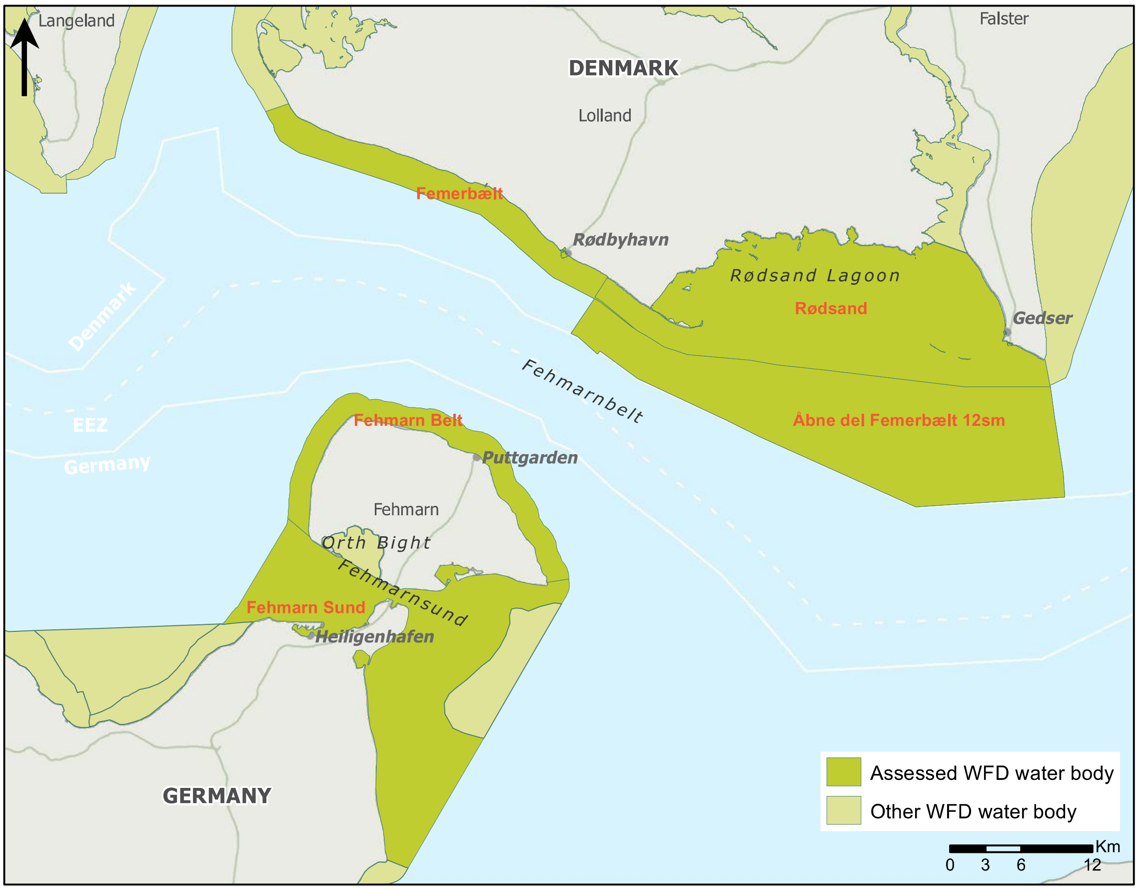


Figure 11.1 Water bodies within the Water Framework Directive in the Fehmarnbelt area. The red annotations are the names of the water bodies in the respective language (Åbne del Femerbælt = Open part of Fehmarnbelt). Water bodies within the EIA assessment area are shown in darker green.

11.1.1 Pressures relevant to the ecological status

Four pressures have been evaluated to have an impact on the benthic fauna:

- Suspended sediments
- Sedimentation
- Footprint
- Solid substrate

These are all relevant for the ecological status of the benthic fauna with respect to the WFD. The main impacts are summarized in sections 7.5 and 8.5. In general, part of the impacts are in deeper waters outside the WFD water bodies and it is estimated that possible impacts in these deeper water do not affect the ecological status in the shallow water bodies that are within 1 nautical mile off the coast.

11.1.2 German water bodies

The German water bodies around Fehmarn belong to the river basin "Schlei/Trave". The corresponding river basin management plan is divided into planning units in order to ensure an effective and coordinated approach. Fehmarn belongs to the planning unit "Kossau/Oldenburger Graben". Significant pressures for this area are:

- pollution from diffuse sources
- discharge
- morphological changes

These pressures are considered fundamental for not achieving the good ecological status and are therefore the basis for management programmes. The planning of the management is coordinated with the neighbouring federal states and with Denmark. The aim of the measures is to achieve the good ecological status and the following measures are listed in the management plan:

- avoid further impairment of the ecological status
- reduction of pressures on the surface waters from nutrients (nitrogen, phosphor, eutrophication)
- reduction of pollution from priority substances (hazardous substances that constitute a considerable risk and for which special measures need to be taken)
- discontinuation of discharge, emission and loss of priority hazardous substances

Tunnel alternative

The impact from suspended sediments is minor for all assessed German water bodies and lasting only for one year. No impact is expected for the water body Fehmarn Sund. Sedimentation has a local minor impact in the Fehmarnbelt water body. Footprint impact (as loss) is restricted to a small area east of Puttgarden in the Fehmarnbelt water body. The impact from solid substrate is also limited to a small area off Puttgarden and will not have a negative impact. On the scale of the water body, these minor and local effects will probably not change the ecological status.

Bridge alternative

No impact is expected from suspended sediments. Sedimentation is generally minor and restricted to local areas in the Fehmarnbelt water body. The impact from footprint (as loss) is restricted to a small area east of Puttgarden in the Fehmarnbelt water body similar to the impact for the tunnel alternative. The impact from solid substrate is also limited to a small area off Puttgarden and will not have a negative impact. On the scale of the water body, these minor and local effects will probably not change the ecological status.

11.1.3 Danish water bodies

Within the investigation area there are two Danish water bodies, Femer Bælt and Rødsand, both belonging to the main catchment area Østersøen. Additionally the outer part of Fehmarnbelt, south of Rødsand ("Åbne del af Femerbælt 12 sm") is also assessed even though it is not strictly a part of the scope of the WRD.

Relevant 1st and 2nd order pressures which can impact achievement of good ecological status for coastal marine areas are:

- Release of toxic substances
- Release of nutrients (N and P)
- Increased sediment concentrations
- Changes in coastal morphology

In the Danish water management plans the good ecological status is assessed only on the basis of depth limits for eelgrass and benthic fauna can only be used as a support parameter. It is not possible to classify the ecological status of the Danish water bodies within the investigation area, due to insufficient data (As described in the water management plan assessed (draft), Miljøministeriet, Naturstyrelsen 2013). To achieve good environmental status the above-mentioned pressures should be reduced.

Tunnel alternative

Suspended sediments have a minor impact on the Danish water bodies that lasts for one year only. Sedimentation has a local medium impact in the Rødsand water body, but the major part of this water body is unaffected or affected with minor severity only. Footprint impact (as loss) is restricted to the Femerbælt water body and acts locally around Rødbyhavn. The impact from solid substrate is also limited to this region and will not have a negative impact. On the scale of the water bodies, all these mainly minor and local effects will probably not change the ecological status.

Bridge alternative

No impact is expected from suspended sediments. Impacts from sedimentation are negligible and restricted to very small areas in the water bodies Femerbælt (eastern part) and Rødsand. The impacts from footprint are much smaller than the ones from the tunnel alternative and limited to the region around Rødbyhavn in the Femerbælt water body. The impact from solid substrate is also limited to this region and will not have a negative impact. On the scale of the water bodies, all these minor and local effects will probably not change the ecological status.

11.2 Marine Strategy Framework Directive (MSFD)

The MSFD is currently being implemented in all European member states. No assessment systems have yet been developed to quantify and classify the current environmental status. The descriptions of the final good environmental status are currently not finished. Thus, the effect of the impacts on the environmental status in terms of the MSFD can currently not be determined.

12 CLIMATE CHANGE

Climate change on a global scale is likely to influence the Baltic Sea and also the Fehmarnbelt area. This change may occur because of natural variability or by human induced factors, such as increased CO_2 and other greenhouse gasses. Climate change is foreseen to induce changes in:

- Temperature (and sea water temperature)
- Sea ice cover
- Precipitation
- Wind speeds
- Sea Level
- Snow
- Freezing surfaces
- Icing
- Visibility
- Storm surge

Of these, changes the temperature, increased precipitation and increased wind speeds (storm surges) can potentially induce changes in the structure of the benthic fauna communities on a large time scale.

The factor which is most likely to change the benthic community structure in the Baltic Sea is a decrease in salinity (Zettler et al. 2008). Climate change will most likely increase precipitation which leads to a larger run-off from land with a resulting decrease in salinity in the surface water layer. Many of the marine species in the Baltic Sea reach their limit of distribution along the salinity gradient on the way from the entrance to the Baltic Sea towards its inner less saline parts (Zettler et al. 2007). If the salinity decreases the limit of species distribution is changed and the community structure will change.

In the Baltic Sea there is a strong vertical zonation of the benthos due to the stratification of the water column (Zettler et al. 2008). The shallow parts of the Baltic is well-oxygenated while the deeper parts can become anoxic during part of the year (FEMA 2013a). Storm events and turbulence due to increased wind speeds can alter the zonation by increasing the oxygenated areas by vertical mixing of the water column and hence change the structure of the benthic fauna communities. Increased oxygen concentration can compensate for a permanent decrease of oxygen in connection to reclamation areas (FEHY 2013a, FEMA 2013d).

An increase in temperature can potentially lead to invasion of new species adapted to warmer waters (boreal species). Colonisation of boreal species can be limited by other factors such as the low salinity and the strong salinity gradient in the Baltic Sea (Zettler et al. 2008).

The impact of climate change is not foreseen to add to the pressures of the tunnel or bridge alternatives. There are no permanent pressures, which can significantly impact the benthic fauna. Recolonisation of fauna in areas where the fauna is lost or reduced due to permanent footprint or sedimentation will most likely occur before the climate change has become so pronounced that they can induce an impact on the marine environment.

13 KNOWLEDGE GAPS

13.1 Suspended sediments and sedimentation

The existing knowledge of impacts of increased sedimentation and suspended sediments on benthic fauna is based on investigations of a very limited number of species. Based on these data the assessment assumes an average group-specific and even community-specific responses related e.g. to the mode of living (epifauna/infauna) and dispersal potential (Norkko et al. 2010). It is not possible to either give quantitative estimates or predict the potential impact taking into account the individual response of all community species including the interactions between them. This also refers to the subtle response of rare species important for the maintenance of biodiversity.

The experiments reported in the literature are mostly focused on the evaluation of impacts of sudden burial (acute burial under 1 to 40 cm simulating the dredge disposal) and not a gradual sedimentation from the sediment spill that results in much thinner accumulation.

Flaws still exist in the thorough understanding of subtle interaction between environmental factors and pressures (e.g. interrelations of factors such as sedimentation, organic content, concentrations of suspended sediments and oxygen in water column etc.). Resilience and recovery of benthic communities is dependent on these interactions as well as on natural-history characteristics and biological traits characteristics of different taxa of the community, e.g. their relative mobility (Norkko et al. 2010).

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Risk assessment of the 23 known non-indigenous species

The following paragraphs briefly discuss the risk of the 23 known non-indigenous species of the EIA assessment area and the surrounding areas towards further spreading by anthropogenic influence from the construction works. The data are taken from (Nehring 2000) and (Gollasch and Nehring 2006) and from expert judgement and the general knowledge of the species' autecology.

Tunicata

(1) *Styela clava* (Ascidiacea) is an euhaline benthic suspension feeder that invaded into the Kattegat and Belt Sea in 1984. It is found in shallow waters on hard substrate and occurs abundantly in sheltered warm water docks and harbour installations. The reproduction is asexual or sexual via planktonic larvae. It can breed in water temperatures above 15° C and salinities above 25–26 psu. Eggs and larvae are planktonic for no more than 2 days. The larvae settle on hard substrate. The current status of invasion is: established in that regions. Risk of accelerated distribution by construction vessels is low due to physiological limitations against lower salinities.

(2) *Aplidium proliferum* (Ascidiacea) is a marine benthic suspension feeder that invaded in 1975. The animal lives attached to hard substrate. The reproduction is asexual or sexual via planktonic larvae. The larvae settle on hard substrate. The current status of invasion is: not successful, vagrant species. Risk of accelerated distribution by construction vessels is not existent.

Bryozoa

(3) *Victorella pavida* a marine benthic suspension feeder that invaded in 1911. The species is sessile and lives in shallow water down to 5 m water depth on hard substrate. The reproduction is asexual or sexual via lecithotrophic larvae (short planktonic phase) or planktonic larvae (long planktonic phase). Reproduction time starts in June. The larvae settle on hard substrate. The current status of invasion is: not successful, vagrant species. Risk of accelerated distribution by construction vessels is not existent.

Crustacea

(4) *Balanus improvisus* (Cirripedia) is a marine benthic suspension feeder that invaded in 1844. The species is sessile and lives in shallow and deeper water on hard substrate. The reproduction is sexual via lecithotrophic larvae. Larvae are released between February and September, with peaks in April and late summer. Larval settling time is up to 30 days. Larval dispersal potential is > 10 km. The larvae settle on hard substrate. The actual status of invasion is: successful, established species, moderate to high abundances. Risk of accelerated distribution by construction vessels is not existent, since the species already inhabits all suitable regions and habitats in the Baltic Sea.

(5) *Eriocheir sinensis* (Brachyura) a limnic benthic omnivore species that invaded in 1926. The animal is mobile and lives in shallow waters, in rivers and estuaries and only tolerates low salinities. The larvae are planktonic. The current status of invasion is: successful in river estuaries and not successful in marine habitats. Risk of accelerated distribution by construction vessels is not existent.

(6) *Gammarus tigrinus* (Amphipoda) is a brackish water benthic omnivore species that invaded in 1975. The animal is mobile and lives in shallow waters, in rivers and estuaries and only tolerates low salinities. There are no larvae, the development is direct. Dispersal potential is up to 1 km. The current status of invasion is: successful in estuaries and not successful in open sea habitats. Risk of accelerated distribution by construction vessels is not existent.

(7) *Rhithropanopeus harrisii* (Decapoda) is a brackish water benthic omnivore species that invaded in 1948. The animal is mobile and lives in shallow waters, in rivers and estuaries and only tolerates low salinities. The larvae are planktonic. The current status of invasion is: successful in estuaries and not successful in open sea habitats. Risk of accelerated distribution by construction vessels is not existent.

Hydrozoa

(8) *Bougainvillia rugosa* (synonym: *Sertularella rugosa*) is a marine euryhaline (down to 8 psu) benthic suspension feeder that invaded in 1900. The animal is sessile and lives attached to algae in deeper waters below approx. 20 m water depth. Reproduction takes places with planktonic stages in spring. The current status of invasion is: not successful, single records, physiological limitations towards distribution into the western Baltic. Risk of accelerated distribution by construction vessels is not existent.

(9) *Cordylophora caspia* is a genuine brackish (0.5–15 psu) benthic suspension feeder that invaded in 1803. It is found in shallow waters, on various hard substrates, submerged vegetation and on the shells of crabs and snails. Reproduction takes place from May to October with planktonic planula larvae. The current status of invasion is: successful, single records, physiological limitations towards distribution into the open Baltic Sea. Risk of accelerated distribution by construction vessels is not existent.

(10) *Garveia franciscana* is a genuine brackish (1–18 psu) benthic suspension feeder that invaded in 1950. It is sessile and lives in various depths on different hard substrates. Reproduction takes place from June to September with planktonic planula larvae. The current status of invasion is: not successful, single records, physiological limitation towards distribution into the open Baltic Sea. Risk of accelerated distribution by construction vessels is not existent.

Insecta

(11) *Telmatogeton japonicus* has aquatic larvae that live as limnic and brackish benthic deposit feeders. The species invaded in 1960. The larvae are mobile and can be found in shallow waters on soft sediment in ports and estuaries. The non-aquatic adults deposit single eggs. The current status of invasion is: not successful, single records, physiological limitations towards distribution into the open Baltic Sea. Risk of accelerated distribution by construction vessels is not existent.

Mollusca

(12) *Crassostrea gigas* (Bivalvia) is an euhaline marine benthic suspension feeder that invaded in 1972. The species is sessile and can be found from the lower shore and shallow sublittoral and down to a depth of around 80 m. Planktonic larvae are released. The current status of invasion is: not successful in the Baltic, physiological limitation towards distribution. Risk of accelerated distribution by construction vessels is not existent.

(13) *Crepidula fornicata* (Gastropoda) is an eu- and polyhaline (down to 18 psu) marine benthic suspension feeder that invaded in 1940. The species lives on various habitats in different depths. Planktonic larvae are released. The planktonic phase is up to 2 months long. Larval dispersal potential is > 10 km. The current status of invasion is: not successful in the Baltic, physiological limitations towards distribution. Risk of accelerated distribution by construction vessels is not existent.

(14) *Ensis directus* (synonym: *Ensis americanus*) (Bivalvia) is a euhaline marine benthic deposit feeder that invaded in 1981. The species is sessile and lives in muddy and sandy sediments in shallow and sublittoral waters. Planktonic larvae are released. The larvae have a very long planktonic phase. This allows for the larvae

to spread over large distances. The larvae settle on sand or mud. The current status of invasion is: successful in the Western Baltic, low abundances, low dominances within physiological limit of distribution. Risk of accelerated distribution by construction vessels is lower than natural reproduction potential within the assessment area or introduction of larvae from marine areas.

(15) *Mya arenaria* (Bivalvia) is a euhaline marine benthic suspension feeder that probably invaded in 1245. The current status of invasion is: very successful in the Baltic, established species, high abundances, high dominances. Risk of accelerated distribution by construction vessels is not existent, since the species already inhabits all suitable regions and habitats in the Baltic Sea.

(16) *Petricola pholadiformis* (Bivalvia) is a euhaline marine benthic deposit feeder that invaded in 1927. It is a mechanical borer into hard clay, chalk, solid mud, peat-moss and limestone in shallow waters (down to 8 m). It has planktonic larvae. The current status of invasion is: not successful in the Western Baltic, physiological limit of distribution. Risk of accelerated distribution by construction vessels is not existent.

(17) *Potamopyrgus antipodarum* (Gastropoda) is a limnic and brackish benthic deposit feeder that invaded in 1887. The species lives in various habitats in estuaries. The reproduction is vivipar without planktonic larvae stage. The current status of invasion is: not successful in the open Baltic, physiological limit of distribution. Risk of accelerated distribution by construction vessels is not existent.

(18) *Teredo navalis* (Bivalvia) is an poly- and mesohaline (down to 9 psu) marine wood borer that invaded in 1853. It is found only in wooden structures such as piers, boat hulls and drifting wood. The planktonic larvae are in the open water up to 3 weeks. The current status of invasion is: successful in the Western Baltic. Risk of accelerated distribution by construction vessels is lower than natural reproduction potential and low considering the limited new wooden structures within the assessment area.

Oligochaeta
(19) *Tubificoides pseudogaster* is a marine (North Sea) benthic deposit feeder feeding on detrital material and bacteria and invaded in 2000 into the Baltic (Gulf of Finland). The gradual expansion in the Gulf of Finland has been accompanied by the drastic decline of the native *Monoporeia affinis* population. Severe decrease of this amphipod population may have marked adverse effects on upper trophic levels. Consequently, invasion of *T. pseudogaster* has great potential to alter ecosystem-level properties and processes in the Gulf of Finland. The worm burrows in muddy and sandy substrates. It has limited mobility. The lifespan of this oligochaete is about two years. It is a hermaphrodite and reproduces throughout the year. The larvae are hatched after about two weeks in a cocoon. The dispersal potential is very low. The worm has a low recoverability. The species lives in shallow estuaries and also in the sublittoral on the open sea down to 25 m water depth. The current status of invasion is: young regional invader with limited mobility. Risk of accelerated distribution by construction vessels is low.

Polychaeta
(20) *Boccardiella ligerica* is a small brackish benthic deposit feeder, tolerating oligo- to mesohaline salinities and invaded in 1960 into the Gulf of Bothnia. Reproduction time with planktonic larvae is June to September (in the North Sea). The animals live in shallow waters and prefer clay. The current status of invasion is: established

in south-west Finland. Risk of accelerated distribution by construction vessels is low.

(21) *Ficopomatus enigmaticus* is a small marine euhaline benthic suspension feeder and invaded in 1939 into Kattegat and Belt Sea. The current status of invasion is: established in that regions. Risk of accelerated distribution by construction vessels is low due to physiological limitations towards lower salinities.

(22) *Marenzelleria neglecta* and (23) *Marenzelleria viridis* are euryhaline benthic deposit and suspension feeders tolerating oligohaline salinities that invaded in 1985 (2005). The reproduction takes place in autumn with long living planktonic larvae. The current status of invasion is: established in the whole Baltic Sea. Risk of accelerated distribution by construction vessels is lower than natural reproduction potential within the assessment area and the species already inhabits all suitable regions and habitats.

A P P E N D I X   B

Description of the numerical model for the mussel population

General model description

The mussel model was originally developed to assist mussel fishermen and environmental authorities to plan a cost-effective mussels fishery with a minimal environmental impact (DHI 2004). In the FEMA model application, the model includes effects of sediment spill mediated through light reduction affecting primary production and concentration of phytoplankton that constitutes the primary food for mussels. Besides maintaining the mussel biomass and a “biofilter” for phytoplankton, production of mussels around Fehmarn and along Lolland is vital for the winter-resting eider ducks. Based on 10 years’ plankton monitoring under HELCOM average plankton biomass (measured as chlorophyll-a) west of Fehmarnbelt (Darss area) is 1.6±0.4 µg l^{-1}, but higher in Mecklenburg Bight at 2.0±0.6, and 2.02 µg l^{-1} (FEMA 2013d) equivalent to an average coefficient of variation of 13% (negative part). At such low levels of chlorophyll-a the growth and biomass of mussels will scale linearly with food concentration (Kiørboe et al. 1980).

The mussel population in Fehmarnbelt is modelled using size structured model with 2 state variables (number and dry organic flesh weight) for each length classes of *Mytilus edulis*, ranging from 2 mm to 75 mm in 12 logarithmic increasing size classes. The growth rate of an individual is a function on available food (quantity & quality), temperature and within size classes increase or decrease (i.e. negative growth) in the weight of soft parts. Within each size class a minimum dry weight is defined, which represents the vital structural parts and tissue of the mussel. Starving mussels approaching this minimum weight will be eliminated (by starvation mortality) from the population. In case of positive growth, individuals reaching a weight defined by the standard condition index CI=4.6 (FEMA 2013a) will be transferred to the next larger size class. During periods of sudden increase in temperature, accumulated body mass above a defined threshold may get “lost” as gametes (spawning). Other loss terms include predation, death due to anoxia and/or hydrogen sulphide, contaminants and toxic algae. Predation pressure by eider ducks are forced by bird counts allowing for a size-selection based on literature values and analysis of stomach content. Other predators include crabs and starfish. Higher trophic levels are not represented.

Model calibration

After minor changes in the Sustainex model, the performance of the mussel model was validated against biomass data collected at 7 stations (5 along Lolland, 2 along Fehmarn) during the winter–spring 2009–2010. In this approach we focused on the physiological growth description of individual mussels using the condition index as testing variable. The temporal variation in the condition index (CI) was compared to model output at the same positions by averaging CI for the two dominating size classes 25 and 30 mm (FEMA 2013a).

The model was able to simulate the temporal variation in condition index (i.e. meat content of a given size class) (Figure App. B.1). At all stations, condition of mussels peaked in early-mid April 2010 at the end of the spring bloom, followed by a decrease in condition when phytoplankton reached a yearly minimum in concentration. Overall, growth rates during spring was highest at the Fehmarn stations which can be explained by the approx. 15% higher availability of food (measured as chlorophyll) and a lower abundance of mussels (caused by a larger predation pressure from eider ducks).

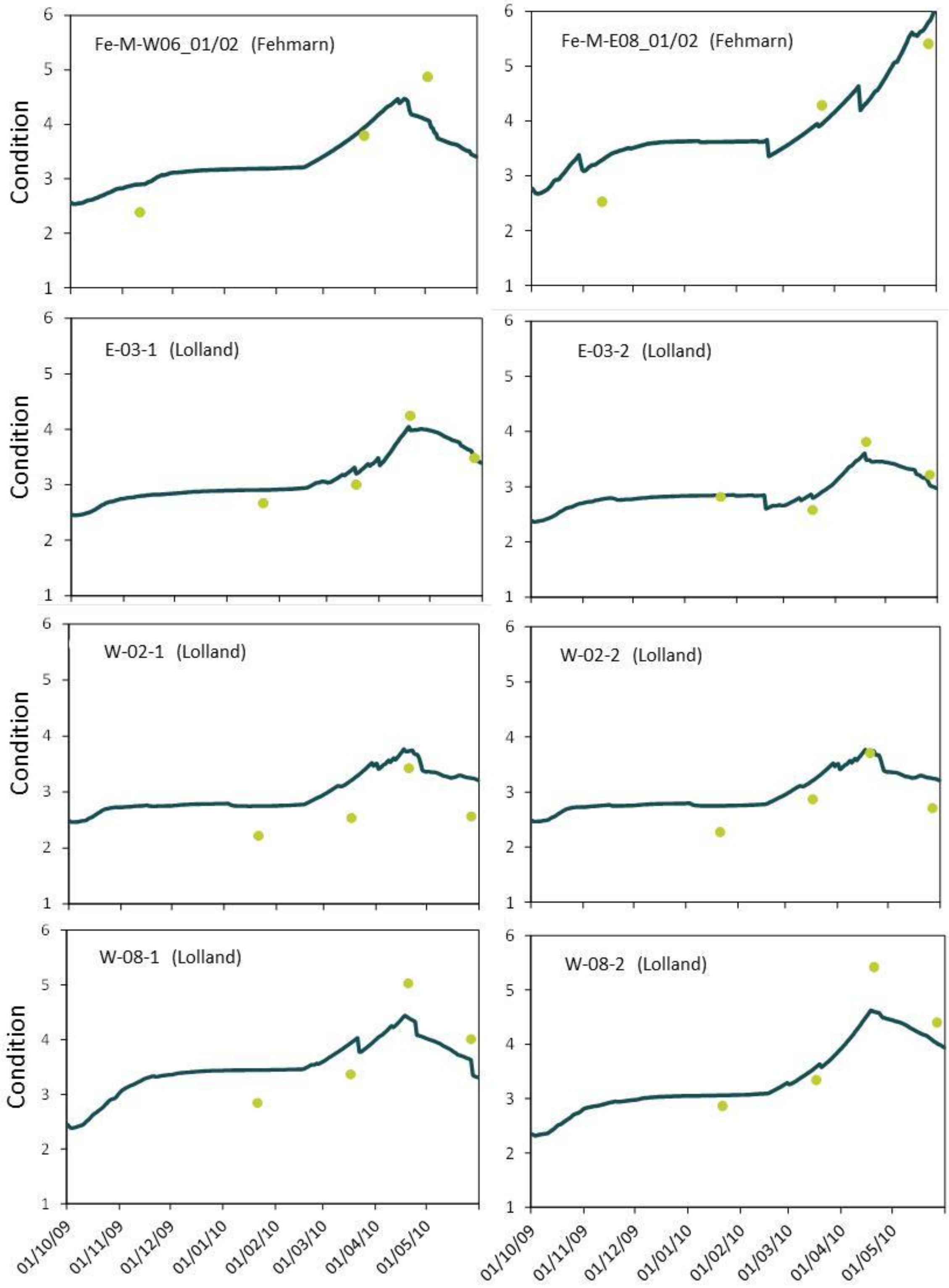

Figure App. B.14 -1 Modeled (line) and observed (●) variation in condition of individual mussels in the 25–30 mm size classes during winter–spring 2009–2010 in the Fehmarnbelt from eight different sampling stations (FEMA 2013a). Two stations are from the coastal area of Fehmarn and six from costal area of Lolland. Station W02-1 and W02-2 lie within the same model grid.

The mussel population model was also validated against the Fehmarnbelt environment by comparing spatial variation in total biomass of the model (all size classes summed) with the observed and interpolated biomass data obtained as part of the baseline study (FEMA 2013a).

A scatterplot between modelled biomass and biomass estimated from measurements and interpolation show an acceptable agreement in spatial pattern ($r^2 > 0.44$), however with the modelled biomass being approx. 2 times higher than the observed. Possible explanations include (1) predation on mussels in the model is underestimated, (2) the model also includes growth of other bivalve filter feeders such as cockles and clams and/or (3) model allows growth of mussels where habitats are unsuitable for mussels e.g. due to lack of appropriate substrate and sediment. The latter two issues are supported by a large number of model predictions where corresponding values representing observations of mussels are zero (Figure App.B.2). This explanation is supported by the baseline study that showed that biomass of filter feeding infauna varied between 10 and 20 g m^{-2} (AFDW) in the three communities Cerastoderma, Dendrodoa and Tannaissus (FEMA 2013a). It follows, that despite biomass of the blue mussel is overestimated by the model, the magnitude of filter feeding impact on plankton is accounted for in the model, because the presence of other filter feeders.

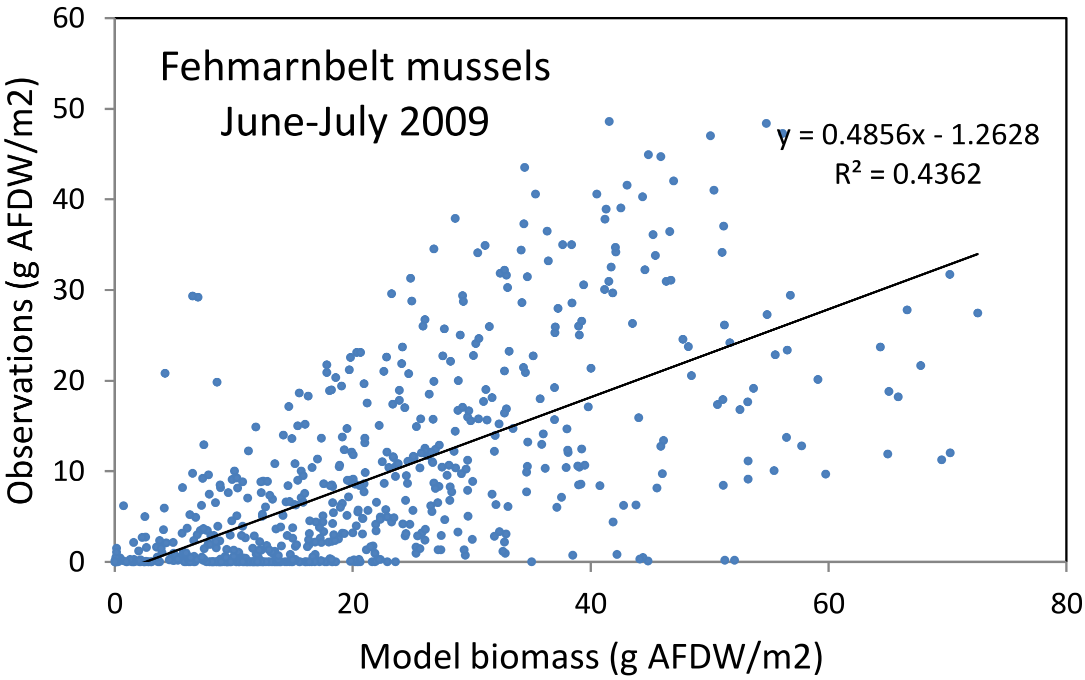

Figure App B.2 Scatterplot between modelled biomass and observed (interpolated) biomass of mussels. Observations of biomass are present at much higher resolution (up to 25 m) than the model resolution (approx. 800–1500 m). Therefore observed values were averaged to correspond to the resolution of the FEMA model.

The performance of the population 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.

(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).

Table App.B-1 shows the numeric performance of the mussel population model based on the validation data (Figure App. B.1). Based on the comparison of the observed biomass of individuals and the prediction of the model (see Figure App.B.1) the mussel model must be regarded as performing excellently as it captures the temporal variation in the biomass of individuals very well.

Table App.B-1 Performance of the mussel population model based on the validation data.

	R^2	ME	P_{bias}
Value	0.70	0.69	1.29
Performance	70% of variation explained	excellent	excellent