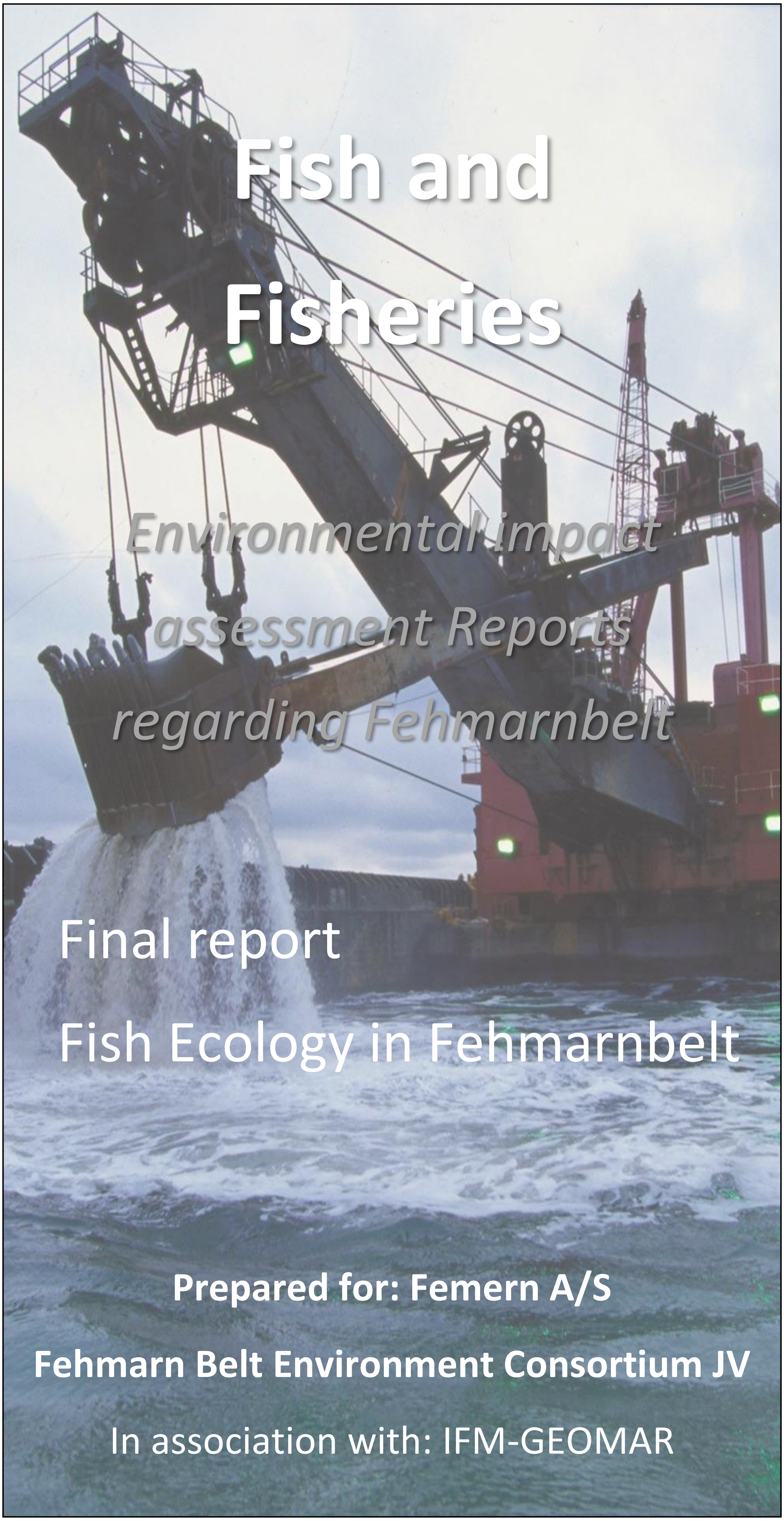

Fish and Fisheries

Environmental impact assessment Reports regarding Fehmarnbelt

Final report

Fish Ecology in Fehmarnbelt

Prepared for: Femern A/S

Fehmarn Belt Environment Consortium JV

In association with: IFM-GEOMAR

E4TR0041

Volume I

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0. Summary

In the present “Environmental Impact Statement” (EIS), which is a part of the overall EIA, all impacts due to construction activities, presence of physical structures and operation of the fixed link, which potentially can affect the existing fish and fish communities are considered. The assessment is based on the technical design of the link solutions and impacts modelled for construction related activities.

Fehmarnbelt plays a key role in the water exchange system of the Baltic Sea and the belt is an important passage way for migrating cod, herring and silver eel, as well as a spawning area for a number of fish species, including cod and flatfish. In the baseline for the present EIS, several components were identified as being key issues regarding the environmental sub-factor concerning fish: Eastern and western Baltic cod (*Gadus morhua*), western Baltic herring (*Clupea harengus*), whiting (*Merlangius merlangus*), European eel (*Anguilla anguilla*), sprat (*Sprattus sprattus*), sea stickleback (*Spinachia spinachia*), snake blenny (*Lumpenus lampretaeformis*), flatfish and shallow water species/minor species. For each environmental component the level of importance of spawning, eggs and larvae drift, nursery, feeding and migration were assessed following the guidelines of the Fehmarnbelt Fixed Link EIA manual.

A large scale infrastructure project like the Fehmarnbelt Link is considered to affect fish communities at different levels of significance caused by all specific activities during construction and operation and physical structures. Levels of impact have in general been assessed according to species or community sensitivity towards temporary or permanent pressures and spatial coverages.

Impact assessment methodology

The methodology used for the present assessment of impairment to the fish fauna has been based on a stepwise process including various elements as: Identification of environmental indicators and pressures, defining sensitivity threshold values towards pressures and quantifying magnitude of pressure and the reduction of environmental components based on exceedance of threshold values and modelled scenarios of the specific pressures. Exceedance of threshold values are considered as loss of function and the reduction of environmental components are expressed as percentage reduction. In general the assessment follows a precautionary principle, and low values have been chosen to describe the sensitivity.

The classification of the degree of impairment has been rated on a set of criteria based on series of arguments deriving from the natural variation of each environmental subcomponent. Depending on the duration of the pressure the specific criteria are defined by factors related to the standard deviation. The severity of impairment of each pressure has then been determined combining the degree of impairment with the level of importance of the specific components rated in the baseline studies. Finally the project impact summarises the accumulated impacts from all pressures. Please notice the distinction between impairment and loss. Loss only refers to physical footprints causing loss of habitat which impact specific sub-components.

In principle all subcomponents including functionalities identified as key issues in the baseline have been assessed for all identified pressures in the areas of investigation. The areas of investigation are defined according to the general guidelines for the impact assessment and include the near zone (500 m zone) for each of the described solutions, the local zones (10 km zone) and EEZ-zones in German and Danish territories.

The identified pressures assessed are seabed reclamation, the hydrological regime, sediment spill, noise/vibration and indirect pressures caused by changes/impairments of fish habitats. For each of these specific pressures the construction and operation phases have been treated separately as is the case, when relevant, with the physical structures. Since the magnitude of

pressure derived from light, electromagnetic fields and contaminants are described to be insignificant for each of the proposed solutions the impact assessment of these pressures have not been treated intensively.

Impact assessment results
Table 0.1 summarises the assessed project impacts from the main tunnel and bridge solution for each environmental component in each area of investigation.

Overall only insignificant or minor impacts are expected outside the near zone. In the near zone most impacts are expected due to footprints, where seabed reclamation in both German and Danish shallow waters reduces nursery areas for cod and flatfish as well as habitats of shallow water species, including the protected sea stickleback. In deeper waters footprints are also expected to impact the protected snake blenny. During the construction phase a number of species are expected to be impacted in the tunnel solution while only sea stickleback is impacted in the bridge solution. During operation only cod is expected to be impacted in the tunnel solution.

In general, the hydrographic regime and the background levels of suspended sediment, noise and vibration in the zero-alternative constitutes more severe pressures to fish than the expected pressures from the construction and operation of either tunnel or bridge solution. This is particularly the case for the drift of eggs and larvae of cod, flatfish, sprat and herring in most areas of Fehmarnbelt due to the variability in the salinity regime and high background levels of suspended sediment during windy conditions. With respect to noise and vibration the existing heavy traffic of the Rødby-Puttgarden ferries produce considerable more noise than the expected noise from both solutions. The establishment of a link would presumably even reduce the noise level in Fehmarnbelt if the ferry service stops.

Table 0.1: Project impact on specific components from the construction, operation and structures of the main tunnel and a bridge solution.

Severity of impairment/loss	**Tunnel**			**Bridge**		
	Construction	Operation	Footprints	Construction	Operation	Footprints
DE 10 km National						
Cod	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Whiting	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Herring	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European sprat	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Flatfish	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Shallow water species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European eel	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Sea stickleback	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Snake blenny	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Protected species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
DE 10 km EEZ						
Cod	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Whiting	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Herring	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European sprat	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Flatfish	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Shallow water species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European eel	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Sea stickleback	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Snake blenny	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Protected species	Minor	Minor	Insignif.	Minor	Minor	Insignif.

DK 10 km						
Cod	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Whiting	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Herring	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European sprat	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Flatfish	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Shallow water species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European eel	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Sea stickleback	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Snake blenny	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Protected species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
DE 500 m National						
Cod	Medium	Minor	Medium	Minor	Minor	Medium
Whiting	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Herring	Minor	Minor	Minor	Minor	Minor	Minor
European sprat	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Flatfish	Medium	Minor	Medium	Minor	Minor	Medium
Shallow water species	Minor	Minor	Medium	Minor	Minor	Medium
European eel	Minor	Minor	Minor	Minor	Minor	Minor
Sea stickleback	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Snake blenny	Medium	Minor	Insignif.	Minor	Minor	High
Protected species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
DE 500 m EEZ						
Cod	Medium	Minor	Insignif.	Minor	Minor	Insignif.
Whiting	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Herring	Minor	Minor	Insignif.	Minor	Minor	Minor
European sprat	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Flatfish	Minor	Minor	Insignif.	Minor	Minor	Medium
Shallow water species	Medium	Minor	Insignif.	Minor	Minor	Insignif.
European eel	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Sea stickleback	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Snake blenny	Medium	Minor	Insignif.	Minor	Minor	High
Protected species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
DK 500 m						
Cod	Medium	Medium	Medium	Minor	Minor	Medium
Whiting	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Herring	Minor	Minor	Minor	Minor	Minor	Minor
European sprat	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Flatfish	Medium	Minor	Medium	Minor	Minor	Medium
Shallow water species	Minor	Minor	Medium	Minor	Minor	Medium
European eel	Minor	Minor	Minor	Minor	Minor	Minor
Sea stickleback	Minor	Minor	High	Medium	Minor	High
Snake blenny	Medium	Minor	Insignif.	Minor	Minor	High
Protected species	Minor	Minor	Insignif.	Minor	Minor	Insignif.

The following summarises the overall impacts on the respective environmental sub-components assessed for the main tunnel and bridge solution.

The main tunnel solution (EME-tunnel solution)

Cod

Only temporary seabed reclamation will lead to medium impairment of spawning, egg-larvae drift and feeding for cod in the near zone. Overall the project impact during the construction phase of the tunnel solution is classified as medium. During operation the physical structures in the DK near zone is expected to cause a medium impairment of cod feeding, and due to seabed reclamation there is a small, but medium severe loss of cod nursery in the DE near zone and in the DK near zone.

Whiting
No impact on whiting exceeds minor in the constructions phase of the tunnel except a medium impact on nursery areas, which is only of minor importance, and the project impact during construction is classified overall minor. A very high project impairment on whiting nursery due to seabed reclamation is expected, but since only of minor importance, the project impact during the operation phase is also classified overall minor.

Herring
The project impact of the construction phase on herring is limited to the near zone, where sediment spill causes a medium impairment of the egg- and larvae survival. During operation no major impacts are expected. Spawning, eggs and larvae, nursery and feeding are not classified as important and the severity is accordingly low. There are no aggregating impacts causing changes in the project impairment, and the project severity for herring is minor during both construction and operation in the respective areas.

Sprat
The project impact of the construction phase on sprat is minor. During operation no major impacts are expected. There are no aggregating impacts causing changes in the project impairment, and the project severity for sprat is medium for construction and minor during operation in the respective areas.

Flatfish
The project impact of the construction phase on flatfish is limited to seabed reclamation in the near zone, where spawning and eggs and larvae are medium impacted in both Danish and German waters. In the German near zone medium impact on feeding areas is expected as well. No impact on flatfish exceeds minor during the operation. There are no aggregating impacts causing changes in the project impairment, and the project severity for flatfish in the near zone is medium for construction in the respective areas. Due to seabed reclamation there is a small, but medium severe loss of flatfish nursery and feeding in the DE near zone and in the DK near zone, where there is an additional small, but medium severe loss of spawning sites.

Shallow water species
There are no impairments on shallow water species exceeding minor during the construction and operation of the tunnel. Due to seabed reclamation there is a medium severe loss of habitats in the DE near zone and in the DK near zone.

European eel
There are no impacts on European eel exceeding minor during the construction and operation of the tunnel.

Sea stickleback
There are no impairments on sea stickleback exceeding minor during the construction and operation of the tunnel. However, due to seabed reclamation there is a highly severe loss of habitats in the DK near zone.

Snake blenny
Temporary seabed reclamation will lead to medium impairment of spawning, egg-larvae drift, nursery and feeding for snake blenny. For all other pressures, no or minor impairment is expected and the project impact for snake blenny during the construction phase is classified as overall medium. During operation no major impacts are expected.

Legally protected species
Apart from stickleback and snake blenny there are no impacts on legally protected species exceeding minor during the construction and operation of the tunnel.

The bridge solution
Cod
There are no impairments on cod exceeding minor during neither construction nor operation of the bridge. Due to seabed reclamation there is a small, but medium severe loss of cod nursery in the DE near zone and in the DK near zone.

Whiting
There are no impacts on whiting exceeding minor during neither construction nor operation of the bridge.

Herring
There are no impacts on herring exceeding minor during neither construction nor operation of the bridge.

Sprat
There are no impacts on sprat exceeding minor during neither construction nor operation of the bridge.

Flatfish
There are no impairments on flatfish exceeding minor during neither construction nor operation of the bridge. Due to seabed reclamation there is a small, but medium severe loss of flatfish spawning, nursery and feeding areas in the DE near zone and in the DK near zone. In the DE EEZ near zone there is a medium severe loss of spawning and feeding areas.

Shallow water species
There are no impacts on shallow water species exceeding minor during neither construction nor operation of the bridge.

European eel
There are no impacts on eel exceeding minor during neither construction nor operation of the bridge.

Sea stickleback
During the construction of the bridge medium impairments on spawning, nursery and feeding areas of sea stickleback is expected in the Danish near zone (500 m) due to temporary seabed reclamation. Thus, the project impact during the construction phase is classified as overall medium. No impairments are expected during operation. Due to seabed reclamation there is a small, but highly severe loss of spawning, nursery and feeding areas in the DK near zone.

Snake blenny
There are no impairments on snake blenny exceeding minor during neither construction nor operation of the bridge. Due to seabed reclamation there are small, but highly severe loss of spawning, nursery and feeding areas in the DK near zone and in both DE near zones.

Legally protected species
Apart from sea stickleback and snake blenny there are no impacts on legally protected species exceeding minor during neither construction nor operation of the bridge.

1. Introduction

In September 2008 Denmark and Germany signed the State Treaty to establish a fixed link across the Fehmarnbelt. The State Treaty was adopted by the national Parliaments and ratified by the two countries in 2009. During the plan and approval process a number of environmental investigations including investigations on fish communities have been conducted from 2008 to 2010 in order to provide information for the identification, description and assessment of the project impacts on fish and fish communities.

In the present “Environmental Impact Statement” (EIS), which is a part of the overall EIA, all impacts caused by construction activities, presence of physical structures and operation of the fixed link, which potentially can affect fish and fish communities are considered. The assessment is based on the technical design of the link solutions and impacts modelled for construction related activities described below.

The cumulative and combined impact of the project and other developments in the region is considered concerning impact on fish and fish communities.

1.1 Importance of Fehmarnbelt for fish communities

Several fish species and fish communities in the Fehmarnbelt area are of ecological importance. Furthermore, several fish species are of economic importance both locally and regionally. The ecosystem in the Baltic Sea is, however, highly dynamic and has undergone large changes in fish communities during the last two decades. Cod, herring and sprat are exploited heavily by commercial fishery, which among others are expressed by a dramatic decrease in cod (*Gadus morhua*) and herring (*Clupea harengus*) stocks (ICES, 2010b). In parallel to this development, a large increase in the sprat (*Sprattus sprattus*) stock and the landings of sprat has been registered (Casini, et al., 2008; ICES, 2007b).

During the baseline investigations a total of 68 different fish species were registered. For the majority of these species the Fehmarnbelt area is of importance as spawning, nursery and feeding area/ground. The availability of nursery areas is an essential and limiting factor in recruitment of many fish species. The shallow waters of Fehmarnbelt provide important nursery and feeding areas. Vegetated areas along the coasts of Lolland and Fehmarn are suitable for fish nursery, and non-vegetated sandy or silty substrates are important feeding grounds for demersal fish species like flatfish.
Since Fehmarnbelt plays a key role in the water exchange system of the Baltic Sea the belt area is also an important migrating route for cod, herring and silver eel (*Anguilla anguilla*).

The fish communities in the Fehmarnbelt can generally be separated in two groups – one community is characterised by primarily bottom living fish (demersal) and one community living in the pelagic. Some fish are strictly pelagic such as herring and sprat, whereas cod primarily is associated to the bottom and the flatfish almost strictly are found on or buried in the seabed. Considerable temporal, spatial and diurnal (day and night) variations in the distribution pattern are found between different species.

Fish-eating birds and marine mammals are characteristic elements in the Natura 2000 sites. They depend on the availability of food resources in Fehmarnbelt, both in the main area and in the shallow water areas and bays along both the Danish and German coast. The shallow waters are of specific importance as nursery grounds for most species of flatfish and a number of shallow water species like sticklebacks including the redlisted (only in Germany) sea stickleback (*Spinachia spinachia*) live and breed there. Beside juveniles of sprat, herring and the sandeels these shallow water species are very important food resources for a various number of seabirds such as terns, divers, grebes, cormorants, mergansers, gulls, guilimots and alks - all common as resting or breeding species in the Fehmarnbelt area. Some diving ducks, common goldeneye (*Bucephala clangula*), velvet scoter (*Melanitta fusca*) occasionally feed on small fish whereas the long tailed duck (*Clangula hyemalis*) mainly feeds on fish eggs and fish larvae. Sandeels, herring, sprat, cod, flatfish and gobies are mentioned as very important food resources for seals and harbour porpoises in the German Natura 2000 areas.

1.2 Environmental pressures and potential effects of the fixed link

A large scale infrastructure project like the Fehmarnbelt Link is considered to affect the environment and hereby the fish communities at different levels of significance during construction and operation.

Levels of impact can be assessed according to e.g. species or community vulnerability, permanent or temporary environmental pressures, spatial coverage and the ability of species or communities to recover. The environmental pressures that may affect fish species and fish communities are caused by specific activities during construction and operation and physical structures.

Short term direct or indirect pressures during construction are mainly related to dredging, excavation and disposal activities. Dredging or disposal of sediment directly affects the seabed and hence habitats for spawning, nursery or feeding for different fish species and fish communities.

Spill and spreading of marine sediments from dredging, will affect water quality by increasing the concentration of suspended sediment followed by an increased sedimentation. Both increased suspended sediment and increased sedimentation can potentially affect pelagic and demersal fish communities, fish migration and impair suitable habitats for fish communities. Early life stages of most fish species are in general more vulnerable to environmental pressures than adults. Fish eggs and fish larvae are highly sensitive to increased concentrations of suspended sediment decreasing the buoyancy of eggs and affecting the feeding of fish larvae.

Physical structures and associated facilities induce permanent pressure and loss of seabed and hence habitats for various fish communities. The physical structures may induce barrier effect for spawning or feeding migration of different fish species or may change the hydrographic regime potentially affecting the distribution or exchange of fish eggs and fish larvae on each side of the fixed link.

Emission of noise, vibration and light from construction and operation activities may have short or long term affects on fish species and fish communities. During operation of the fixed link the fish communities will mostly be affected by light (in case of a bridge), noise and vibration caused by traffic. This might cause a barrier effect on migrating fish from and to spawning or feeding areas/grounds avoiding areas close to the alignment or by temporary interruption of migration. Cod, herring and the European eel are the most important migratory species in the Fehmarnbelt and they are known to migrate over large distances to feed or spawn.

The cumulative pressures from the establishment of the fixed link across Fehmarnbelt and other projects like offshore wind farms in the area may have a combined effect on fish migration through the belt.

Not only pressures from the construction of the fixed link are supposed to affect fish communities in Fehmarnbelt. Due to the long lifetime of the fixed link it is necessary to consider possible climate induced changes in the environmental conditions in the assessment and interference of the impact on fish communities of the project.

This EIS report provides the results from the impact assessment for fish communities taking all necessary considerations of relevant impacts from the construction and operation of the fixed link across Fehmarnbelt into consideration.

1.3 Importance

The importance of several key components in the fish communities' characteristic for Fehmarnbelt is considered, evaluated and used in the assessment.

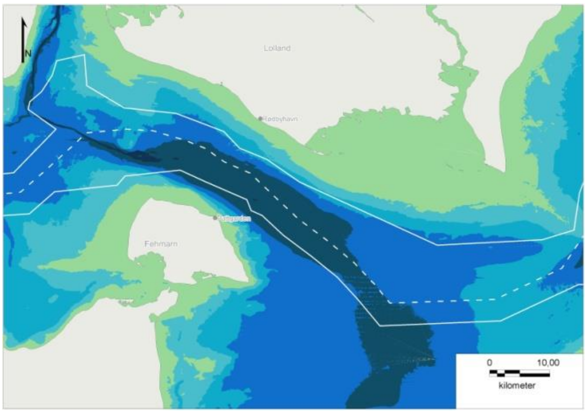


Figure 1.1: Sites of potential importance for shallow water fish communities.

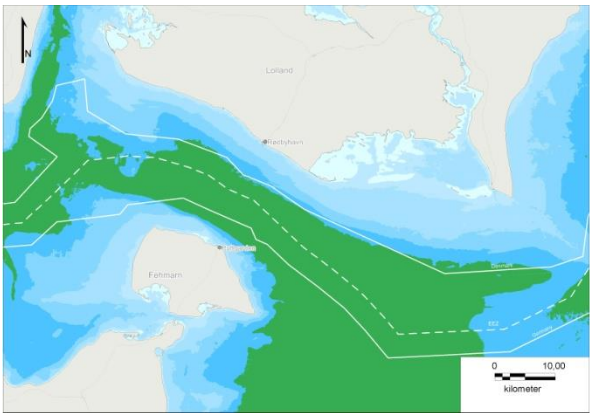


Figure 1.2: Areas of potential importance for spawning of cod in Fehmnarnbelt and adjacent areas.

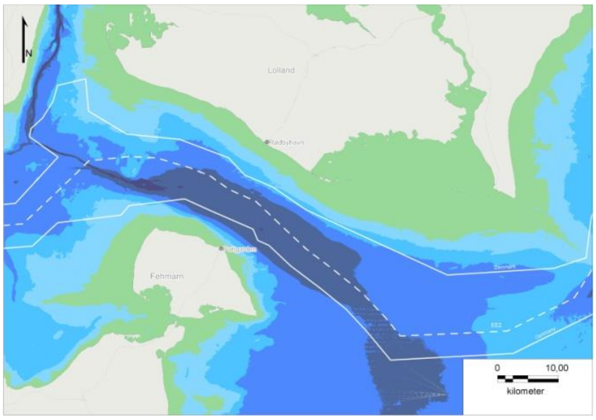


Figure 1.3: Areas of potential importance as nursery areas for cod in Fehmnarnbelt and adjacent areas.

Figure 1.4: Areas of potential importance as foraging areas for cod in Fehmnarnbelt and adjacent areas.

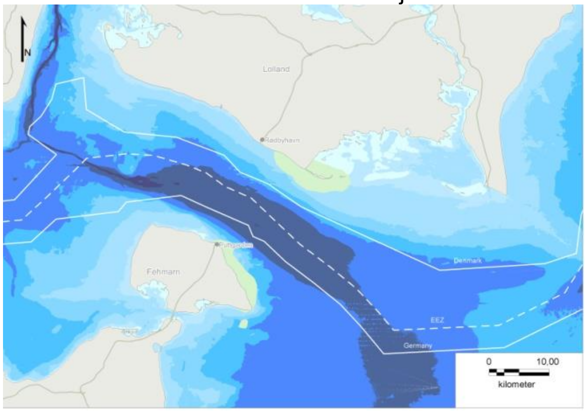


Figure 1.5: Areas of potential importance for the spawning of herring in Fehmarnbelt and adjacent areas.

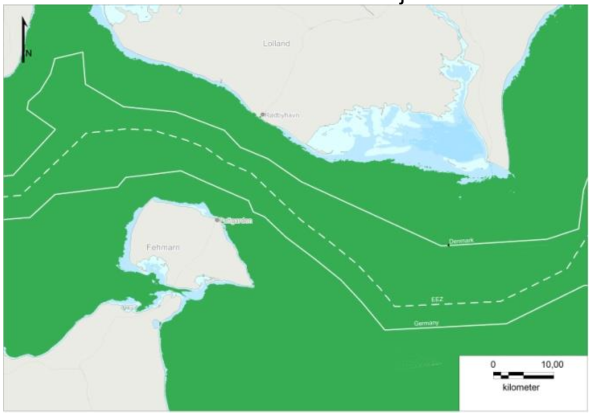


Figure 1.6: Areas of potential importance for the migration of herring in Fehmarnbelt and adjacent areas.

Figure 1.7: Areas of potential importance for the spawning of sprat in Fehmarnbelt and adjacent areas.

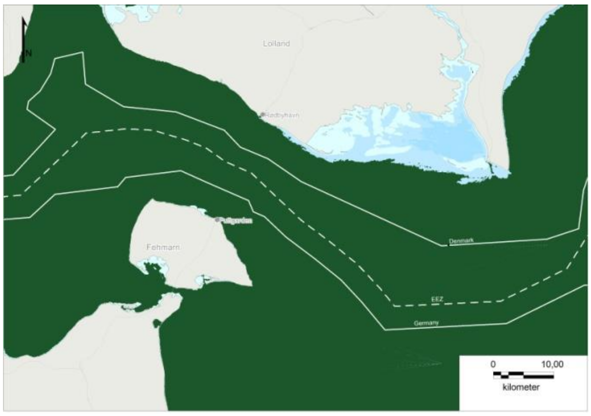


Figure 1.8: Areas of potential importance for the migration of European eel in Fehmarnbelt and adjacent areas.

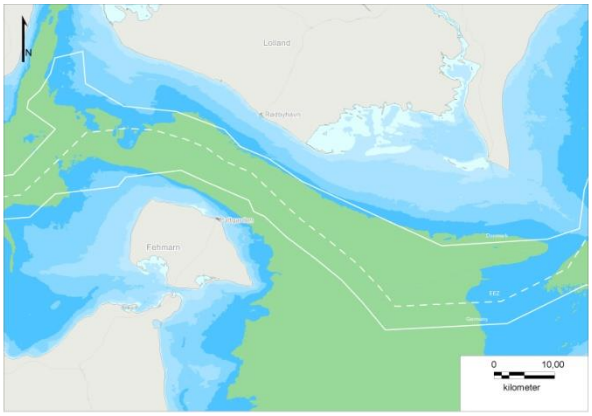


Figure 1.9: Areas of potential importance for the spawning of flatfish species in Fehmarnbelt and adjacent areas.

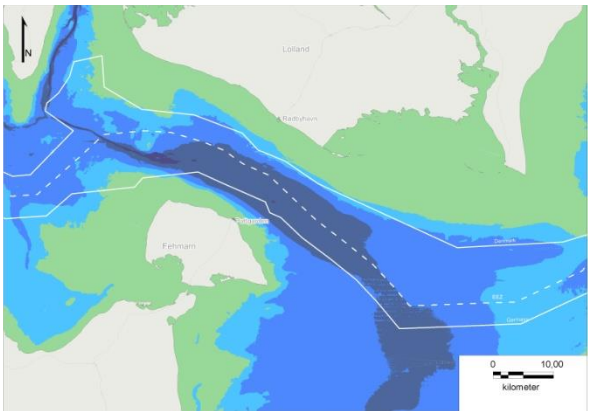


Figure 1.10: Areas of potential importance as nursery grounds for flatfish species, except dab, in Fehmarnbelt and adjacent areas.

Importance
- 🟩 Very high
- 🟩 High
- 🟩 Medium
- 🟩 Minor

Bathymetry
- 🟦 0 - 2 m
- 🟦 2 - 5 m
- 🟦 5 - 10 m
- 🟦 10 - 15 m
- 🟦 15 - 20 m
- 🟦 20 - 25 m
- 🟦 25 - 30 m
- 🟦 > 30 m

Table 1.1: Importance of fish species/components in Fehmarnbelt.

Environmental component	**Spawning**	**Egg-larvae drift**	**Nursery**	**Feeding**	**Migration**	**Overall**
Atlantic cod	High	High	Medium	Medium	High	High
Whiting	-	-	Minor	-	Medium	Medium
Herring	Minor	Minor	Minor	Minor	High	High
European sprat	Medium	Medium	Minor	Minor	Medium	Medium
Flatfish	Medium	Medium	Medium	Medium	Minor	Medium
Shallow water species	Medium	Minor	Medium	Medium	-	Medium
Protected species:						Very high
European eel	-	-	Minor	Minor	Very high	Very high
Redlisted species:						High
Sea stickleback	High	Minor	High	High	-	High
Snake blenny	High	High	High	High	-	High

1.4 Area of investigation

The areas of investigation are defined according to the general Fehmarnbelt guidelines for the impact assessment and include the near zone (500 m zone) for each of the described solutions and the local zone (10 km zone exclusive the 500 m zone) in German and Danish territories (Table 1.2). In German territory the two zones are furthermore subdivided in the national respective the Exclusive Economic Zone (EEZ).

Table 1.2: Description of the near and local zones addressed with respect to fish ecology in the present EIS of the Fehmarnbelt fixed link. The name refers to the abbreviations used in the tables in the present report.

Zone	Territory	Description of area	Name
Near zone	DE-national	+/- 500 m around the project Tunnel based on IMT-E-ME August 2011 Bridge based on Var2-BE-E October 2010	DE 500 m Nat.
	DE-EEZ	Do	DE 500 m EEZ
	DK	Do	DK 500 m
Local zone	DE-national	+/- 10 km from the alignment (excl. near zone). Alignment IMT-E-ME August 2011.	DE 10 km Nat.
	DE-EEZ	Do	DE 10 km EEZ
	DK	Do	DK 10 km

In addition to these zones Rødsand Lagoon is assessed with respect to impacts from sediment spill since the modelled excess concentrations of suspended sediment in the lagoon from the construction of both the tunnel and bridge solution are the highest expected in the Fehmarnbelt area. Furthermore, impacts from modelled changes in the hydrological regime on the reproduction volume of cod in the Arkona Basin have been included in the assessment.

Figure 1.11 shows the respective zones and Rødsand Lagoon that have been addressed in the present assessment.

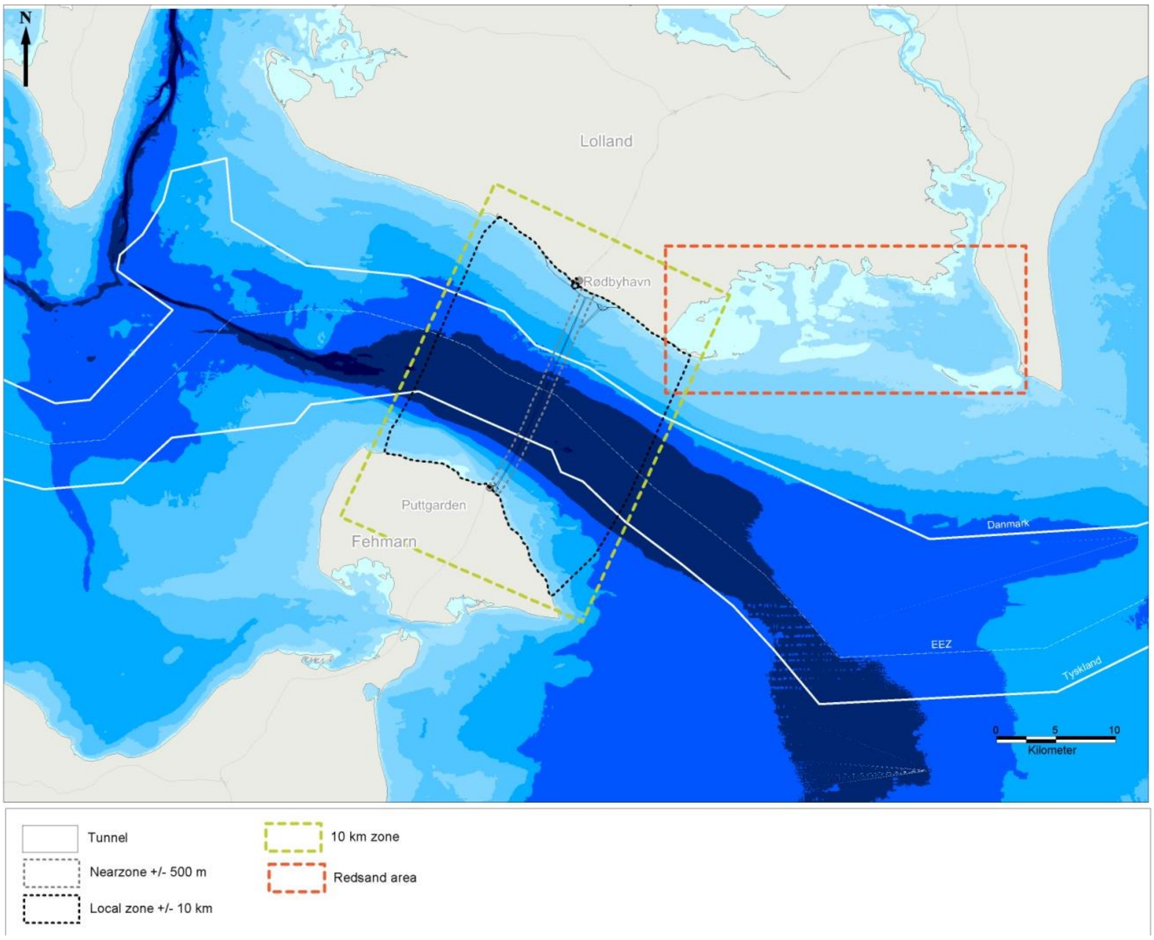


Figure 1.11: Areas of investigation addressed in the present impact assessment of the subcomponent fish ecology towards the proposed solutions of the Fehmarnbelt link.

In general, the boundaries of the areas refer to direct, on-site effects alone. However, the classification of the severity of impairment includes the rating of the importance of the specific components, which are classified according to their regional and transboundary significance. This means that regional and transboundary impacts implicit are assessed all though not quantitatively.

2. Technical project description

1.1 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

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 NATURA 2000 sites.

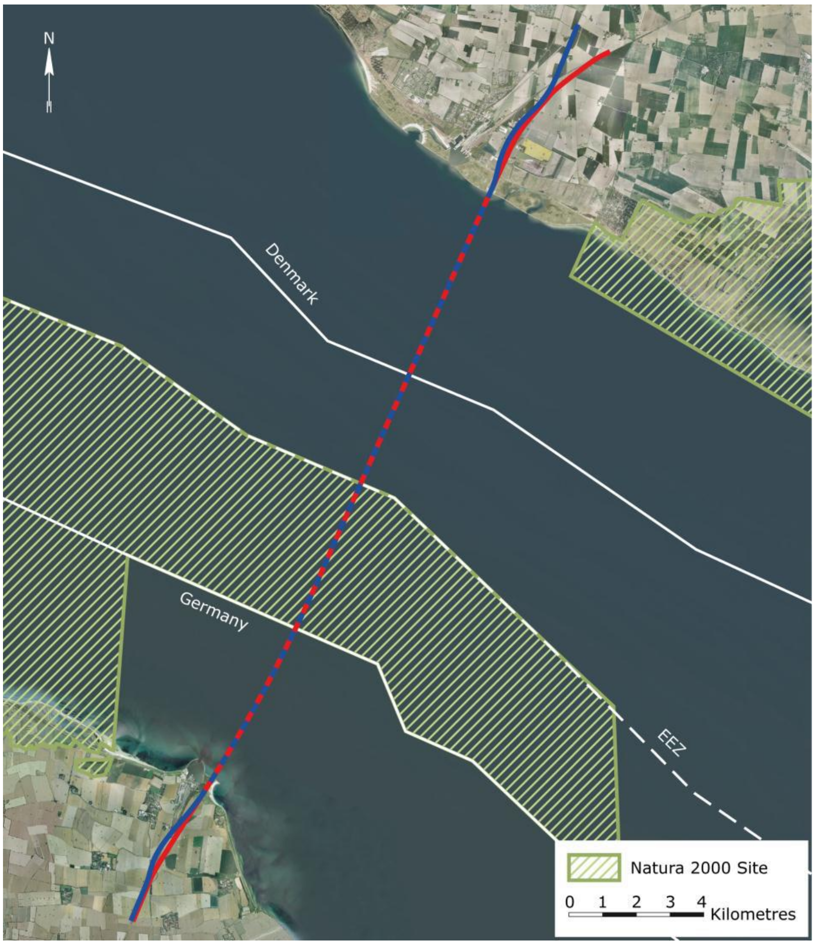


Figure 2.1: Proposed alignment for immersed tunnel E-ME (August 2011). © Femern A/S

Tunnel trench

The immersed tunnel is constructed by placing tunnel elements in a trench dredged in the seabed, see Figure 2.2. The proposed methodology for trench dredging comprises mechanical dredging using Backhoe Dredgers (BHD) up to 25m water depth and Grab Dredgers (GD) in deeper waters. A Trailing Suction Hopper Dredger (TSHD) will be used to rip the clay before dredging with GD. The material will be loaded into barges and transported to the near-shore reclamation areas where the soil will be unloaded from the barges by small BHDs. A volume of approximately 14.5 mio. m^3 sediment is handled.

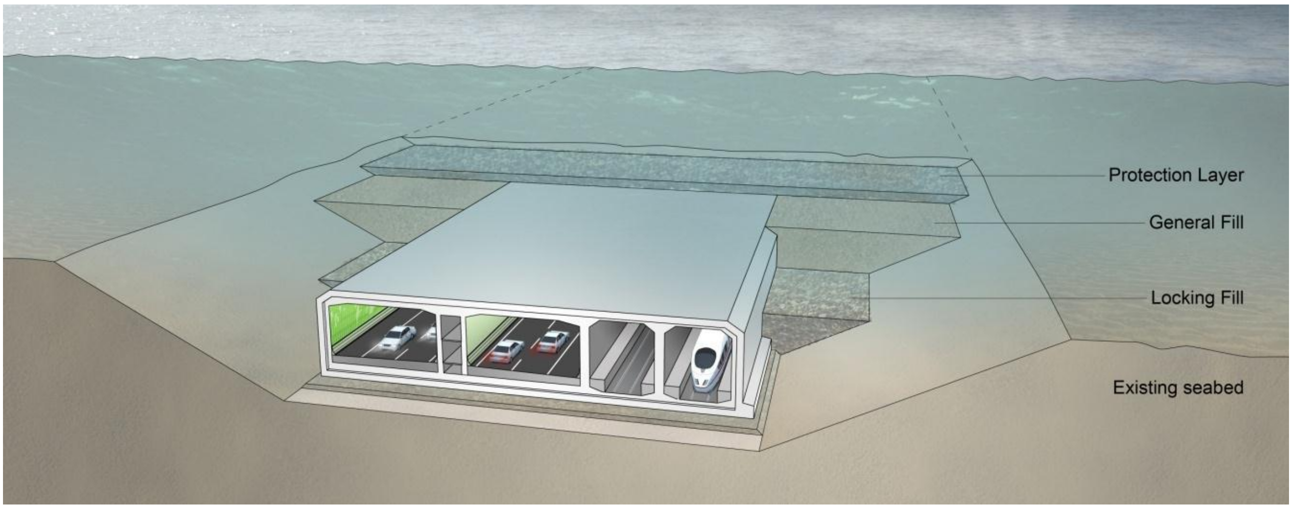


Figure 2.2: Cross section of dredged trench with tunnel element and backfilling. © Femern A/S

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 Kriegers Flak.

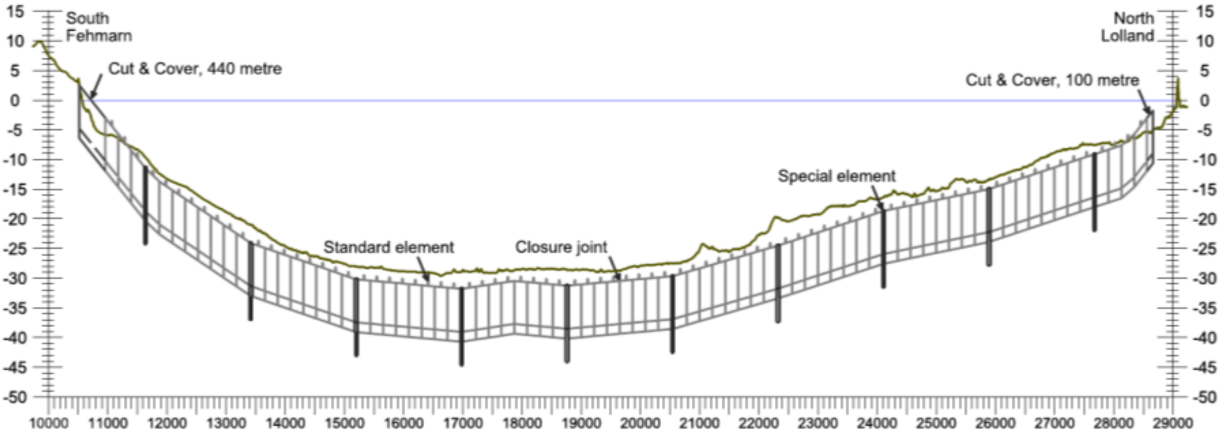


Figure 2.3: Vertical tunnel alignment showing depth below sea level. © Femern A/S

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. © Femern A/S

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 3.5 km 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. © Femern A/S

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 harbour on Lolland an access channel is also provided. These harbours will be integrated into the planned reclamation areas and upon completion of the tunnel construction works, they will be dismantled/removed and backfilled.

Production site
The current design envisages the tunnel element production site to be located in the Lolland east area in Denmark. Figure 2.6 shows one production facility consisting of two production lines. For the construction of the standard tunnel elements for the Fehmarn tunnel four facilities with in total eight production lines are anticipated.

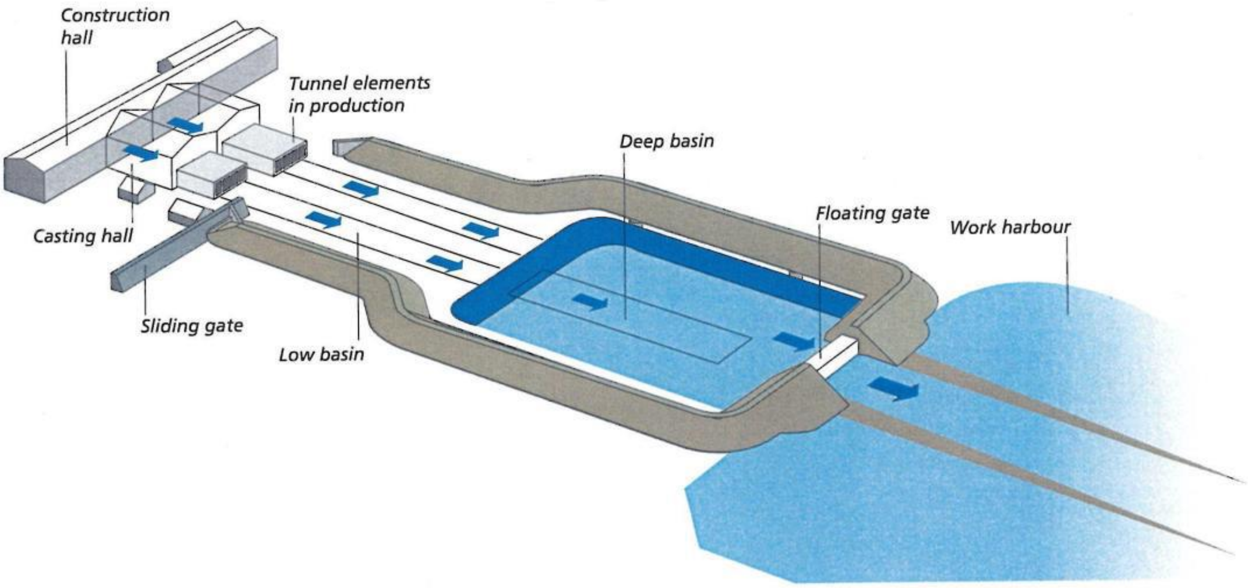


Figure 2.6: Production facility with two production lines. © Femern A/S

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

Figure 2.7: Proposed lay-out of the production site east of Rødbyhavn. © Femern A/S

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. © Femern A/S

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. © Femern A/S

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.

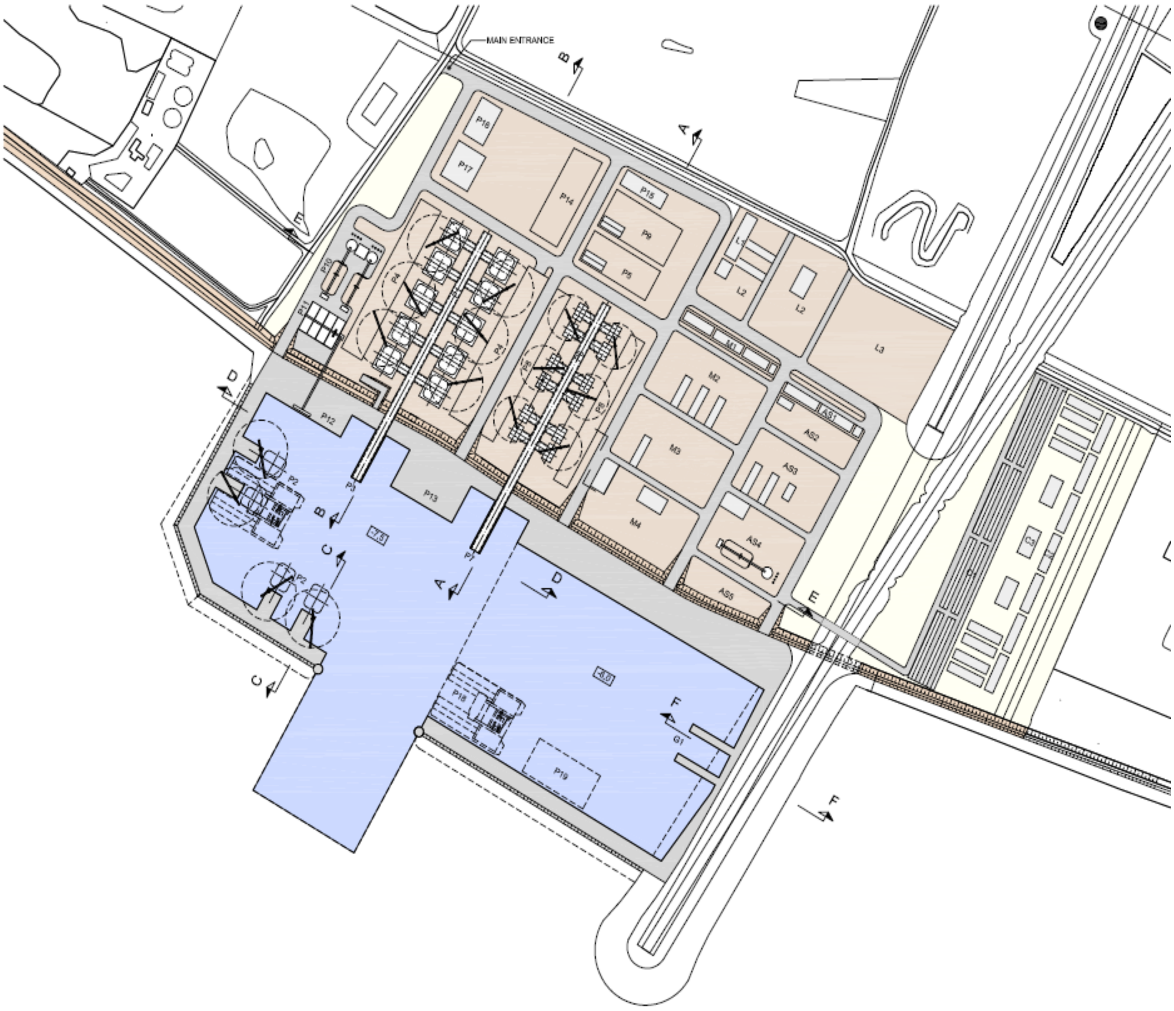


Figure 2.10: Proposed lay-out of the production site at Lolland east of Rødbyhavn. © Femern A/S

3. Data and Methods

3.1 The Assessment Methodology

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

As the impact assessments cover a wide range of environs (terrestrial and marine) and environmental factors, the general methodology is further specified and in some cases modified for the assessment of the individual environmental factors (e.g. the optimal analyses for migrating birds and relatively stationary marine bottom fauna are not identical). These necessary modifications are explained in Section 3.1.2. The specification of methods and tools used in the present report are given in the following sections of Chapter 3.

3.1.1 **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 for assessing the impacts of the Project. They may represent different characteristics of the environmental system; from specific species to biological communities or specific themes (e.g. trawl fishery, marine tourism).	Component/sub-komponent	Komponente
Construction phase	The period when the Project is constructed; including permanent and provisional structures. The construction is planned for 6½ years.	Anlægsfase	Bauphase
Structures	Constructions that are either a permanent elements of the Project (e.g. bridge pillar for bridge alternative and land reclamation at Lolland for tunnel alternative), or provisional structures such as work harbours and the tunnel trench.	Anlæg	Anlage

Operation phase	The period from end of construction phase until decommissioning.	Driftsfase	Betriebsphase
Permanent	Pressure and impacts lasting for the life time of the Project (until decommissioning).	Permanent	Permanent
Provisional (temporary)	Pressure and impacts predicted to be recovered within the life time of the project. The recovery time is assessed as precise as possible and is in addition related to Project phases.	Midlertidig	Temporär
Pressures	A pressure is understood as all influences deriving from the Fixed Link Project; both influences deriving from Project activities and influences originating from interactions between the environmental factors. The type of the pressure describes its relation to construction, structures or operation.	Belastning	Wirkfaktoren
Magnitude of pressure	The magnitude of pressure is described by the intensity, duration and range of the pressure. Different methods may be used to arrive at the magnitude; dependent on the type of pressure and the environmental factor to be assessed.	Belastningsstørrelse	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.	Arealinddragelse	Flächeninanspruchnahme
Assessment criteria and Grading	Assessment criteria are applied to grade the components of the assessment schemes. Grading is done according to a four grade scale: very high, high, medium, minor or a two grade scale: special, general. In some cases grading is not doable. Grading of magnitude of pressure and sensitivity is method dependent. Grading of importance and impairment is as far as possible done for all factors.	Vurderingskriterier og graduering	Bewertungskriterien und Einstufung
Importance	The importance is defined as the functional values to the natural environment and the landscape.	Betydning	Bedeutung
Sensitivity	The sensitivity describes the environmental factors capability to resist a pressure. Dependent on the subject assessed, the description of the sensitivity may involve intolerance, recovery and importance.	Følsomhed/ Sårbarhed	Empfindlichkeit
Impacts	The impacts of the Project are the effects on the environmental factors. Impacts are divided into Loss and Impairment.	Virkninger	Auswirkung
Loss	Loss of environmental factors is caused by permanent and provisional loss of area due to the footprint of the Project; meaning that loss may be permanent or provisional. The degree of loss is described by the intensity, the duration and if feasible, the range.	Tab af areal	Flächenverlust
Severity of loss	Severity of loss expresses the consequences of occupation of land (seabed). It is analysed by combining magnitude of the Project's footprint with importance of the environmental factor lost due to the footprint.	Omfang af tab	Schwere der Auswirkungen bei Flächenverlust
Impairment	An impairment is a change in the function of an environmental factor.	Forringelse	Funktionsbeeinträchtigung

Degree of impairment	The degree of impairments is assessed by combining magnitude of pressure and sensitivity. Different methods may be used to arrive at the degree. The degree of impairment is described by the intensity, the duration and if feasible, the range.	Omfang/grad af forringelser	Schwere der Funktionsbeeinträchtigung
Severity of impairment	Severity of impairment expresses the consequences of the Project taking the importance of the environmental factor into consideration; i.e. by combining the degree impairment with importance.	Virkningens væsentlighed	Erheblichkeit
Significance	The significance is the concluding evaluation of the impacts from the Project on the environmental factors and the ecosystem. It is an expert judgment based on the results of all analyses.		

It should be noted that in the sections below only the term environmental factor is used; covering all levels of the receptors of the pressures of the Project (factors, sub-factors, component, sub-components). The relevant level depends on the analysis and will be explained in the following methodology sections (section 3.1.3 and onwards).

3.1.2 The Impact Assessment Scheme

The overall goal of the assessment is to arrive at the severity of impact where impact is divided into two parts; loss and impairment (see explanation above). As stated in the scoping report, the path to arrive at the severity is different for loss and impairments. For assessment of the *severity of loss* the footprint of the project (the areas occupied) and the *importance* of the environmental factors are taken into consideration. On the other hand, the assessment of severity of impairment comprises two steps; first the *degree of impairment* considering the magnitude of pressure and the sensitivity. Subsequently the severity is assessed by combining the degree of impairment and the importance of the environmental factor. The assessment schemes are shown in Figure 3.1-Figure 3.3. More details on the concepts and steps of the schemes are given below. As mentioned above, modification 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.

3.1.3 Assessment Tools

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

The matrices applied for assessments of severity of loss and degree of impairment are given in the scoping report (Table 6.4 and Table 6.5) and are shown below in Table 3.1-Table 3.2, respectively.

Table 3.1: The matrix used for assessment of the severity of loss. The magnitude of pressure = the footprint of the Project is always considered to be very high.

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

The approach and thus the tools applied for assessment of the degree of impairment varies with the environmental factor and the pressure. For each assessment the most optimal state-of-the-art tools have been applied, involving e.g. deterministic and statistical models as well as GIS based analyses. In cases where direct analysis of causal-relationship is not feasible, the matrix based approach has been applied using one of the matrices in Table 3.2 (Table 6.5 of the scoping report) combining the grades of magnitude of pressure and grades of sensitivity. This method gives a direct grading of the degree of impairment. Using other tools to arrive at the degree of impairment, the results are subsequently graded using the impairment criteria. The specific tools applied are described in the following sections of Chapter 3.

Table 3.2: The matrices used for the matrix based assessment of the degree of impairment with two and four grade scaling, respectively.

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

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

To reach severity of impairment one additional matrix has been prepared, as this was not included in the scoping report. This matrix is shown in Table 3.3.

Table 3.3: The matrix used for assessment of the severity of impairment.

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

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

3.1.4 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.

3.1.5 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).

3.1.6 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 chapter 3.2.

The importance criteria are grading the importance into two or four grades (see section 3.1.4). 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.

3.1.7 **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.

3.1.8 **Severity of loss**

Severity of loss is assessed by combining information on magnitude of footprint, i.e. the areas occupied by the Project with the importance of the environmental factor (Figure 3.1. Loss of area is always considered to be a very high magnitude of pressure and therefore the grading of the severity of loss is determined by the importance (see Table 3.1). The loss is estimated as hectares of lost area. As far as possible the spatial distribution of the importance classes is shown on maps.

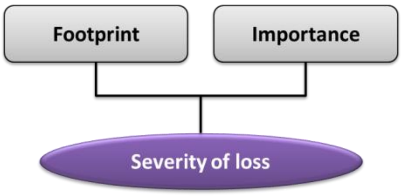


Figure 3.1: The assessment scheme for severity of loss

3.1.9 **Degree of impairment**

The degree of impairment is assessed based on the magnitude of pressure (involving intensity, duration and range) and the sensitivity of the given environmental factor (Figure 3.2). In worst case, the impairment may be so intensive that the function of the environmental factor is lost. It is then considered as loss like loss due to structures, etc.

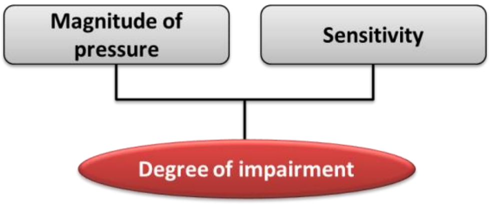


Figure 3.2: The assessment scheme for degree of impairment

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

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

3.1.10 **Severity of Impairment**

Severity of impairment is assessed from the grading's of degree of impairment and of importance of the environmental factor (Figure 3.3) using the matrix in Table 3.3. If it is not possible to grade degree of impairment and/or importance an assessment is given based on expert judgment.

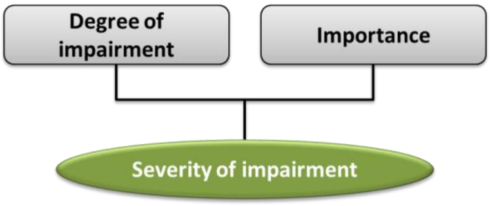


Figure 3.3: The assessment scheme for severity of impairment

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

3.1.11 **Range of impacts**

Besides illustrating the impacts on maps, the extent of the marine impacts is assessed by quantifying the areas impacted in predefined zones. The zones are shown in Figure 3.4. In addition the size of the impacted areas located in the German national waters and the German EEZ zone, respectively, as well as in the Danish national plus EEZ waters (no differentiation) are calculated. If relevant the area of transboundary impacts are also estimated.

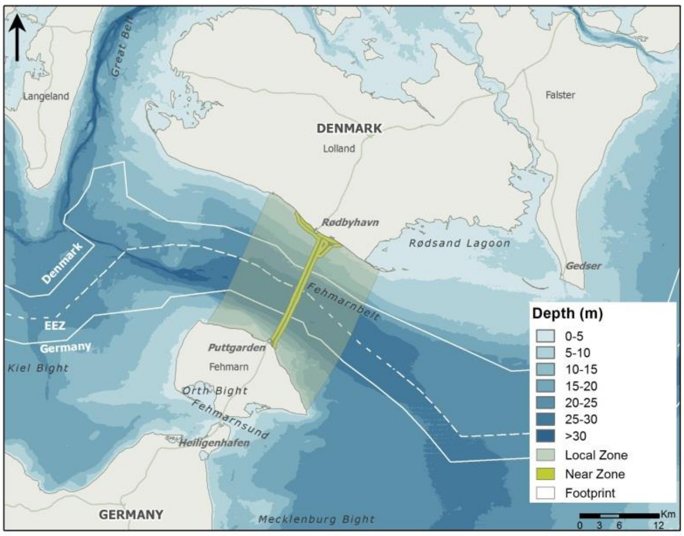


Figure 3.4: The assessment zones applied for description of the spatial distribution of the impacts. The near zone illustrated is valid for the tunnel alternative. It comprises the footprint and a surrounding 500 m band. The local zone is identical for the two alternatives. The eastern and western borders are approximately 10 km from the centre of the alignment.

3.1.12 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 3.4 as a framework.

Table 3.4: 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

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).

3.1.13 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.

3.1.14 Comparison of environmental impacts from project alternatives

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

3.1.15 Cumulative impacts

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

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

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

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

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

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

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

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

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

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

3.1.16 Impacts related to climate change

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

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

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

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

- The importance of climate change is considered in relation to possible impacts caused by the permanent physical structures and by the operation of the fixed link.

- The assessment of project related impacts on the marine hydrodynamics, including the water flow through the Fehmarnbelt and thus the water exchange of the Baltic Sea, is based on numerical model simulations, for baseline and the project case, combined with general model results for the Baltic Sea and climate change.

- Possible consequences of climate change for water birds are analysed through climatic niche models. A large-scale statistical modelling approach is applied using available data on the climatic and environmental factors determining the non-breeding distributions at sea of the relevant waterbirds in Northern European waters.

- The possible implications of climate change for marine benthic flora and fauna, fish, marine mammals, terrestrial and freshwater flora and fauna, coastal morphology and surface and ground water are addressed in a more qualitative manner based on literature and the outcome of the hydrodynamic and ecological modelling.

- Concerning human beings, soil (apart from coastal morphology), air, landscape, material assets and the cultural heritage, the implications of climate changes for the project related impacts are considered less relevant and are therefore not specifically addressed in the EIA.

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

3.1.17 **How to handle mitigation and compensation issues**

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

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

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

3.2 Assessment criteria specific related to fish ecology

The criteria for the determination of the degree of impairment are based on the level of the natural variation for the specific environmental components. The estimation of the level of natural variation was based on landing statistics in the Fehmarnbelt area and on surveys on cod, sprat and herring recruitment.

The natural variability is often rather high for environmental components related to recruitment with standard deviations (SD) in the range 30-50 % (Köster et al., 2003a; Oeberst and Bleil, 2003), while the variability in migration is related to the biomass of the adults, which often is less (e.g. Götze and Gröhsler, 2003; ICES, 2010a). An example of variation in silver eel landings is given in Figure 3.5.

For matters related to feeding areas it is important to include, that most of the economically important species are regulated by fishery. The availability of feeding areas is thus not necessarily a limiting factor, which should be reflected in the assessment criteria. As a consequence the general SD for migration is set to 20 % and for matters related to recruitment and feeding areas to 30 %. For a number of environmental components like shallow water fish communities, the natural variation in Fehmernbelt is unknown, and for these the natural variation might be larger. However for precautionary reasons these populations are given the general value of 30 %.

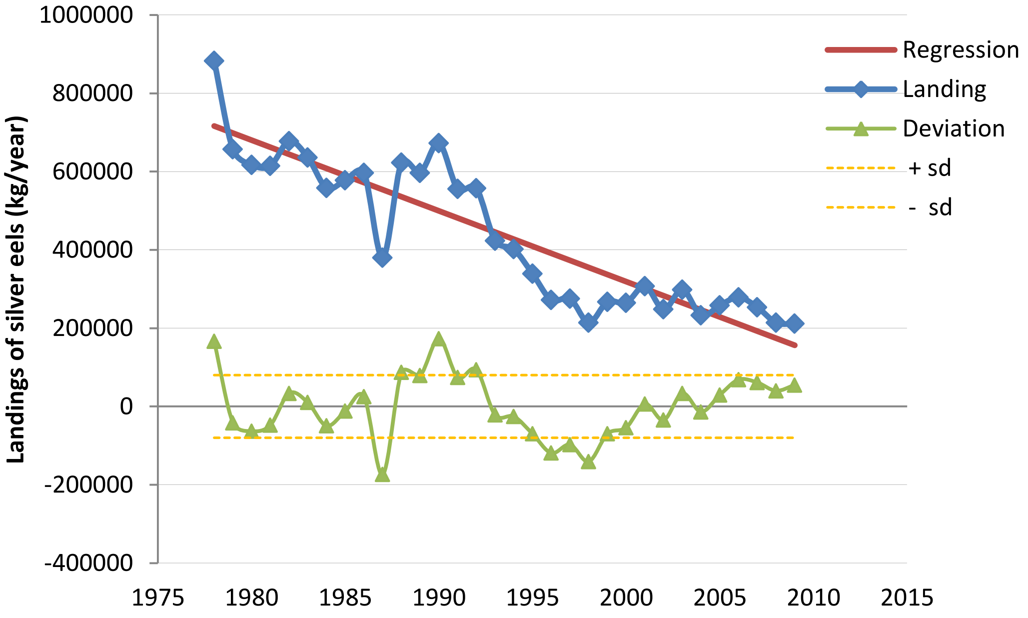


Figure 3.5: Landings of silver eels from Fehmarnbelt, Great Belt and Little Belt in the years 1975-2009. Source: Fiskeridirektoratet (2010).

By definition reductions of up to 1 SD are considered to have "medium" degree of impairment and reductions up to 2 SD are considered to have "high" degree of impairment. Under the assumption that the observations are normally distributed, ±1 SD includes approx. 68 % of the observations and ±2 SD includes approx. 95 % of all observations. In summary:

- A one year reduction less than half of the SD is considered ”low”
- A reduction below the SD, “medium”
- A reduction between 1-2 times the SD is “high”
- A reduction beyond this “very high” (=loss of function)

Since, a longer lasting impact in general is more critical to almost any environmental sub-component, the criteria are set lower for longer lasting impairments. The natural variation of the mean is thus lowered by a factor 1/no. years. From the definitions described above a set of criteria has been developed;

Environmental component	Environmental sub-component	Reduction %			Degree of impairment
		Construction 1 year*	Construction 3 years*	Operation	
Cod, herring, silver eel, whiting, legally protected species	Migration	> 40	> 20	> 10	Very high
		< 40	< 20	< 10	High
		< 20	< 10	< 5	Medium
		< 10	< 5	< 2	Minor

Environmental component	Environmental sub-component	Reduction %			Degree of impairment
		Construction 1 year*	Construction 3 years*	Operation	
Cod, herring, silver eel, whiting, legally protected species	Spawning, eggs and larvae, nursery and feeding	> 60	> 30	> 15	Very high
		< 60	< 30	< 15	High
		< 30	< 15	< 8	Medium
		< 15	< 8	< 4	Minor

Environmental component	Environmental sub-component	Reduction %			Degree of impairment
		Construction 1 year*	Construction 3 years*	Operation	
Shallow water communities, flatfish, sprat, sea stickle-back, snake blenny	Overall	> 60	> 30	> 15	Very high
		< 60	< 30	< 15	High
		< 30	< 15	< 8	Medium
		< 15	< 8	< 4	Minor

*****The maximal reduction during 1 year respective 3 successive years in the construction phase**.**

The construction, operation and structure of a fixed link can have a permanent impact on fish stocks. Previous studies of herring migration for example, indicated that the young herring in a stock learn how to return to specific spawning, feeding and wintering grounds from the older specimens. Thus, impact of the migration of herring during several years could impact future generations (Corten, 2002). However, it is assessed that only minor parts of the individual fish stocks are affected by a Fehmarnbelt fixed and thus not will impact future generations. Furthermore, it is generally assumed that fish communities and fish stocks recover more or less instantly after the conclusion of the specific pressures due to the small impacts on the stocks. Hence, the recovery time was not taken into account in the assessment criteria.

4. Introduction to pressure and sensitivity

4.1 Hydrological regime

The Baltic Sea is one of the World’s largest brackish water areas and several marine species have adapted to the low salinity. Salinity in the Baltic Sea is maintained by inflows of saline water from the North Sea through Øresund and the Belt Sea. As a consequence, salinity in the Baltic Sea decreases from west to east and south to north. The renewal of the bottom water is mainly driven by the major inflow of saline and oxygen-rich water from the North Sea. Thus, these have a large impact on the exchange between the surface and bottom water layers. However, these inflows are very irregular causing stagnant water conditions with decreasing salinity and oxygen concentrations. Strong haloclines occurs regularly causing oxygen depletion in the bottom layer.

Fehmarnbelt is a part of the transition area between the Baltic Sea and the North Sea. It has a maximum depth of approximately 30 m and the depth in the adjacent areas Mecklenburg Bight and Kiel Bight are almost similar. Darss Sill east of Mecklenburg Bight has a maximum depth of 18 m and is bordering the central Baltic Sea (Figure 4.1).

The upper water layers consist of low saline water from the central Baltic Sea, which flows through the Belt Sea and Kattegat close to the surface. The bottom water layer consists of high saline water from the North Sea. The two water layers in Fehmarnbelt are strongly stratified in June when the wind conditions often are very weak.

In the upper 15 m water layer the current is outwards towards the North Sea and inwards towards the Baltic Sea in the lower 15 m water. The vertical current distribution has opposite current directions in the upper surface layer and the lower bottom layer (FEHY, 2011a).

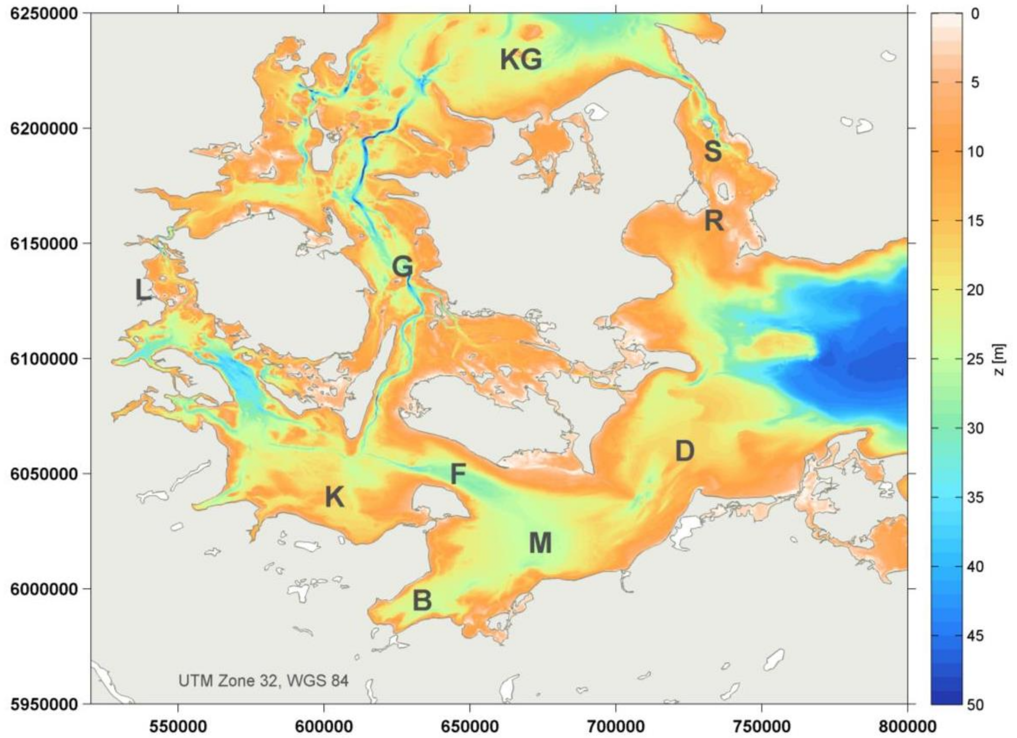


Figure 4.1: Bathymetry of the Belt Sea: southern Kattegat (KG), Little Belt (L), Great Belt (G), Øresund (S), Fehmarnbelt (F), Kiel Bight (K), Mecklenburg Bight (M), Lübeck Bight (B), Darss Sill (D) and Drogden Sill (R). Source: FEHY (2013b).

The salinity conditions in Fehmarnbelt are related to the current conditions. Longterm outflow results in low salinity where as longterm inflow from the North Sea to the Baltic Sea increase salinity. Furthermore, inflows renew the deeper layers with oxygen-rich water.

4.1.1 Environmental indicators

Hydrological changes are natural occurring pressures for fish in the Baltic Sea and marine species living here are specially adapted to the brackish water conditions with events of oxygen depletion in the deeper water layers. Important fish species such as cod, herring, sprat, plaice, dab and flounder spawns in the western Baltic. The salinity, temperature and oxygen conditions are important especially for species with pelagic eggs for e.g. the fertilisation success and buoyancy of eggs. These parameters are also important for the match-mismatch between copepods, the main larval prey and the predatory post yolk sac fish larvae. Furthermore, the water flow determines the dispersal of eggs and larvae. Thus, the hydrological conditions have a major impact on the recruitment success.

The environmental indicators relevant to assess in relation to hydrological regime are listed in Table 4.1.

Table 4.1: Environmental indicators selected for the assessment of pressures from the hydrological regime. (-) indicates no relevans of assessment in Fehmarnbelt.

Environmental indicators	Spawning	Egg-larvae drift	Nursery	Feeding	Migration
Atlantic cod	x	x			
Whiting	-	-			
Herring	x				
European sprat	x	x			
Flatfish	x	x			
Shallow water species					
Protected species:					
European eel	-	-			
Sea stickleback					
Snake blenny					

4.1.2 Sensitivity to pressure

The sensitivity to pressure from the hydrological regime differs between species as well as the different life stages. Furthermore, the sensitivity to changes in hydrological parameters differs. Several fish species living in the Baltic Sea are sensitive to change in salinity, temperature and oxygen concentrations. Temperature, salinity and oxygen are the key drivers for recruitment success for cod in the Baltic Sea. This is because it is a large brackish water area occasionally with unfavourable oxygen conditions in the deeper water masses. Furthermore, the drift of pelagic eggs and larvae is important for the recruitment. Important species in the western Baltic Sea with pelagic eggs are cod, sprat, flounder, plaice and dab. Hydrological changes can also impact the copepod composition, abundance and seasonality causing a mismatch between the important prey and the predatory post yolk sac larvae of some fish species. Thus, fish species are sensitive to changes in vertical mixing of water layers, water exchange and current pattern.

Salinity

Salinity condition is important for the hatching success of pelagic fish eggs. For example, low salinity is inhibiting the activation of spermatozoa and the fertilisation will thus be limited. It is crucial for pelagic eggs to obtain neutral buoyancy and avoid the unfavourable oxygen conditions often prevailing in the deeper water layers in order to increase survival probabilities. Furthermore, the density of fish eggs might be influenced by the salinity of the water experienced during the fertilisation (e.g. FeBEC, 2011; Petereit, et al., 2009).

Temperature

Temperature is an essential parameter affecting the metabolism of individuals. The development time from fertilisation of egg to hatch is determined by temperature. However, studies of egg mortality have shown that egg survival is greatest within a specific temperature range. The exact timing of critical transitions during early life history is extremely important for larval survival and thus the success of the cohort. The surrounding water temperature determines the speed of the yolk sac depletion. Prey availability is essential for the larvae as soon as endogenous reserves are consumed and morphological changes such as functional visual system, functional jaw formations and gap opening allow successful foraging (Petereit, et al., 2008).

Oxygen

Respiration of oxygen is the base of the reproduction, development, growth, activity etc. of the majority of the living organisms. Thus, for example egg survival depends on a certain oxygen concentration and is only limited by a lower threshold. Furthermore, adult individuals avoid oxygen depleted areas.

The ability to remain buoyant and thus to avoid the low oxygen levels in the bottom layers, is crucial for the development of pelagic eggs in the Baltic Sea (Table 4.2).

The threshold values of the hydrological parameters for the different environmental components and their life stages are listed in Table 4.2.

Table 4.2: Threshold values found in literature of different hydrological parameters impacting the life stages of the environmental components.

Environmental component	Life stage	Threshold concentration	Effect	Reference
Atlantic cod	Egg	Oxygen: ≥ 2 mg/l Oxygen: < 5 mg/l	No egg survival Large decrease in egg survival	Wieland et al. (1994)
	Egg	Salinity: > 15-16 psu WB and > 11-12 psu EB 20-22 psu WB and 14.5 ±1.2 psu EB	Spermatozoa activation Egg buoyancy	Nissling et al. (1997)
	Egg hatching time	Temperature: 4-8°C 5.5-8.5°C 1.5°C 1°C ≥ 11°C	Optimal Fehmarnbelt Optimal Mecklenburg Bight Threshold level Low viable hatch of Baltic cod eggs Significant decrease in egg survival of Baltic cod	von Westernhagen (1970) Bleil (1995) Aro (1989) Nissling (2004) Nissling (2004)
	Egg	Water exchange and current pattern	Change in drift can impact recruitment success	
	Larvae	Water exchange and current pattern	Change in drift can impact recruitment success	
	Yolk sac larvae	11°C	Decrease in larval viability	Nissling (2004)
	Post yolk sac larvae	Vertical mixing	Match-mismatch between predatory larvae and prey (copepod)	
Herring	Egg	Salinity: 4 psu Temperature: 4°C	Threshold WBSS Herring eggs are fairly resistant to salinity fluctuations Threshold WBSS	Klinkhardt (1996)
	Egg	Oxygen	Baltic eggs survive well even under rather poor oxygen conditions. Even under alternating saturation levels the egg survival is good.	Aneer (1987)
European sprat	Egg	Salinity ≥ 4 psu ≥ 14 psu	Tolerates wide range of salinity and large fluctuations Eggs are buoyant (fish from Bornholm Basin)	Ojaveer et al. (2010) Petereit et al. (2009)
	Egg	Temperature > 4°C < 14.7°C > 3.4°C	Significantly lower viable hatch No hatching Hatching success significantly reduced	Nissling et al. (2002b) Petereit et al. (2008)
	Egg	Oxygen ≥ 2 ml/l	Significantly lower survival	Nissling et al. (2002b)
	Larvae	≤ 5°C	Decrease in larval viability	Nissling (2004)
Plaice	Egg	Salinity > 10 psu SD 23-24	Spermatozoa mobility	Nissling et al. (2002a)
	Egg	Salinity 15 – 15.7 psu	Neutral buoyancy	Nissling et al. (2002a)
Flounder	Egg	Salinity > 10 psu SD 23-24	Spermatozoa mobility	Nissling et al. (2002a)
	Egg	Salinity 13.1 – 26.7 psu	Neutral buoyancy	Nissling et al. (2002a)
Dab	Egg	Salinity > 11 psu SD 23-24	Spermatozoa mobility	Nissling et al. (2002a)
	Egg	Salinity 19.2 – 27.1 psu	Neutral buoyancy	Nissling et al. (2002a)

Spawning of marine fishes with pelagic eggs in the Baltic Sea is, due to low saline surface water, primarily restricted to the deep basins. Conditions for successful reproduction in the deep basins are thus governed by the highly irregular inflow events, and those very variable spawning conditions have implications for recruitment and stock development.

Pelagic fish eggs usually float in water layers with sufficient oxygen conditions. However, pelagic fish eggs in the Baltic Sea faces special conditions related to their brackish environment. The reduced salinity conditions lead to heterogeneous distribution of eggs which float in the layers with appropriate density (salinity) conditions. Therefore, particular attention has been paid to the exact position of the eggs in the water column since large parts of the bottom layers have low, reduced or even oxygen-free conditions. Small deviations from the usual neutral buoyancy of the eggs may lead to passive transport to potential negative conditions (oxygenation, sea bottom).

The buoyancy of pelagic cod, flounder and plaice eggs in the western Baltic Sea were analysed as a part of this impact assessment. A sediment dose-response experiment was conducted in relation to these analyses. For further details on the results of the dose-response experiment see chapter 4.3.2.1.

Egg buoyancy/density

Even small changes in density will cause objects to sink and thus especially pelagic eggs are vulnerable to changes in density and buoyancy. For winter and spring spawning species in Fehmarnbelt the danger of sinking is primarely to hit the sea bottom while summer and early autumn spawners might as well be encountered by anoxic water layers before hitting the bottom.

The neutral buoyancy of pelagic eggs varies between species, individuals of different size/age, seasons and even between different locations. The egg density among eastern Baltic cod is for example smaller than among western Baltic cod adapted for the different saline regimes in the two waters (Nissling, et al., 1997), but even seasonal differences in egg densities has been found for instance among sprat in the Baltic (Nissling, et al., 2003; Petereit, et al., 2009). Among flatfish dab and flounder have also adapted to the lower salinity in the Baltic Sea and enabled their eggs to stay floating by taking up more water. This means that the eggs are larger the further into the Baltic Sea from Øresund. The eggs of plaice are only marginally larger compared to the North Sea and turbot do not seem to have this adaptation at all (Florin, 2005).

Table 4.3 gives an overview of density measurements of cod and flatfish eggs fertilized immediately after catch of parental fish from northern Kiel Bight in 2011. The egg densities corresponded to neutral buoyancy at psu (at 8 ^{o}C) from 17.6 psu for plaice over 18.9 for cod to 20.7 psu for flounder. Among cod eggs there were a marked increase in the density before hatch, while there were no such trend among flounder and plaice eggs. Salinity at fertilisation had no effect on either cod or plaice egg, while the density among flounder eggs increased with higher salinities. There was no significant trend in egg densities collected in January, February and March among neither species.

Table 4.3: Average density, weight and diameter of eggs from different batches of cod, plaice and flounder from nothern Kiel Bight sampled January-March 2011 and general trend in ontogenetic and seasonal density as well as from low to high incubation salinity (FeBEC, 2011).

Species	Cod	Plaice	Flounder
Egg density (g/cm^3)	1.0148	1.0136	1.0160
Egg density ~ PSU (8 °C)	18.9	17.6	20.7
Egg dry weight (mg)	0.082	0.156	0.039
Egg diameter (mm)	1.43	1.80	1.06
Salinity versus egg density at fertilisation	no coherent pattern	no coherent pattern	increasing density with increasing salinity
Ontogenetic change in egg density	slight decrease until stage III followed by marked increase until hatch	no clear trend	no clear trend
Hatch time at 7.3 °C (h)	312	~400	~192
Seasonality	decreased diameter but no significant trend in density		no clear trend

In summary the hydrological regime can affect a variety of environmental indicators in Baltic Sea:

Atlantic cod
Cod are one of the most ecological and economically important fish species in the Baltic Sea. Cod eggs are pelagic and hydrographic parameters as salinity, temperature and oxygen are important for successful reproduction. Furthermore, the water exchange and current pattern are important for the recruitment success.

The reproductive volume (RV) is defined as the water volume where conditions are suitable for successful egg survival. For the western Baltic cod this is defined by a salinity > 15 psu (threshold for egg fertilisation), oxygen concentration > 2 mg/l and temperature > 2°C (Nissling, et al., 1997). The same temperature and oxygen concentration defines the RV of the eastern Baltic cod stock, but as this stock produce larger, more buoyant eggs a minimum salinity of only 11 psu is required (Plikshs, et al., 1993).

The spawning areas of cod in the western Baltic are located in Kiel Bight, Mecklenburg Bight, Fehmarnbelt and the Arkona Sea (Bleil, et al., 2000; Bleil, et al., 2002; FeBEC, 2013). The sensitivity is high during main spawning season December-March in the western Baltic (FeBEC, 2013) and is progressively delayed towards east ending in July-August in the eastern Baltic Sea.

The hydrographic conditions in the Arkona Basin impact the survival of cod eggs from both the eastern and western Baltic cod stock as they spawn in this area. The magnitude of impact will mainly depend on the amount of salt and oxygen introduced into the bottom waters of the Arkona Basin and the Bornholm Basin. The temperature effects are less clear and most likely minor. Contrary, the hydrography only has a minor impact on cod recruitment west of Fehmarnbelt and Mecklenburg Bight (Vitale, et al., 2008; Hüssy, 2011).

Despite relatively poor conditions for egg survival in later years, a recent increase in recruitment of eastern Baltic cod has been observed. This indicates that hydrographic conditions have a lower impact on recruitment than previously thought. Marine copepods are very important as larval food resource and thus important for the recruitment of cod. Copepods are main food items for larval cod and these are very sensitive to low salinities in the central Baltic. The spatial and temporal match of specific copepods (*Pseudoclalanus acuspes* nauplii) and cod larvae is probably prerequisite for enhanced larval survival. Thus, changes in copepod composition and abundance can affect the survival probability of cod larvae. Knowledge of the importance of food availability for the survival of cod larvae in the western Baltic does not exist. However, the salinity in the western Baltic is higher which indicate that the same pressure does not occur in this area.

Flatfish
The most common flatfish species in the western Baltic Sea are dab, flounder and European plaice. The eggs of these three flatfish species are pelagic and sensitive to hydrographical changes. Additionally, the dispersal of eggs and larvae of these species are sensitive to changes in water exchange and current pattern impacting the recruitment success. Backtracking of eggs from plaice, flounder and dab indicated that possible spawning areas primarily are found in the deeper waters of Fehmarnbelt. Plaice spawns during winter, flounder in spring and dab in spring/summer (Figure 4.2). Thus, the seasonality of sensitivity to hydrological changes differs between the three species.

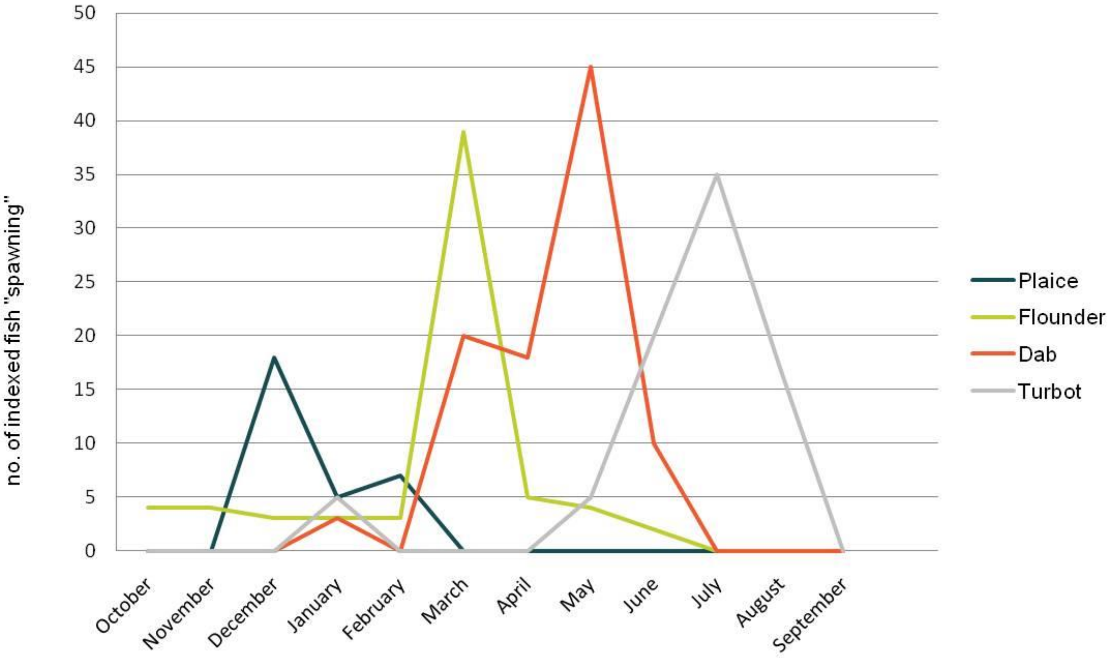


Figure 4.2: An overview of the spawning seasons of the most common flatfish in Fehmarnbelt. The values represent number of investigated fish determined as spawning (maturity stage 4). The fish were caught by a local fisherman and during hydro acoustic surveys. Source: FeBEC (2013).

Dab requires a higher salinity to activate spermatozoa and successfull fertilisation of eggs and to stay buoyant in water layers with suitable oxygen content for egg development compared to plaice and flounder (Nissling, et al., 2002a). Furthermore, dab spawns later in year and the eggs are thus more likely to be exposed to oxygen depleted water occurring during this season.

The choice of spawning areas is based on certain criteria. Important parameters are oxygen, salinity and specific current conditions which influence the drift of eggs and larvae to optimal nursery grounds.

Herring
Historically two major herring stocks have been distinguished in the western Baltic: The Western Baltic Spring Spawning (WBSS) herring, which spawns in February-May in shallow waters (<12-15 m), and the Western Baltic Autumn Spawning (WBAS) herring, which spawns during September-November at greater depths of about 10-20 m. Both stocks are regarded as “open sea stocks”, which undertake annual migrations between the feeding grounds in Skagerrak and the eastern North Sea and the spawning grounds in the western Baltic (ICES, 2007c). In addition to these two major stocks, there is a number of local spring and winter spawning her-

ring stocks that only migrate between local feeding and spawning grounds in the western Baltic Sea.

Herring eggs are benthic and Baltic herring seem to prefer spawning on vegetation rather than on pebbles and stones, although the type of preferred substrate may change over time (Schabell, 1988; Aneer, 1989).

The larval stage can last for several months (Blaxter, et al., 1963) and passive drift may bring juvenile herring to nursery areas far away from their original spawning grounds. In general, herring tend to have their nursery areas in shallow waters such as in bays and fjords, separate from the adults. When herring are approximately two years old they move into deeper waters and join the adults in their feeding and spawning migrations. However, very little is known about the migration from nursery areas to feeding grounds.

Both juveniles and adult herring are primarily pelagic and their distribution is affected by hydrographical features such as temperature, depth of the thermocline, mixing, frontal systems and the abundance and composition of the zooplankton on which they feed.

Since herring eggs are attached to the bottom substrate until hatching they are less affected by horizontal stratification compared to species with pelagic eggs but decrease in oxygen content near bottom will have severe impact on egg survival. Herring eggs are fairly resistant to salinity fluctuations (Klinkhardt, 1996). However, during the baseline study there were very few indications, only from backtracking of few larvae, of spawning areas in Fehmarnbelt. No eggs and a very low number of spent herring were caught during spring (FeBEC, 2013).

Sprat
Sprat and herring are the most commercial and ecological important pelagic fish species in the Baltic Sea (Cardinale, et al., 2000; Arrhenius, et al., 1993). In the Baltic Sea sprat is of key importance as a predator on the zooplankton community but it is also a major prey species for cod, marine birds and mammals (Köster, et al., 2000; Bagge, et al., 1994).

The period between the late larval and early juvenile stage is critical for the sprat recruitment and variables such as ambient temperature and wind stress affects this life stage (Köster, et al., 2003a). The buoyancy of sprat eggs is in general higher than other pelagic fish eggs in the Baltic Sea. Sprat in the Baltic Sea may live near the northern limit of distribution. Thus, sprat in the Baltic Sea is controlled by temperature as the egg mortality increases at temperatures below 5ºC. Furthermore, the gonad development is slow in cold water (Stepputtis, 2006). Thus, they are less affected by oxygen depletion in the deep water but sensitive to low temperatures.

However, the gravity of sprat eggs decrease throughout the spawning season. During the early spawning season eggs are mainly distributed in the deep layers whereas they occur in and above the halocline during peak spawning. In the end of the spawning season they occur above the halocline. The mean density of sprat eggs in the eastern Baltic Sea during the main spawning period was 1.009 g/cm^3 (Nissling, et al., 2003).

Prior to this assessment, studies during the baseline aimed to identify spawning seasons and possible spawning areas. Hotspots of spawning sprat were identified in the deeper parts of Fehmarnbelt, Mecklenburg Bight and the Belt Sea. Sprat eggs are pelagic and the spawning period is from April to August (FeBEC, 2013). As sprat eggs are pelagic the reproduction success and recruitment is sensitive to pressures caused by changes in the hydrological conditions.

European eel
The international protected European eel is included on both the German and Danish Red List (Fricke, et al., 1996; Fricke, et al., 1998; DMU, 2011). Thus, pressure on eel will be of great concern during the present assessment.

The Danish sounds and belts are important passages for the European eel between the Baltic Sea and the North Sea. This applies both to glass eel and elvers arriving from their passage over the Atlantic from the Sargasso Sea, where the European eel is believed to spawn, and to the migration of silver eel back to the spawning grounds.

The importance of Fehmarnbelt as a passageway was studied prior to the assessment, as it is the only major alternative to Øresund as an escapement route for silver eel from the entire hinterland of the Baltic Sea. The results indicate that the choice of migration route of European eel between Øresund and Fehmarnbelt not depend on imprinting during the juvenile stage. The final route may therefore depend on the present conditions regarding water currents and salinity in the Arkona Basin (FeBEC, 2013).

4.1.3 **Pressure indicators**

Marine fish species are affected by the hydrological changes and threshold values can be found in the literature. These values regard primarily eggs and larvae as these life stages are most sensitive to changes in the hydrology. The overall pressure indicators selected for the present impact assessment are mortality of eggs and larvae and decrease in recruitment. The specific assessment is based on potential critical levels of the fertilisation and buoyancy of eggs.

The density of sea water is primarily determined by salinity and temperature and the buoyancy of eggs are thus affected by these parameters. A decrease in the ambient density can thus be critical for the egg survival as the eggs could sink to the bottom or into bottom water layers with critical oxygen concentrations.

The chance of eggs sinking down to either the seabed or below the thermo- or halocline is at minimum determined by:

- Initial egg density, which settles the initial drift water layer
- Salinity gradient between initial drift and bottom water layer
- Concentration and composition of exposure, which determines the rate of density increase
- Duration of exposure, which determines the total density increase
- Spawning time and time between first exposure and hatch

Apart from this local currents/upwellings might temporarily postpone or enhance sinking. Water temperature influences also the density of water and thereby egg buoyancy, but this is minor compared to salinity.

The salinity regime in Fehmarnbelt is highly dynamic as described previously. In the deeper parts of Fehmarnbelt there usually is a distinct stratification in summer with a mixed layer down to 15-19 m depth and average salinity around 11-12 psu at the surface and 26 psu at the bottom (Figure 4.3). In winter there is no definite halocline although the salinity in the years 2009-2010 at the main station in the southern part of Fehmarnbelt (MS02) increased from 14 psu at the surface to 20 psu at the bottom.

The much less saline water at the bottom means that drifting eggs in the winter has a greater risk of sinking to the seabed compared to the situation in the summer. This is particularly the case since the mean bottom water density only is slightly higher than the egg density found in the present assessment. Thus, neutral salinity buoyancy was established at 17.6 psu for plaice, 18.9 psu for cod eggs and 20.7 psu for flounder eggs. All three species spawns primarily in the winter and spring, which means that the eggs are buoyant relatively close to the seabed (Figure 4.3). This is above all the case for flounder eggs, which risks bottom contact about half the time. With only 2-3.5 psu between neutral salinity bouyancy and the bottom water the tolerance towards salinity decrease is also limited among cod and plaice eggs. Particular late in the development the risk raises among cod eggs since the ontogenetic density development showed a marked increase towards hatch reaching a maximum of neutral buoyancy at 21.3 psu.

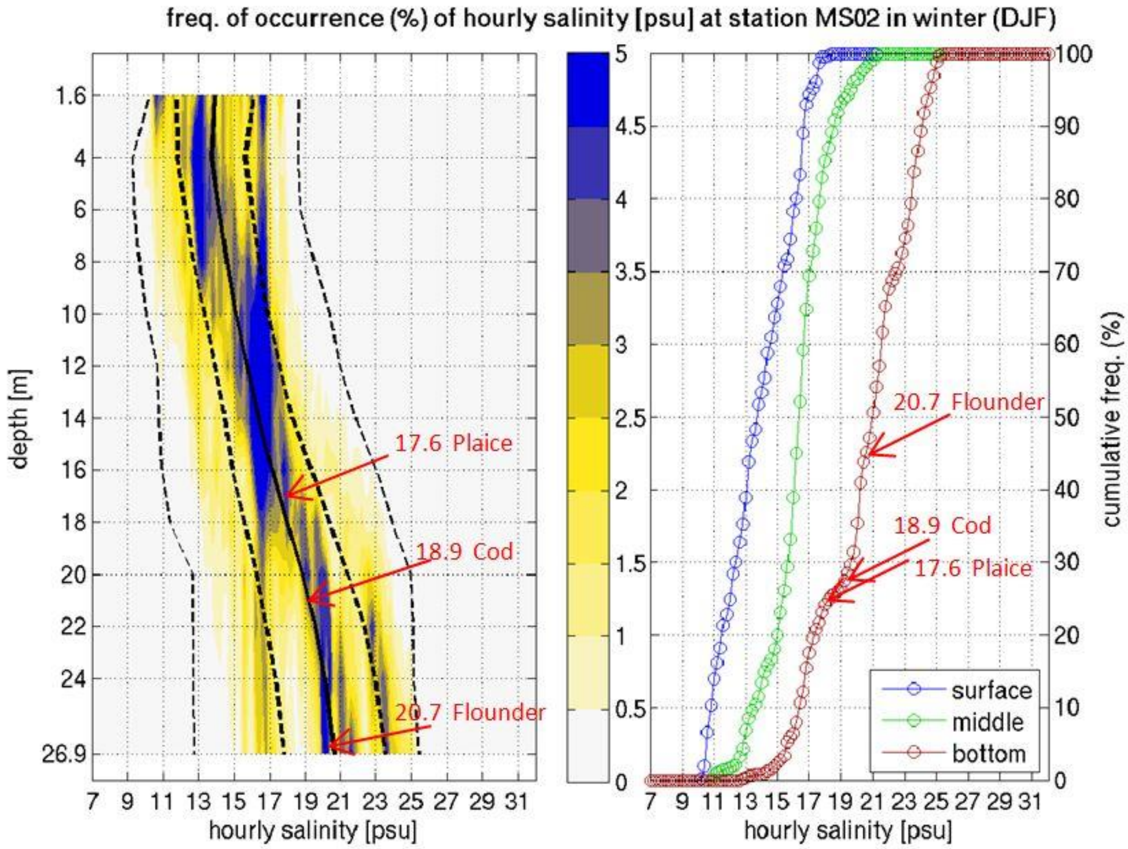


Figure 4.3: Frequency of occurrence (in % of time) of salinity (colour), temperature and buoyancy frequency MS02 in winter. Bold lines: averaged profile, bold dashed lines: averaged profile ± standard deviation, simple dashed lines: all-time minimum and maximum salinity at depth level, –o– : cumulative frequency of occurrence of salinity at uppermost, central and lowest observed depth levels (temperature and salinity interval when calculating percentage is 0.2 psu). Source: FEHY (2013b). Red figures correspond to salinities of neutral egg buoyancy found by experimental trials of plaice, cod and flounder to the present assessment, FeBEC.

Among fish species spawning later in the season the likelihood of hitting the seabed presumably diminishes along with stratification of the water column and higher salinities in the bottom. Flounder may for example spawn well in to May, where the salinity is in the range 24-25 psu at the bottom (Figure 4.5). Regarding other flatfish present in Fehmarnbelt the numerous dab has its peak spawning time in April-June, while turbot represents the latest spawner typically going from June until August (Figure 4.2). In these months the average salinity at Fehmarnbelt light vessel in the years from 1965-85 were in the range 25-28 psu which enhances the tolerance margin towards getting heavier, given that the egg density are in the same range as among plaice and flounder.

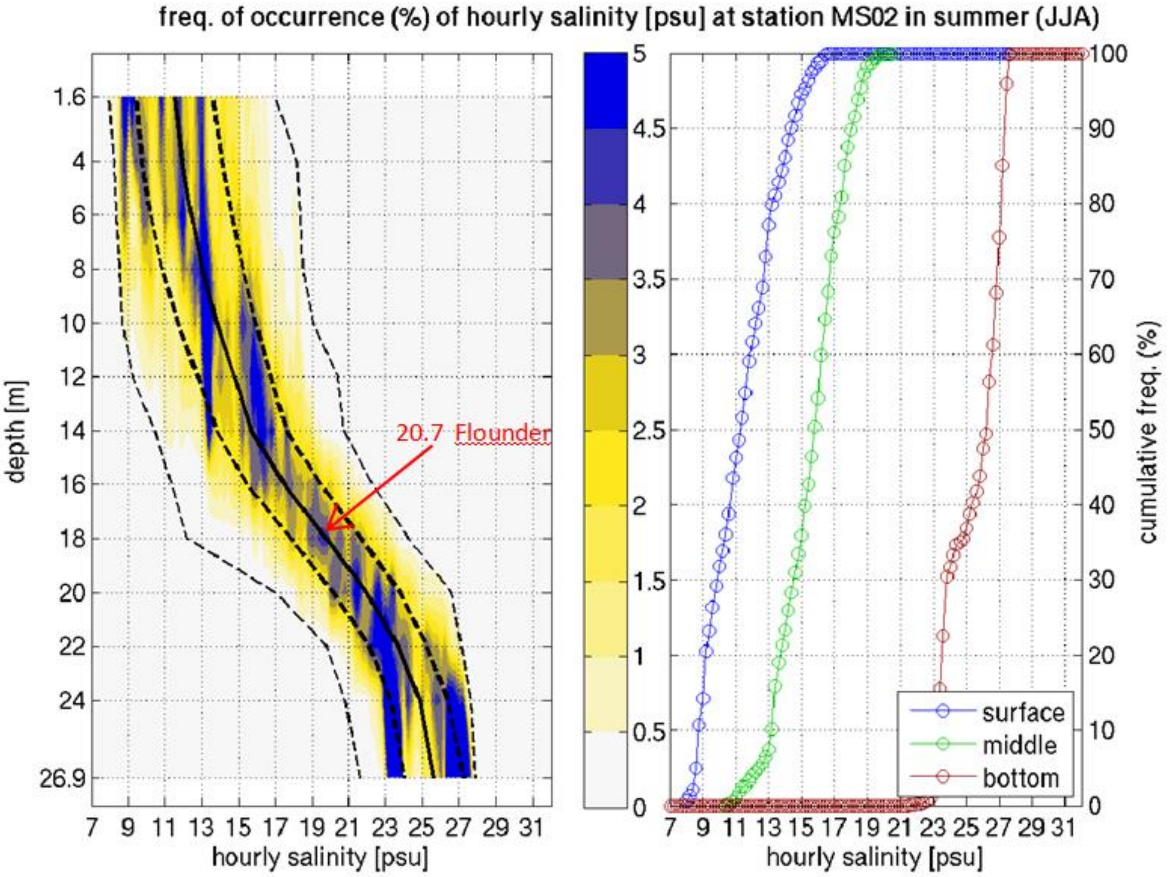


Figure 4.4: Frequency of occurrence (in % of time) of salinity (colour), temperature and buoyancy frequency MS02 in summer. Bold lines: averaged profile, bold dashed lines: averaged profile ± standard deviation, simple dashed lines: all-time minimum and maximum salinity at depth level, –o– : cumulative frequency of occurrence of salinity at uppermost, central and lowest observed depth levels (temperature and salinity interval when calculating percentage is 0.2 psu). Source: FEHY (2013b). Red figures correspond to neutral egg buoyancy found by experimental trials of plaice, cod and flounder to the present assessment, FeBEC.

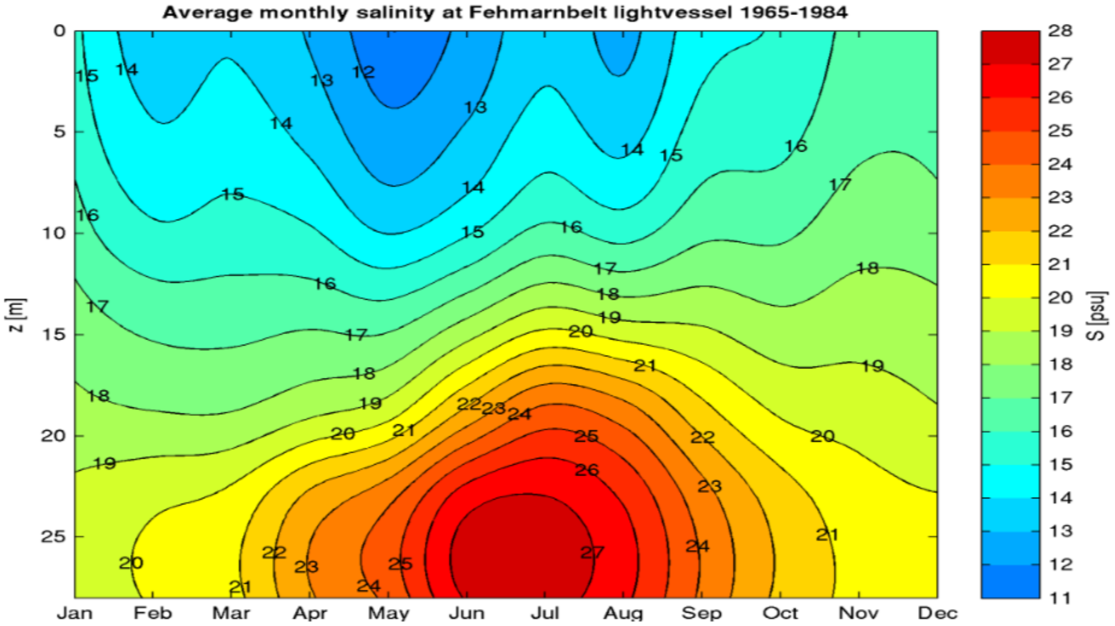


Figure 4.5: The yearly salinity variation at Fehmarnbelt light-vessel redrawn after Lange et al. (1991). Source: FEHY (2013b).

However, at the same time deoxygentation starts to develop and the risk of facing critical oxygen levels in the bottom water arises. In 2010 oxygen concentrations in the bottom water were for example below the critical 2 mg/l in most of the summer going from mid June until mid October. These critical levels were found at salinities greater than 26 psu and below 24 psu the oxygen concentrations were in general below 4 mg/l (Figure 4.6).

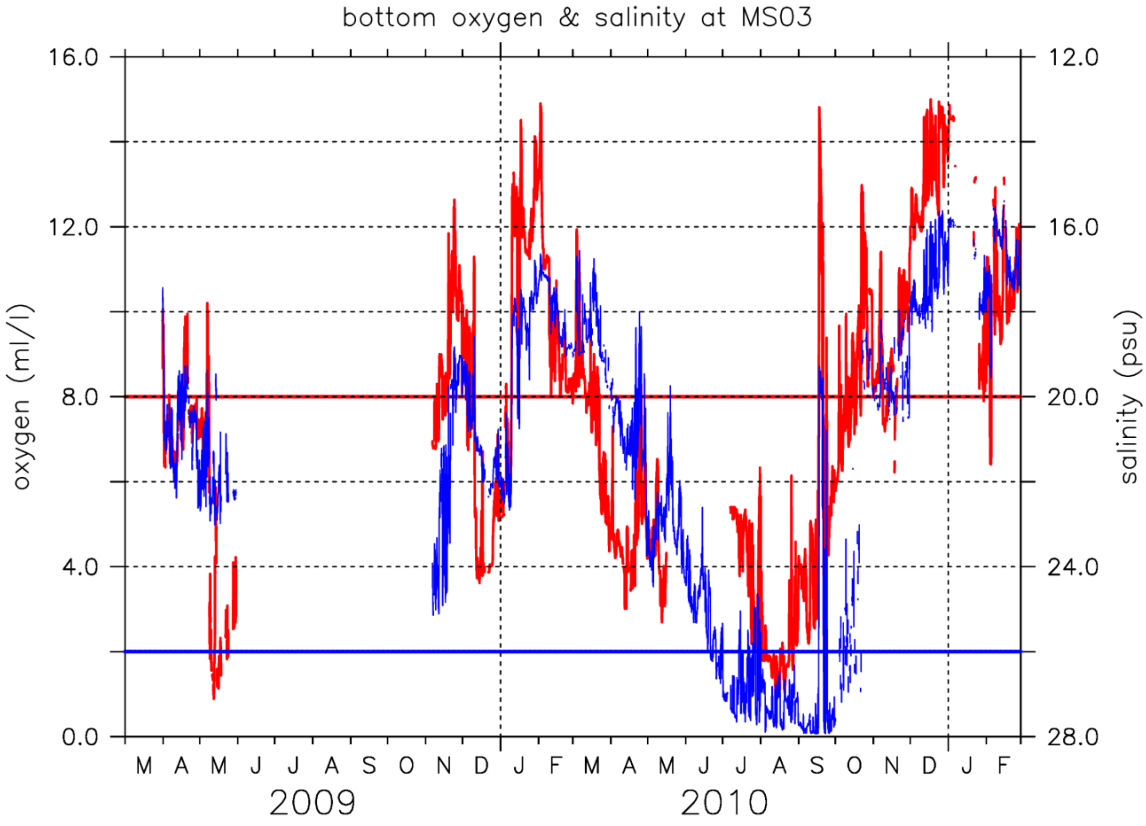


Figure 4.6: Bottom oxygen (blue) and salinity (red) at station MS03 observed during the 2009-2011 baseline period. Source: FEHY (2013b).

The threshold values used in the present assessment in relation to the hydrological regime is based on the salinities listed in

Table 4.4: Threshold values regarding salinity selected for the assessment of pressures from the hydrological regime. (-) indicates no relevans of assessment in Fehmarnbelt.

Environmental indicators (salinity, psu)	Spawning	Egg-larvae drift	Nursery	Feeding	Migration
Atlantic cod	15	18,9			
Whiting	-	-			
Herring					
European sprat	4	14			
Flatfish	11	17,6-20,7			
Shallow water species					
Protected species:					
European eel	-	-			
Sea stickleback					
Snake blenny					

4.2 Seabed reclamation

Physical structures in relation to offshore projects can inhibit the utilization of habitats. The area of suitable habitats for spawning, nursery and feeding can be reduced. Furthermore, the transport of eggs and larvae and the migration can be affected by seabed reclamation due to barrier effect. On the other hand, physical structures tend to attract several fish species and can act as an artificial reef.

4.2.1 Environmental indicators

Environmental components and indicators, which are assessed in the EIS in relation to seabed reclamation, are specified in Table 4.5.

The most important fish stocks occuring in the Fehmarnbelt area are cod, flatfish, sprat and spring spawning herring. Especially cod uses Fehmarnbelt as spawning area. The current based transport of cod larvae from this spawning area to the central and eastern parts of the Baltic Sea is generally considered to be important for the recruitment of the eastern Baltic cod stock. However, the results of a recent study contradict earlier findings and indicate that there is no transport of eggs and early stage larvae towards east (see 7.1.1 and Köster et al., 2011). Fehmarnbelt is also an important area for sprat with respect to their natural life cycle. They spawn in deep parts of the Baltic Sea and afterwards the eggs and larvae drift into shallow water areas where they mature, including the Fehmarnbelt.

The shallow water areas of Fehmarnbelt are in general essential spawning and nursery areas for some economic (e.g. flatfish) and ecological (shallow water species) important fish species. The vegetated habitats along the coast of Fehmarn and Lolland are important for species which are substrate-spawners frequently practicing brood care. The existence of high-quality nursery grounds is a significant factor for the preservation and stabilisation of fish species which are exploited by fishery and fish species which are restricted to specific habitat types. These vegetated areas are also important feeding grounds for many other fish species. On the other hand the non-vegetated, sandy areas are also essential feeding and nursery grounds, especially for ground-dwelling fish species such as flatfish (at all life stages).

Many fish species use Fehmarnbelt area as a transit area. Cod for example is known to migrate long distances between spawning and feeding areas. Also the spring- and autumn spawning herring uses Fehmarnbelt as a transit area for migrating to and from their main spawning grounds around the island Rügen. However, actual studies show that spawning activities of herring in Fehmarnbelt is very low or even none existing. Knowledge on the exact migration routes and the occurrence of European eel in the western Baltic Sea are limited. However, recent tagging studies during the baseline investigation indicates that up to 30 % of the silver eel migrates through Fehmarnbelt. Whereas Øresund seems to be the most important migration route (FeBEC, 2013).

Based on the footprints of the tunnel alternative permanent habitat loss will occur especially in the coastal regions of Lolland and Fehmarn. Therefore loss of habitat particularly affects fish species which use these shallow water areas for different purposes. These habitats are important for reproduction and feeding, especially for fish species which entire life cycle are closely related to these kinds of habitat types (e.g. sea stickleback).

Table 4.5: Overview of environmental components and indicators that are assessed. (*included FFH-annex II species: River lamprey, twaite shad, European sturgeon and Red listed species: Atlantic salmon, sea trout).

Environmental indicators	Spawning	Egg-larvae drift	Nursery	Feeding	Migration
Atlantic cod	x	x	x	x	-
Whiting	-	-	x	x	x
Herring	x	x	x	x	x
European sprat	x	x	x	x	x
Flatfish	x	x	x	x	x
Shallow water species	x	x	x	x	-
Protected species*:	-	-	-	-	x
European eel	-	-	x	x	x
Redlisted species					
Sea stickleback	x	x	x	x	-
Snake blenny	x	x	x	x	-

4.2.2 Sensitivity to pressure

In general, permanent or temporary habitat loss is one of the greatest threats for a species and is often associated with a permanent or temporary reduction of the population size. The extent of the reduction of population size is mainly determined by spatial (= area) and temporal extent (= timing and duration) of habitat loss. The sensitivity to habitat loss varies highly between species and their life stages due to their different habitat requirements and spawning seasons (see Table 4.6).

Many fish species are affected directly or indirectly by the loss of habitat. For cod, whiting and flatfish especially their juvenile life stages are affected because the structured habitats at the coastal waters of Lolland and Fehmarn are important nursery areas. An effect on the environmental indicators spawning and egg/larvae-drift is not likely because these life stages take place in the pelagic zone which is not affected by habitat loss. For the substrate-spawning species herring, a loss of vegetated habitat within the near-shore area of Fehmarnbelt would be severe, but no spawning sites of herring were identified during the baseline investigations in the area of the planned Fehmarnbelt fixed link. The main disturbance based on habitat loss is expected for the shallow water communities. Based on habitat loss, the highest impact is predicted for the shallow water species. Depending on the environmental indicator, these species have habitat preferences. Regarding these species, it is decisive what habitats are temporally or permanently lost. The area of the alignment corridor is not relevant to shallow water species. Based on the project footprints, these areas are dominated by sandy habitats with low coverage of vegetation. These poorly structured areas are of low importance for spawning and egg/larvae-drift of the former mentioned fish species. Many shallow water fish species are substrate-spawners and practicing brood care, i.e. they are associated to highly structured habitats. However, the affected areas are important feeding areas.

Table 4.6: Overview of the sensitivity of pressures in relation to the environmental components.

Environmental component	Life stage	Impact	Effect
Cod	Egg	not relevant	No habitat loss.
	Larvae	not relevant	No habitat loss.
	Juvenile	Loss of nursery ground.	Habitat loss. Avoidance behaviour.
	Adult	Loss of feeding ground.	Habitat loss. Avoidance behaviour.
Whiting	Egg	not relevant	No habitat loss.
	Larvae	not relevant	No habitat loss.
	Juvenile	Loss of nursery ground.	Habitat loss. Avoidance behaviour.
	Adult	Loss of feeding ground.	Habitat loss. Avoidance behaviour.
Herring	Egg	Loss of spawning ground.	Habitat loss. Reduced spawning potential.
	Larvae	not relevant	No habitat loss.
	Juvenile	Loss of nursery ground.	Habitat loss. Avoidance behaviour.
	Adult	Loss of feeding ground.	Habitat loss. Avoidance behaviour.
European sprat	Egg	not relevant	No habitat loss.
	Larvae	not relevant	No habitat loss.
	Juvenile	Loss of nursery ground.	Habitat loss. Avoidance behaviour.
	Adult	Loss of feeding ground.	Habitat loss. Avoidance behaviour.
Flatfish	Egg	Not relevant.	No habitat loss.
	Larvae	Not relevant.	No habitat loss.
	Juvenile	Loss of nursery ground.	Habitat loss. Avoidance behaviour.
	Adult	Loss of feeding ground.	Habitat loss. Avoidance behaviour.
Shallow water species	Egg	Loss of spawning ground.	Habitat loss. Reduced spawning potential.
	Larvae	Loss of nursery ground.	Habitat loss. Reduced recruitment.
	Juvenile	Loss of nursery ground.	Habitat loss. Reduced recruitment.
	Adult	Loss of feeding ground.	Habitat loss. Avoidance behaviour.
Protected species	Egg	not relevant	not relevant
	Larvae	not relevant	not relevant
	Juvenile	not relevant	not relevant
	Adult	Loss of feeding ground.	Habitat loss. Avoidance behaviour.
European eel	Egg	not relevant	No habitat loss.
	Larvae	not relevant	No habitat loss.
	Juvenile	Loss of nursery ground.	Habitat loss. Avoidance behaviour.
	Adult	Loss of feeding ground.	Habitat loss. Avoidance behaviour.
Sea stickleback	Egg	Loss of spawning ground.	Habitat loss. Reduced spawning potential.
	Larvae	Loss of nursery ground.	Habitat loss. Reduced recruitment.
	Juvenile	Loss of nursery ground.	Habitat loss. Reduced recruitment.
	Adult	Loss of feeding ground.	Habitat loss. Avoidance behaviour.
Snake blenny	Egg	Loss of spawning ground.	Habitat loss. Reduced spawning potential
	Larvae	not relevent	No habitat loss.
	Juvenile	Loss of nursery ground.	Habitat loss. Avoidance behaviour.
	Adult	Loss of feeding ground.	Habitat loss. Avoidance behaviour.

4.2.3 Pressure indicators

The essential indicators for a significant impact are the extent of temporal and spatial loss of habitat. The degree of impairment results from the magnitude of pressure (like duration, extention, intensity and change in structure/function) in regard to its spatial and temporal extent and is described in chapter 6.2.1.

4.3 Suspended sediment and sedimentation

Suspended sediment and sedimentation is a natural premise for many fish species in various habitats. Increasing marine construction activities and exploitation of the seabed constitutes, however, an ever increasing threat towards fish and fish populations in many waters. Particular the process of dredging and disposing of dredged material causes inevitable spill to the water phase which may have consequences not only for fish but a wide range of biological components (Figure 4.7). Alone the shading of primary production may affect the whole food web, but also most food sources of fish and fish themselves may be affected directly in various ways.

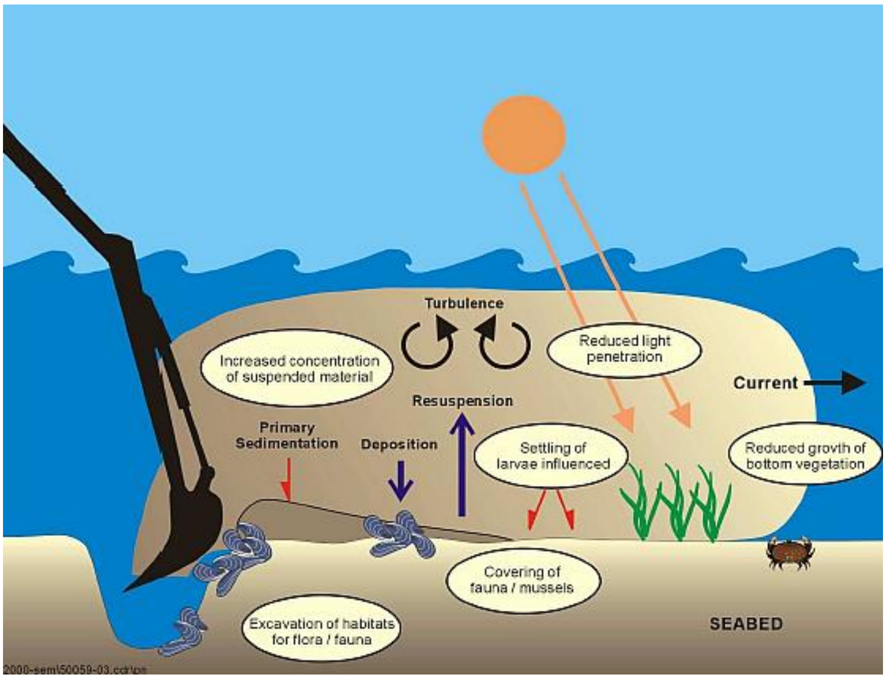


Figure 4.7: Schematic illustration of possible impacts on biological components from marine dredging activities. Source: Jensen (1997).

For example, suspended sediment may adhere to pelagic fish eggs and cause them to sink. Demersal eggs may be harmed by suffocation caused by overloads of settled particles. Fish larvae may be injured one or the other way with reduced growth rates and breeding success as possible effects. Visual feeders, especially planktonic feeders, may be restricted in their feeding and flight behaviour may occur. Coarse particles may lead to skin injuries and fine sediments may clog gills and cause suffocation even among adults. In general the sensitivity is highly influenced by the duration, concentration and composition of the exposure.

Further, indirect impacts affecting fish include all kinds of loss, changes or deteriorations of suitable habitats and food resources affected by sediment exposure.

Among common human activities discharging sediments to the marine environment are mining, trawling, dumping and building of harbours/offshore constructions. However, natural erosion and resuspension often overrules excess concentrations from anthropogenic dredged material. Particular in exposed coastal waters the concentration of suspended sediment may vary significantly from day to day due to varying beating of waves. Overall, both large- and local scale weather patterns, in- and outflow of water between Kattegat and the Baltic Sea and geomorphology are important factors determining the concentration of suspended sediment and deposition in the Fehmarnbelt.

4.3.1 Environmental indicators

Although suspended sediment and sedimentation is a natural characteristic of many habitats most life stages of fish may be affected given certain threshold values are exceeded. Consequently all environmental subcomponents have been selected as indicators to assess sediment spill (Table 4.7). Regarding pressures from suspended sediment this has been done with respect to egg and larvae drift, nursery, feeding and migration life stages while sedimentation/deposition has focused on benthic spawning among herring, shallow water species snake blenny and sea stickleback. Among shallow water species the pressure of suspended sediment towards egg and larvae drift has, however, not been assessed, since most of the species are benthic spawners and in addition has various strategies to protect eggs and larvae.

Indirect impacts caused by sediment spill on fish habitats and food items are likely to have greater consequences for many of the fish species present in Fehmarnbelt than direct impacts. Indirect pressures are generally dealt with seperatly and pooled for all pressures in chapter 6.5. For a number of protected species like salmon, seatrout, lampreys etc. the baseline knowledge of their presence in Fehmarnbelt is not comprehensive enough to make a detailed assessment of impacts from sediment spill.

Table 4.7: Environmental indicators selected for the impact assessment of pressures from suspended sediment (ss) and sedimentation (sed) from the construction and operation of the proposed solutions for the Fehmanbelt Link. (-) indicates no relevans of assessment in Fehmarnbelt.

Environmental indicators	Spawning	Egg-larvae drift	Nursery	Feeding	Migration
Atlantic cod		ss	ss	ss	ss
Whiting		-	ss	ss	ss
Herring	sed	ss	ss	ss	ss
European sprat		ss	ss	ss	ss
Flatfish		ss	ss	ss	ss
Shallow water species	sed		ss	ss	-
Protected species:					ss
European eel	-	-	ss	ss	ss
Sea stickleback	sed		ss	ss	-
Snakeblenny	sed	ss	ss	ss	-

4.3.2 Sensitivity to pressure

The sensitivity of fish to suspended or settled particles varies highly between species and their life stages, and depends on sediment composition, concentration and duration of exposure (Newcombe, et al., 1996). High levels of suspended sediment for a short period of time may be less of a problem than a lower level that persists longer and depending on the exposure the severity of impacts may go from behavioral effects, to sublethal and lethal effects. The figure below shows varying ways fish might be affected.

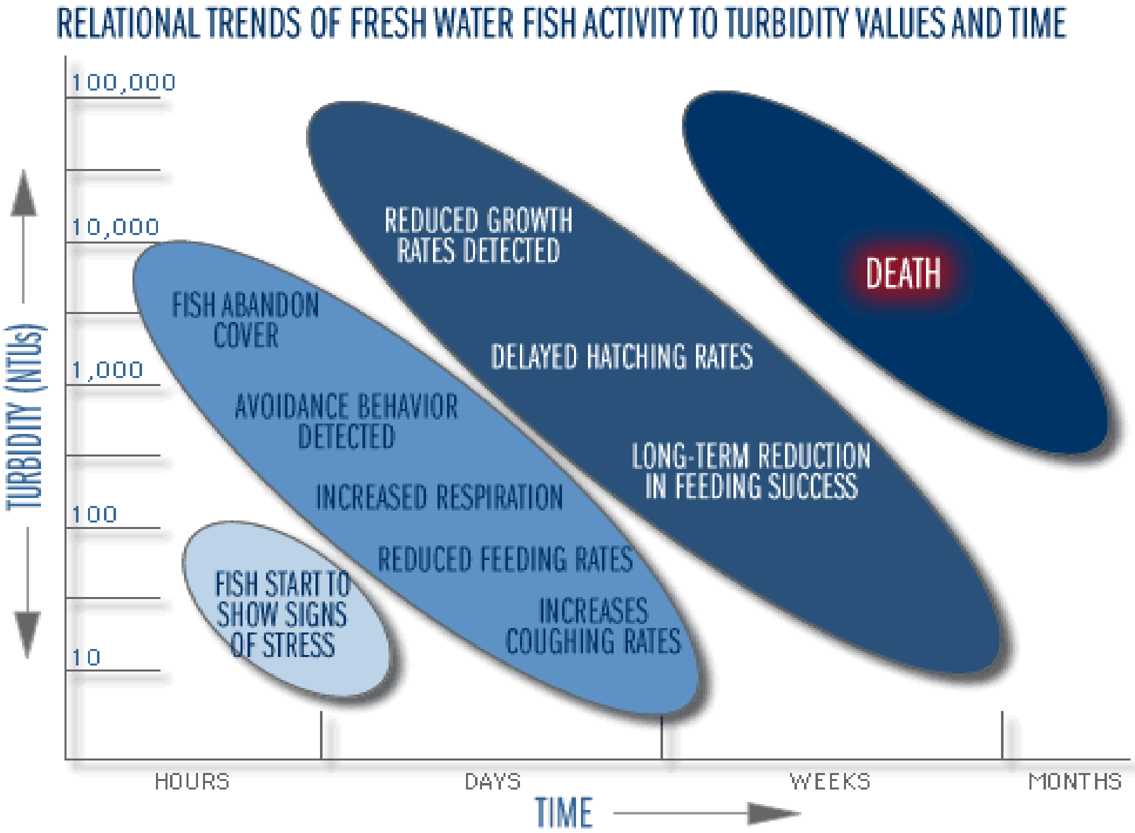


Figure 4.8: Idealized model of fish response to increased suspended sediments. Schematic adapted from "Turbidty: A Water Quality Measure". Source: Newcombe et al. (1996).
http://www.waterontheweb.org/under/waterquality/turbidity.html

In general, early life stages of fish are more vulnerable to sediment plumes than adults presumably because they are more fragile and are often not capable of escaping. Thus, concentrations in the range of milligrams per litre can be lethal for eggs and larvae, while for juveniles and adults this effect is not to be expected below concentrations of grams per litre (Engell-Sørensen, et al., 2002). This overall trend is indicated in accumulated data from studies of estuarine and coastal fish from the American continent shown in Figure 4.9 (Clarke, et al., 2000) and separate attention has therefore been given to the sensitivity among early respectively adult life stages.

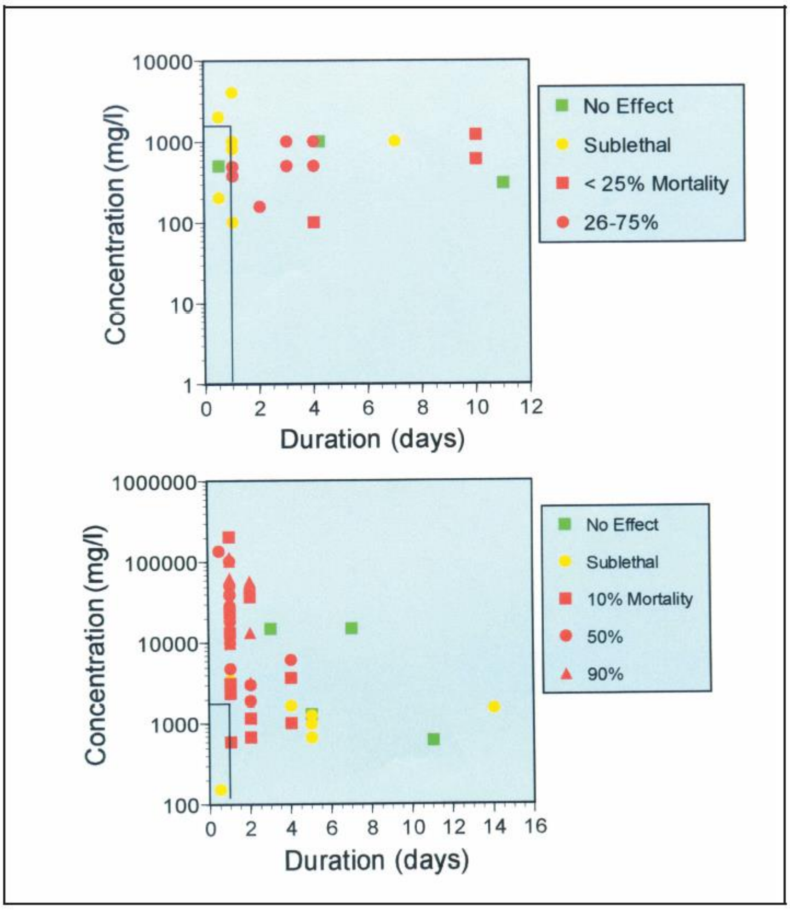


Figure 4.9: Responses of estuarine and anadromous fish eggs and larvae (top) and adults (bottom) to suspended sediment concentrations at the given dosages. The area within the rectangles depicts a probable dosage range associated with most dredging operations. Source: Clark and Wilber (2000).

4.3.2.1 Sensitivity of eggs and larvae

Both pelagic and benthic eggs as well as yolk sac larvae are practically abandoned to overloads of particles in the water and the adherence of particles to the surface of the eggs or the skin of larvae may have severe consequences. Small density increments invokes eggs to sink which becomes even more critical when neutral egg buoyancy is close to the sea bottom as in Fehmarnbelt for several species (see section 4.1.2). To this may be added that the sediment itself might physically damage the eggs or the larvae, and particularly benthic eggs are in danger being potentially exposed to both suspended sediment and sedimentation.

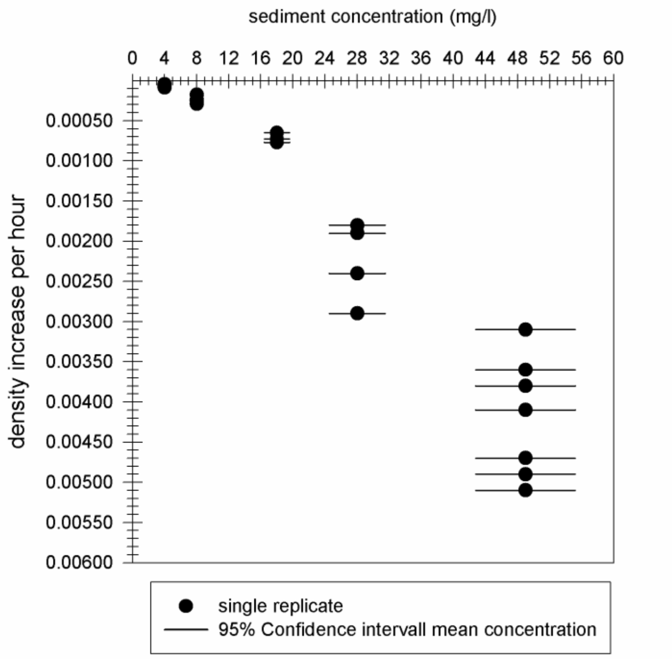
Dose-response experiments

As a part of the present impact assessment dose-response experiments of effects of sediment spill on eggs and larvae were performed. Species in focus were cod and herring as models for respective pelagic and benthic spawning species, but also effects on eggs and larvae from plaice and flounder were studied. Further details can be found in FeBEC (2010) and FeBEC (2011). Selected results of the experiments are summarised in the following:

Egg buoyancy/density

The buoyancy of cod eggs exposed to 4, 8, 18, 28 and 49 mg/l sediment concentrations decreased almost linearly with increased load (Figure 4.10). The relation was determined as the log10 density increase of a cod egg per hour = 1.6483 (±0.04 S.E.) * log (dry weight sediment concentration) -5.1372 (±0.05 S.E.). The function was determined for specific Fehmarnbelt fine sediment and used in the present assessment to determine a threshold value for the tolerance of pelagic eggs towards suspended sediment.

Figure 4.10: Cod egg buoyancy decrease per hour during exposition to 5 defined sediment concentrations (dry weight). Each dot reflects the density increase of one single replicate (one column) which contained >30 individual eggs. The bars show the 95% confidence interval of each respective concentration. Source: FeBEC (2010).



Hatch rate/egg mortality

As shown in Table 4.8 exposure of sediment loads in concentrations up to 1000 mg/l had only few significant impacts on the survival and overall fitness of eggs and larvae hatched from exposed eggs among cod and flounder. In the few cases, where significant differences could be detected, there were no clear trends in the results.

Table 4.8: Results from dose-response experiments with sediment spill on fertilization rate, egg mortality, hatch rate and larval condition among eggs of cod, flounder and herring.

Sediment exposure of eggs (5-1000 mg/l)	Cod	Flounder	Herring
Fertilisation rate			500 and 1000 mg/l coarse sediment decreased rate significantly
Egg mortality	n.s. But more eggs survived in the sediment free treatments	n.s. But more eggs survived in the sediment free treatments	n.s
Hatch rate	n.s. But hatch rate was higher in the sediment free treatments	n.s. But hatch rate was higher in the sediment free treatments	Only 1000 mg/l coarse sediment decreased rate significantly
Larvae dry weight (DW)	n.s.	no clear trend	no clear trend
Larvae length (SL)	n.s.	no clear trend	n.s. But descending trend in SL with coarse sediment
Larvae RNA:DNA	n.s.	n.s.	

Herring eggs exposed during the fertilization process (either 15 min or 120 min), however, showed signifcant reduced egg fertilization rates at 500 and 1000 mg/l coarse sediment load. Figure 4.11 shows clearly adherence of coarse sediment on the herring eggs, but also fine sediment can be seen on the surface. Although not significant the fertilization rate at high concentrations of fine sediment also decreased. In addition, herring larval hatch rate was statistically reduced at 1000 mg/l concentration of the coarse sediment type.

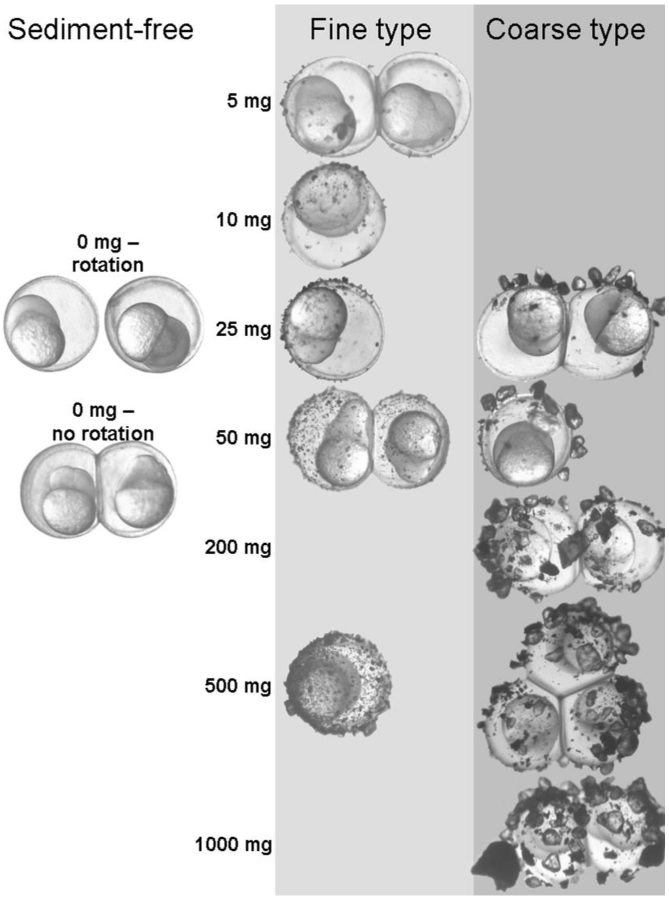


Figure 4.11: Herring egg chorion appearance after 15-minute sediment exposure to different sediment types and different sediment concentrations (mg/l) and subsequent 24-hour sediment-free incubation at 8°C. Source: FeBEC (2010).

In contrast, fertilized herring eggs attached to artificial seagrass and exposed to 0, 5, 10 or 50 mg/l fine sediment for 1, 2 or 14 days showed no significant effect in overall embryo and larval survival rate. In addition, herring larvae exposed to seven concentrations in the range 5-1000 mg/l (coarse and fine sediment) did not lead to increased ad hoc mortality of herring larvae. Nevertheless, high concentrations of fine particulate sediments may have caused a clogging or a partial restriction of the mouth opening. A 24-hour exposition to constant sediment concentrations (25 mg/l) showed likewise no coherent results with respect to heartbeats as a measure of vital functions. A continuously increasing proportion of larvae with sediment particles in the head and mouth region were though observed. Even though possible derogations due to particles in the mouth could not be followed until first feeding stage, it seems most unlikely that these particles can be disgorged or do not interact with successful feeding.

Egg- and larvae suspended sediment literature review

Auld et al. (1978) conducted laboratory experiments to determine how suspended clays, a common source of turbidity in estuaries or due to spilling or dredging works, affected hatching success of eggs and six species of anadromous and estuarine fish. They found no deleterious effects at concentrations up to 500 mg silt/l, and a reduced hatching success in two of the species at a concentration of 1000 mg/l.

Kiørboe, et al. (1981) performed herring exposure experiments with different constant concentrations of suspended silt (5-300 mg/l) or a short-term high concentration (500 mg/l) at different times during embryonic development and found embryonic development unaffected by suspended silt. They stated that "as far as suspended particles are concerned, no harmful effects of dredging to herring spawning grounds are likely to occur".

Recent experiments (Griffin, et al., 2009) with Pacific herring (*Clupea pallasi*) eggs exposed to dredged suspended sediments indicated sublethal and lethal effects of 250 or 500 mg/l in the course of the first hours post fertilization due to increased self-aggregation of the eggs. During the first two hours after the eggs got contact with water, a high adhesiveness could be found which led to permanent attachment of sediment particles to the chorion. However, after two hours the membrane became non-adhesive and no effects could be observed on fertilization and larval hatch rates although precocious hatch and a higher amount of abnormal larvae was found.

Isono et al. (1998) analysed the impact of suspended kaolinite on eggs and early larval stages of four marine fish species under five concentrations in the range from 32-10,000 mg/l. They found no significant effect on hatching success or developmental rates at a maximum suspension of 10,000 mg/l for 24 h. However, short-term exposure (1, 3, 12 h) lead to 50 % egg mortality at a concentration of 1000 mg/l after 12 h and a change in appearance of egg colour from clear to white due to adhesion of kaolinite particles onto the egg surface was observed. They considered this phenomenon to reduced buoyancy and tested this assumption by exposing eggs to different kaolinite suspension in small tubes, where an increase in settled eggs was observed with increased suspension concentration. Above concentrations of 350 mg/l a significant amount of eggs from two analysed species was settled and at the maximum of 10,000 mg/l they observed a complete settlement of all eggs. They put forward that particle adherence may lead to serious insufficient oxygen condition if eggs get completely covered with sediments under stagnant water conditions.

Fish larvae tend to be more sensitive to suspended sediments than fish eggs of the same species (Engell-Sørensen, et al., 2002). This has been proven in tests with cod larvae and cod eggs which were simultaneously exposed to the same test conditions. Thus Rönnbäck et al. (1996) found that cod larval mortality was about three times higher than egg mortality. Already at concentrations of 10 mg/l they observed significantly increased mortality rates among cod larvae.

At the end of the yolk sac stage most fish larvae start to prey on small zooplankton organisms and the larvae of many fish species use sight for food searching. Fish larvae can not survive starvation for more than a few days before they are too weak to feed. Several laboratory studies suggest that feeding success in fish larvae can be affected by the interaction between light intensity and turbidity (Johnston et al., 1982; Boehlert et al., 1985; Phillips et al., 1996). Blaxter (1966) demonstrated that light is required and that the time available per day for feeding varies greatly with season and lattitude.

Among herring larvae it is only after metamorphosis that rods develop in the retina and that the retinal pigment starts to show its characteristic responses to changes in light intensity (Blaxter, 1968). Thus for a period of some months the larva feeds, avoids predators, and performs limited vertical migrations without the full adult visual equipment. However, reduced ingestion rates of Atlantic herring larvae were found by Johnston and Wildish (1981) at suspension rates of 20 mg/l. Furthermore, they found a correlation between the impact intensity and the age of the larvae. The smaller the larva the stronger was the impact. On the other hand Utne-Palm (2004, in Ogle, 2005) found an increase in prey attack rates among Atlantic herring larvae at intermediate turbidity (35 JTU), although the attacks decreased at higher turbidity (80 JTU) (2004, in Ogle, 2005). Increase in the percentage of fish that fed has also been reported by (Boehlert, et al., 1985) among Pacific herring larvae at suspended sediment concentrations in the range 500-1000 mg/l. Ingestion rates decreased first at 2000 mg/l.

Larvae of species like anchovy, plaice, sole, turbot and cod sight their prey at a distance of only a few millimetres (usually less than one body length) (Bone et al., 1995 in Engell-Sørensen et al., 2001). Blaxter (1969) found that sole larvae could feed in the dark from the early post-hatching stage, while plaice larvae only at metamorphosis. Thus light intensity thresholds for feeding were only determinable in younger plaice larvae (Blaxter, 1969).
Reduced growth rates and direct mortality among herring larvae has been reported for a varying range of concentrations. Thus Boehlert et al. (1985) found no effect on survival among herring larvae at concentrations up to 8000 mg/l while Hansson (1995) found lethal consequences among herring larvae at particle concentrations of > 100 mg/l. Messieh et al. (1981) found significantly reduced growth rates at sediment concentrations of 540 mg/l and 100 % mortality at 19 g/l and an exposure time of 48 hours.

Table 4.9 summarises selected threshold concentrations found in literature of suspended sediment impacting eggs- and larvae of species included in the present assessment.

4.3.2.2 Sensitivity of juveniles and adults

A fundamental difference between fish eggs/yolk sac larvae and juveniles/adults is mobility, i.e. the capacity to swim. It is reasonable to presume that most fish capable of swimming moves away if conditions deteriorate, and therefore sediment spill, unless in the absolute vicinity of the mechanical excavation itself, probably seldom has direct lethal consequences among juveniles and adults. Low visibilities may however disrupt feeding before avoidance takes place and when avoidance is not possible dosages in excess may cause clogging of gills, skin injuries and possible also death among vulnerable species.

Exclusion from a particular habitat, whether this is a permanent residence or a spawning/feeding area, may have serious consequences depending on the exclusiveness of the habitat for the specific species and the duration of the exclusion. Detoriation of habitats and food sources caused by impacts from suspended sediments represents most likely the most serious threats towards most juvenile and adult fish.

Avoidance behaviour
Atlantic cod and herring have been recorded to display avoidance behaviour when encountering sediment plumes of equally sized particles of clay or lime concentrations of between 2 mg/l and 8-9 mg/l, where the background concentration of suspended matter was less than 0.4 mg/l (Appelberg, et al., 2005). When cod was exposed to the plume during night, the response was noted, which meant that there was a non-visual component in the response, and avoidance was not based on seeing the plume but by an excursion through it.

For salmons evasive movements are proved at significantly higher sediment concentrations (> 100 mg/l) and exposure times (one hour) (Newcombe et al., 1991 in: Keller et al., 2006). Lethal effects are documented by the authors at concentrations from 1 - 49 g/l and exposure times of four days. Plaice (*Pleuronectes platessa*) survived suspensions of 3000 mg/l for a period of fourteen days (Newton 1973 in: Keller, et al., 2006). Erman and Lignon (1988) (in: Kerr 1995) found that the number of three-spined stickleback and prickly sculpin were significantly reduced in areas exposed to a frequent flow of water laden with fine sediments.

In general the pelagic is a more unspecific and wide spread habitat compared to many benthic habitats. Most pelagic fish species are not tied greatly to a specific area, while many benthic species are resident and even tied to a specific area of a specific habitat. Fleeing may therefore constitute a greater barrier for these fish species. However, it seems also true that many benthic fish in general are more tolerant towards suspended sediment.

Clogging of gills.
If sediment particles deposit in or on the gills, the gas exchange with the water is constrained leading to decreased oxygen transfer (Essink 1999; Clarke et al., 2000). This effect is strong-

est for juvenile fish, since they have smaller gills, so that the openings between the gill arches are more easily clogged or stuck together. Moreover, the metabolism rates of small fish are significantly higher than those of larger fish (oxygen demand/body weight), making them less tolerant to reduced oxygen transfer (Moore, 1978). Clupeideae in particular are vulnerable to gill clogging because of their long, densely-spaced gill-rakers (Engell-Sørensen et al., 2002).

Histological analyses of gill lamellae of cod exposed to mud concentrations of 550 mg/l for 24 hour showed acute pathological changes in the form of multifocal degenerative lesions (Humborstad et al., 2006). After five days of exposure adaptive changes to cope with the turbid environment were observed comprising hypertrophy and hyperplasia of the gill epithelium which became more marked after ten days exposure. No mortality was observed in any of the experimental groups.

Reduced visibility
The degree to which visual predators are hindered by increased turbidity is determined by several factors. Some of these are related to the predator itself, e.g. different light threshold and resolutions of the fish eye in juvenile and adult specimens. Other factors relate to the prey size and enhanced escape chances in more turbid water (de Jonge et al., 1993). Also the prey may be affected by decreased visibility. Thus, increased turbidity and predator attack speed was found to reduce the escape success among juvenile cod in laboratory experiments (Meager et al., 2006). Changes in water clarity have also been claimed to affect the schooling ability of species such as herring and other clupeids using visual schooling cues (Blaxter and Parrish 1965 cited in: Appleby, et al., 1989). Presumably, sight-dependent schoolers lose track of each other when water clarity is reduced.

Habitat alteration
The substrate of a preferred habitat can be highly altered by substrate removal or by sedimentation affecting particularly species that depend on certain bottom substrates for nursery, spawning and feeding. Moles and Norcross (1995) found a strong selection for different grain size and sediment type among juveniles of four flatfish species. They also found that none of the species selected sediments as granular and pebbles, which were too coarse to allow the flatfishes to bury themselves. Sandeels spend long periods at night and during winter buried in the sea floor and various studies have shown they prefer mainly sandy substrates with medium to very coarse grain sizes (0.25- 1.2 mm) while mud and silt and medium to coarse sand as well as stones are avoided (Jensen, 2001; Wright, et al., 2000; Macer, 1966; Pinto et al., 1984; Reay, 1970; Scott 1973, all cited in: Jensen, et al., 2003).

A change in sediment composition can also negatively affect reproduction success (ICES, 2001). Thus, various studies have shown that changes in sediment that serve as spawning grounds either prevent fish from spawning or cause them to lay their eggs in less adequate areas (de Groot, 1980). This might especially be true for species as herring whose complex demands on the spawning habitat are mostly met locally on smaller areas (Kiørboe, et al., 1981).

In Table 4.9 selected threshold concentrations found in literature of suspended sediment impacting juveniles and adults of species included in the present assessment is shown.

Table 4.9: Literature threshold concentrations of suspended sediment, sedimentation and turbidity impacting the life stages of the environmental components.

Species	Life stage	Threshold concentration/sedimentation	Effect	Reference
Herring	Egg	250 or 500 mg/l	Increased and lethal effects on eggs the first 2 h after hatching. After 2 h no increases in precocious larval hatch and higher percentages of abnormal larvae and larval mortality.	Griffin et al. (2009)
	Egg	5-300 mg/l and short-term 500 mg/l	Embryonic development unaffected	Kiørboe et al. (1981)
	Eyed egg	Thin layer respective 10 mm sedimentation	85 % respective 100 % mortality	Messieh et al. (1981) in Kelly et al. (1986)
	Egg hatch	Up to 7000 mg/l	No deleterious effect on hatching succes	Messieh et al. (1981) in Kelly et al. (1986)
	Post yolk sac larvae	Reduced light intensity	Reduced food intake	Blaxter (1968)
	Post yolk sac larvae	Increased turbidity due to turbulence during tide	No clear negative effect on feeding succes	Fox et al. (1999)
	Larvae	3 mg/l	Reduced feeding rate	Messieh et al. (1981) in Kelly et al. (1986)
	Larvae	540 mg/l	Significantly reduced growth rates	Messieh et al. (1981) in Kelly et al. (1986)
	Juvenile	9-12 mg/l	Avoidance behaviour	Johnston et al. (1981)
	Juvenile	20 mg/l	Reduced feeding rate	Johnston et al. (1982)
	Juvenile	9.5-12 mg/l	Avoidance behaviour	
	Adult	19 mg/l fine sediment (+/- 5 mg) and 35 mg/l coarse sediment (+/- 5 mg)	Avoidance behaviour	Wildish et al. (1977)
	Adult	3-5 mg/l (type)	Avoidance behaviour	Appelberg et al. (2005)
	Adult	3-5 mg/l (type)	Avoidance behaviour	Appelberg et al. (2005)
Cod	Egg	5-40 mg/l	Decreased buoyancy proportional to dosage and duration of exposure	Rönnbäck et al. (1996) Westerberg et al. (1996)
	Egg	100 mg chalk/l (3 days exposure)	Increased mortality	Rönnbäck et al. (1996) Westerberg et al. (1996)
	Egg	200 mg moraine clay/l (3 days exposure)	No significant higher mortality	Rönnbäck et al. (1996) Westerberg et al. (1996)
	Yolk sac larvae	10-40 mg chalk/l (6 days)	Increased mortality	Westerberg et al. (1996)
	Juvenile	Turbidity	No strong effect on habitat preference	Meager et al. (2008)
	Adult	550 mg/l (1d-10d exposure)	No significant mortality but moderate gill lesions that might be reversible.	Humborstad et al. (2006)
	Adult	3-5 mg/l (type)	Avoidance behaviour	Appelberg et al. (2005)
	Adult			
Flatfish	Post yolk sac larvae	Reduced light intensity	Reduced food intake	Blaxter (1969)
	Adult	3000 mg/l	No mortality among plaice during 14 days exposure	Newton in Keller et al. (2006)
Eel	Elvers	1100 NTU	No avoidance response of elvers (australis) up to 1100 NTU	Boubee et al. (1997)
Salmon and sea trout	Adult	1-49 g/l, exposure 4 d	Lethal effects	Newcombe et al. (1991) in Keller et al. (2006)
		100 mg/l, exposure 1 h	Salmon exhibit evasive behaviour 100 mg/l, exposure 1 h	Newcombe et al. (1991) in Keller et al. (2006)
Ninespine stickleback		150 NTU	No avoidance reactions at at two different temperatures	Chiasson (1993)

4.3.3 Pressure indicators

Since the specific life stages of the specific fish species may be affected by sediment in multitude ways, and the literature shows a wide range of threshold values the present assessment has aimed to select some operational pressure indicators based on rather few assumptions. Overall the selection of indicators has distinguished between eggs/larvae and juveniles/adults in the view that juveniles and adults presumably will escape before facing more serious concentrations while drifting eggs- and larvae not are able to do this.

Eggs and larvae
For drifting eggs and yolk sac larvae the threshold value towards suspended sediment is based on a potential critical level for density increase causing sinking to the sea bottom or, with critical oxygen levels in the bottom water layers, below the thermo/halocline. Exceeding the threshold is presumed to equalize total loss.

From the general relation between sediment exposure and increase in egg density found in the dose-response experiments with cod eggs the time for an exposed egg to sink from initial neutral buoyancy at a given salinity to more saline water can be approximated. Figure 4.12 shows the relation between exposure duration and corresponding salinity along with decreased buoyancy. The initial buoyancy is set to 19 psu which corresponds fairly to the average neutral buoyancy found among eggs from cod, plaice and flounder. From Figure 4.12 it can be seen that eggs exposed to sediment concentrations exceeding 10 mg/l sinks from 19 psu to 24 psu in less than 20 hours. If the salinity at the bottom is around 21 psu, which is close to the average at the bottom in the winter/early spring, it takes less than 10 hours to sink to the bottom. At 5 mg/l sediment exposure, which was the lowest dosage used in the dose-response experiments, the calculated time to sink from 19 to 24 psu is 59 hours while it only takes 24 hours reaching 21 psu. These figures should be seen in the light that the hatch time of cod and plaice in the experiments were 314 respective 370 hours.

Background levels of suspended sediment in the deeper parts of Fehmarnbelt are however considerable lower than 5 mg/l. During the baseline years the medians of the concentrations in the mid water and at the seabed were in the range 0.6-1.7 mg/l (FEHY, 2013a). Assuming same logarithmic relation between the tested dosages (~5-50 mg/l wet weight sediment) and lower concentrations the approximated time for an egg to sink from 19 psu to 24 psu is 269 hours and 843 hours at exposures of 2 mg/l respectively 1 mg/l. Considering the hatch times this indicates that 1 mg/l suspended sediment seldom will present a serious threat affecting egg density while there at times might be problems with respect to concentrations between 1 mg/l and 2 mg/l. Therefore the threshold level for drifting eggs and yolk sac larvae towards suspended sediment has been set to 2 mg/l, which is considered representing 100 % mortality.

For benthic spawning species threshold values for pressures caused by sedimentation on spawned eggs has been set to 0.1 mm/d corresponding to 1 mm net settlement over an average hatching time of 10 days.

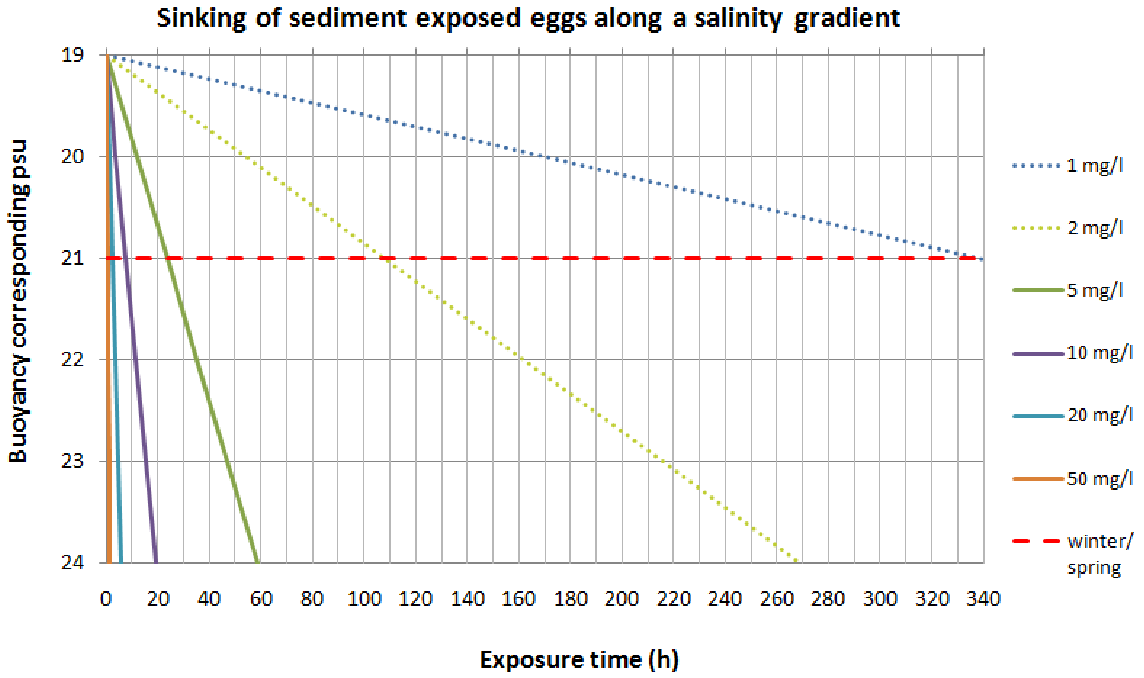


Figure 4.12: Estimated relation between duration of exposure of pelagic eggs with suspended sediment and decreased buoyancy induced sinking to higher salinities starting with buoyancy at 19 psu. Calculated from dose-respons experiments with cod eggs exposed with 4 mg - 48 mg dw/l Fehmarnbelt fine sediment assuming the found relation can be extrapolated to doses of 1 mg and 2 mg.

Juvenile and adults

For juveniles and adults the selected thresholds values are based upon avoidance behaviour, since this is the reaction expected before other impacts set in. Avoidance is regarded as escape from a specific nursery area for juvenile fish or feeding area for adult fish, which according to the general assessment principle equalizes total loss in a worst case scenario. This principle is also applied with respect to migration where avoidance equalizes unsuccessfull mission, either this is a spawning or feeding migration. The thresholds has been set to 10 mg/l suspended sediment for pelagic fish species as whiting, herring, sprat and cod while 50 mg/l has been set for more benthic species as flatfish, snake blenny and shallow water species. The threshold value for migrating silver eel has been set to 50 mg/l, which definitely is worst case scenario for this species.

Threshold values

The threshold values for each pressure indicator are listed in Table 4.10.

Table 4.10: Threshold values of suspended sediment (mg) and sedimentation (mg/d) for each environmental indicator for the assessment of pressures caused by the construction and operation of the proposed solutions of the Fehmarnbelt Links. (-) indicates no relevans of assessment in Fehmarnbelt.

Environmental indicators	Spawning	Egg-larvae drift	Nursery	Feeding	Migration
Atlantic cod		2 mg	10 mg	10 mg	10 mg
Whiting	-	-	10 mg	10 mg	10 mg
Herring	0.1 mg/d	2 mg	10 mg	10 mg	10 mg
European sprat		2 mg	10 mg	10 mg	10 mg
Flatfish		2 mg	50 mg	50 mg	50 mg
Shallow water species	0.1 mg/d	2 mg	50 mg	50 mg	-
Protected species:					10 mg
European eel	-	-	50 mg	50 mg	50 mg
Sea stickleback		2 mg	50 mg	50 mg	-
Snakeblenny	0.1 mg/d	2 mg	50 mg	50 mg	-

4.4 Noise and vibration

Underwater noise is inevitable when large offshore constructions are established, and because sound propagates over long distances in water, impacts from noise might cover a substantial area. The exposure might be scaled from underwater explosive blasts and air guns causing death or injury to fish, and pile driving and heavy ship traffic causing avoidance behaviour to traffic noise only slightly above the local ambient background noise. The latter will at worst cause interference with the sound based communication and orientation in fish.

Sound is characterized by frequency and magnitude of sound waves. Vibrations (or infra sound) is very low frequent sound (<20 Hz).

Underwater sound consists of two components: Particle displacement and sound pressure. The particle displacement is characterized by high near field values, rapidly decreasing with the distance to the source, and a more moderate far field particle displacement dependent on the sound pressure, the impedance of the water and the sound frequency.

Frequency is measured in Hertz (Hz, oscillations pr. second) and sound pressure is measured in Pascal (Pa), but the sound level is measured in decibel (dB) defined as $20 \cdot \log\left(\frac{\mathrm{P}}{\mathrm{Pref}}\right)$, where P is the measured pressure, and P_{ref} is a reference pressure (1 µPa in water).

The sound pressure can be measured as peak to peak level, peak level, root mean square (rms), which is the average level within a given time or sound exposure level (SEL), which is a measure for accumulated exposure.

The speed of sound is approximately five times higher in water than in air, and because of the much higher density of water, the sound level there is much higher in water than in air (app. 62 dB) given the same acoustic intensity. Cross-media comparisons between air and water should thus be avoided or done with great precaution.

The received level (RL) of sound depends on the level at the source (SL) and the transmission loss (TL). The transmission loss represents the loss in intensity or pressure of the acoustic field strength as the sound propagates from source to receptor. In general terms the transmission loss is given by $TL = N \log(R) + \mu R$, where R is the range from the source in meters, N is a factor for attenuation due to geometric spreading, and µ (in dB/m) is a factor for the absorption of sound in water.

Hence, the received sound level at a range R from a source is given by $RL = SL – TL$, which can be written in the form: $RL = SL – N \log(R) - \mu R$. The absorption coefficient (µ) is ignorable for frequencies below 2 kHz, but significant for high frequencies.

The factor for attenuation due to geometric spreading is 20 for spherical spreading and 10 for cylindrical spreading on deep waters, but in shallow waters the conditions are more complicated due to sound reflection and absorption from the bottom and the surface.

The geometric loss has been measured during a number of pile driving operations (Table 4.11) and the attenuation factors ranged from 17-28.

Table 4.11: Underwater sound transmission loss factors for peak to peak noise measured during pile driving operations (from Kongsberg Maritime, 2010 and Hudson, 2009).

Location	Water Depth (m)	Geometric loss (N)	Reference
North Hoyle	11-26	17	Parvin et al., (2006b)
Kentish Flats	3	20	Parvin et al. (2006b)
Scoby Sands	4-43	20	Parvin et al. (2006b)
Barrow	10-30	18	Parvin et al. (2006b)
Burbo Bank	7-10	21-23	Parvin et al. (2006a)
Port of Melbourne	13	28	Hudson (2009)

In Fehmarnbelt ITAP measured a broadband geometric loss of 22 in the central parts and 25 in the shallow parts during an estimation of the broadband noise from ships in 2009 (ITAP, 2011).

The propagation of low frequent sound in shallow water is complicated, as wavelength exceeding four times the water depth cannot propagate. This means that noise with frequencies below 75 Hz cannot propagate in coastal waters with water depth below 5 m.

The noise emitted during the establishment and operation of a fixed link in Femarnbelt depends on the choice of construction, and might imply pile driving, dredging or drilling and traffic noise from vessels used in the construction work. Properties of typical anthropogenic noise at sea are shown in Table 4.12.

Table 4.12: Properties of different types of anthropogenic underwater noise. Source levels are at 1 m. From OSPAR (2009), COWRIE (2007) and Nedwell et al. (2003).

Sound	Source level (dB re 1 µPa)	Amplitude (Hz)	Duration (ms)
TNT (1-100 lbs)	272 - 287 peak	6-21	1-10
Airgun array	260-262 peak to peak	10-120	30-60
Pile driving	244-254 peak	100-300	50
Dredging	168-186 rms	100-500	Continous
Drilling	145-190 rms	<100	Continous
Large vessels	180-190 rms	>200	Continous
Small ships	160-180 rms	>1000	Continous

4.4.1 Environmental indicators

Several fish species are potentially impacted by noise and vibrations in the zero-alternative. Silver eel and cod use Fehmarnbelt as an important spawning migration route, and also herring, sprat, whiting and potentially a number of legally protected species migrate in Fehmarnbelt. Noise is known to provoke avoidance reactions if the noise is loud enough, and both migrating fish passing a source and resident fish in the vicinity of a source of noise might thus be impacted.

The environmental components that are relevant to assess regarding noise and vibration are shown in Table 4.13. For a number of protected species like salmon, sea trout, lampreys etc. the knowledge is not comprehensive enough to make a detailed assessment. For these species the assessment will be performed more extensively.

Table 4.13: Environmental components that are potentially impacted from noise and vibrations in a zero-alternative.

Environmental indicators	Spawning	Egg-larvae drift	Nursery	Feeding	Migration
Atlantic cod	x		x	x	x
Whiting			x		x
Herring	x		x	x	x
European sprat	x		x	x	x
Flatfish	x		x	x	x
Shallow water species	x		x	x	-
Protected species:					
European eel			x	x	x
Sea stickleback	x		x	x	
Snake blenny	x		x	x	

4.4.2 **Sensitivity to pressure**

The impact of noise on fish in Fehmarnbelt depends not only on the noise level but also on the species specific sensitivity to the emitted noise. The hearing ability of fish is very species specific and varies significantly with both sound level and frequency.

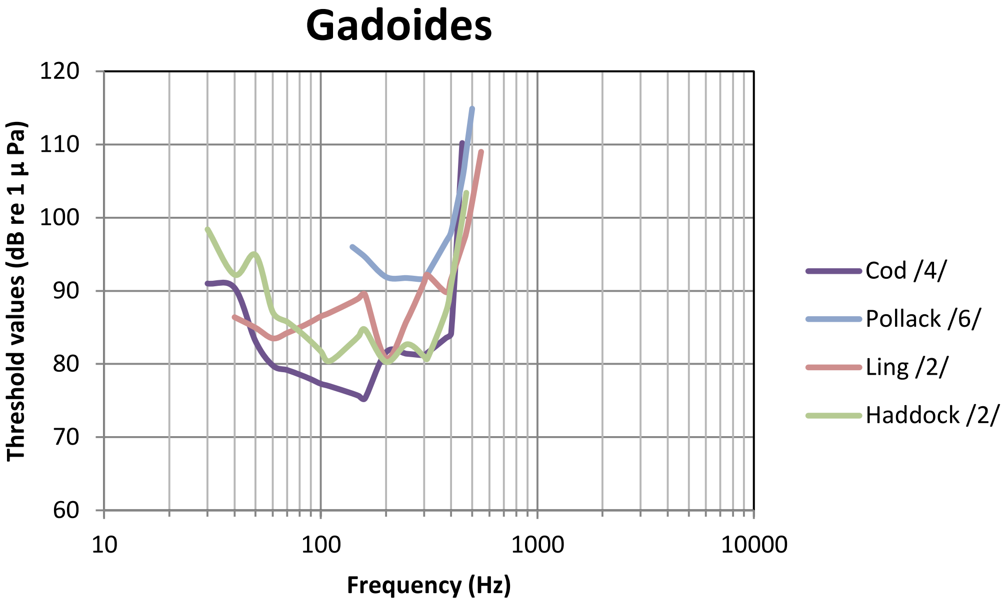
Fish have several organs sensing sound. The lateral line organ responds to very low-frequent oscillations of less than 200 Hz and serves primarily to perceive water movements relative to the fish’s body (Sand et al., 1986; Enger et al., 1989). The inner ear senses primarily frequencies up to one kHz, as the otoliths and the associated sensory hair cells primarily react to particle displacement of the water (Bone et al., 1995).

Fish with a close association between the swim bladder and the ear are sensitive to sound pressure, while those lacking gas filled cavities only are sensitive to particle motion (ICES, 2005). The gas filled swim bladder is more compressible than water and acts as a “pressure fluctuation transducer” that transmits the sound-induced pressure fluctuation via the endolymph to the otoliths. There, deflections of the hair cells are eventually induced (Bone, et al., 1995).

Fish can be characterized as hearing generalists or hearing specialists (Fay, et al., 1999), where the generalists do not sense frequencies beyond one kHz. Fish without swim bladder like flatfish are practically deaf to frequencies above 250 Hz while fish with swim bladder with no other specialization can hear a range up to 500 Hz (Westerberg, 1993). Hearing specialists, like herring have specializations for linking the swim bladder to the inner ear. They basically react to pressure fluctuations.

Experiments have shown that fish can distinguish sounds coming from different directions (Enger et al., 1989; Hawkins, 1973), although the auditory mechanisms that permit this are poorly understood (ICES, 2005).

The hearing abilities have only been investigated in a relatively few species. Hearing abilities are visualized in audiogrammes describing the hearing threshold value at a given frequency. The audiogrammes for a number of fish species are shown in Figure 4.13.



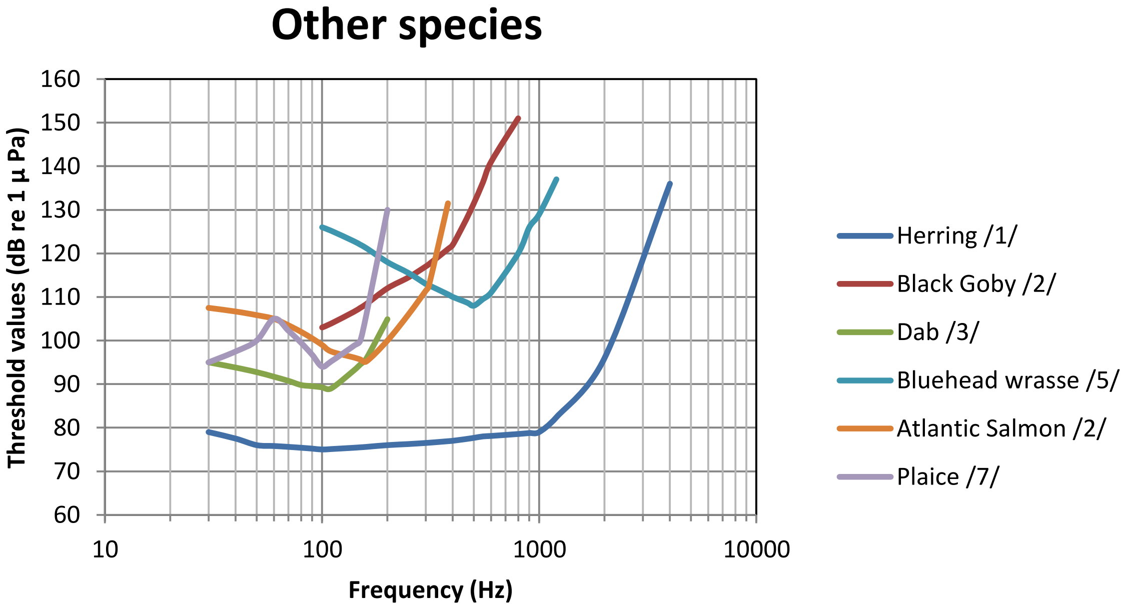


Figure 4.13: Audiogrammes of several species /1/ Enger (1967), /2/ Fay (1988), /3/ Nedwell et al. (2004), /4/ Chapman et al. (1973), /5/ Tavolga et al. (1963) /6/ Chapman et al. (1974), /7/ Hastings et al. (2005).

As the audiograms suggest the hearing “generalists” are insensitive to frequencies above 1000 Hz, but are sensitive to low frequencies. For most “generalists” the lowest overall threshold sound pressure (75-110 dB re.1 µPa) is situated between 100 to 500 Hz.

Clupeids (Herring, sprat, shad and anchovy)
All clupeids (herring-fish) investigated so far have a unique ear structure in which a pair of thin air-filled tubes project from the swimbladder and terminate in air chambers that are connected with the utricles of the inner ear. Herring can hear frequencies up to 4 kHz (Mann et al., 2001) and members of the clupeid family Alosinae, which includes shad, are able to detect sounds to well over 100 kHz (e.g. Enger, 1967; Mann et al., 1998; Mann et al., 2005).

Gadoids (Atlantic cod, whiting)

Cod (*Gadus morhua*) has two short, air filled tubes as an extension of the swimbladder. The tubes are directed towards the inner ear but do not reach it. The short tubes are probably the reason why cod hear slightly better than other fish with a swimbladder and no specialities. Cod is a hearing “generalist” but it is known to detect sounds of at least 38 kHz, meaning it has ultrasonic hearing ability (Astrup et al., 1993). If the cod are to detect the ultrasound, the sound pressure has to be very high (app. 200 dB). Cod have also been shown to react on infra sound below 20 Hz (Sand et al., 1986).

Flatfish (Flounder, plaice, dab, turbot, brill)

In flatfish the swimbladder degenerates after the larval phase. Therefore these fish have poor hearing capabilities, and can probably not hear at frequencies above 250 Hz. Flatfish might be sensitive to infra sound, as plaice (*Pleuronectes platessa*) have shown to react to infra sound (Karlsen, 1992).

Europaen eel

Jerkø et al. (1989) found that European eel *(Anguilla anguilla*) has an upper audible frequency limit of app. 300 Hz. The lowest threshold (95 dB re 1 µPa) was measured at 80 Hz. This is consistent with results by Hawkins, et al. (1978), who found, that the upper audible frequency limit in eel was 380 Hz. The lowest sound pressure threshold (95 dB re. 1 µPa) was measured at 180 Hz. Eel was recorded to have a similar avoidance response as salmon at 10 Hz (Sand, et al., 2000).

Salmonids (salmon, sea trout)

Salmonids are hearing generalists with relatively poor hearing abilities. They are sensitive to low frequency sound, and juvenile salmonids display strong avoidance reactions to near-by infrasound at 10 Hz reacting on particle acceleration > 0.01 ms^{-2} (Knudsen et al., 1992; Knudsen et al., 1994). On the other hand Ploskey et al. (2000) found that sound at 10-35 Hz did not elicit avoidance from juvenile salmon, even at 160 dB.

Other hearing generalists

Sea scorpion, eelpout, sandeel and gobies have no swimbladder after the larval phase, and these fish have all poor hearing capabilities, and can probably not hear at frequencies above 250 Hz.

Eggs and larvae

The effects of sounds on fish eggs and larvae have been reviewed by Popper et al. (2009): A non peer-reviewed study using sounds from 115-140 dB (re 1 µPa, peak) on eggs and embryos in Lake Pend Oreille (Idaho) reported normal survival or hatching, but few data were provided to evaluate the results (Bennett et al., 1994). In another study, Kostyuchenko (1973) reported damage to eggs of several marine species at up to 20 m from a source designed to mimic seismic airguns, but few data were given as to effects.

Similarly, Booman et al. (1996) investigated the effects of seismic airguns on eggs, larvae, and fry and found significant mortality in several different marine species (Atlantic cod, saithe, herring) at a variety of ages, but only when the specimens were within about 5 m of the source. The most substantial effects were to fish that were within 1.4 m of the source. While the authors suggested damage to some cells such as those of the lateral line, few data were reported and the study is in need of replication.

Moreover, it should be noted that the eggs and larvae were very close to the airgun array, and at such close distances the particle velocity of the signal would be exceedingly large. However, the received sound pressure and particle velocity were not measured in this study.

The hearing abilities for a number of fish species present in Fehmarnbelt or for related species are summarized in Table 4.14.

Table 4.14: Overview over important parameters for hearing abilities among selected fish species. /1/ Thomsen et al. (2006), /2/ Suga et al. (2005), /3 Belanger et al. (2004), /4/ Beatrice (2005). Peak frequency indicates the part of the overall hearing frequency range to which the species are particularly sensitive. In: Klaustrup et al. (2007).

Species	Scientific name	Hearing frequency (Hz)	Approximate peak frequency (Hz)	Threshold at peak frequency (Hz), dB re 1µ Pa - 1m.
Atlantic cod /1/	*Gadus morhua*	10-800	160	75
Dab /1/	*Limanda Limanda*	30-250	110	89
Haddock /4/	*Merluccius merluccius*	30-500	100-300	80.4-84.9
Herring /1/	*Clupea harengus*	30-4000	100	75
American shad /1/	*Alosa Sapidissima*	100-5000	200	105
Ling /4/	*Molva molva*	40-600	200	80.8
Pollack /4/	*Pollachius pollachius*	40-500	200-300	91.6-91.9
Atlantic salmon /1/	*Salmo salar*	30-380	160	95
Japanese sandeel /2/	*Ammodytes personatus*	128-512	128-181	116
Round goby /3/	*Neogobius melanostomus*	100-600	-	140

4.4.3 Pressure indicators

The effects of underwater noise on fish vary depending on the received noise level. Five different levels of response are recognized in adult fish:

- Detection level.
  - The noise level that the species would normally be able to detect. In a quiet sea this would be equal to the hearing threshold value; in a noisy sea this would equal the background noise. This noise level might mask the fish perception of natural sounds and thus disturb any sound related behaviour.

- Avoidance level
  - The noise level at which the species would start to exhibit active avoidance behaviour, such as swimming away, in order to avoid the noise.

- Temporary hearing damage level
  - The noise level that would cause a temporary but reversible shift in the individual's hearing sensitivity.

- Permanent hearing shift level
  - The noise level that would cause a permanent shift in the individual's hearing sensitivity.

- Physical damage level
  - The noise level or pressure level that would result in gross physical damage to the organism's auditory system, other organs or tissues.

The sensitivity to noise of the specific fish species is dependent on the fish perception of the given noise. The perception of noise can be estimated by filtering the sound through the audiogram for the specific species. Nedwell et al. (2003) proposed this resulting sound level, $\text{dB}_{\text{ht (species)}}$ used for assessing the impact of noise on fish and marine mammals.

Based on a review of the literature and on laboratory studies he suggested threshold values shown in Table 4.15 for the specific effects (Nedwell et al., 2007).

Table 4.15: Criteria in dB above hearing threshold suggested for the effects of noise (Nedwell et al., 2007).

Level in dBht(Species)	Effect
Less than 0	None
0 to 50	Mild reaction in minority of individuals, probably not sustained
50 to 90	Stronger reaction by majority of individuals, but habituation may limit effect
90 and above	Strong avoidance reaction by virtually all individuals
Above 110	Tolerance limit of sound; unbearably loud
Above 130	Possibility of traumatic hearing damage from single event

On this basis, areas around a noise source within which the key auditory effects of noise will occur can be calculated. Fish within the area bounded by the 90 dB_{ht} level contour will if possible flee the noise. Fish within the area bounded by the 130 dB_{ht} level contour may suffer injury or permanent damage to hearing. The latter would only be the case when air guns or explosives are applied or in the near region of a pile hammer. None of these methods are planned to be applied in the construction of the fixed link, and the assessment will there for be limited to avoidance behavior. For the assessment the threshold values in Table 4.16 are applied.

Table 4.16: Threshold values used for the assessment of noise.

Fish group	Theshold dB	50 % avoidance 70 dB_{ht}	100 % avoidance 90 dB_{ht}
Gadoids/Clupeids	75 dB	> 145 dB	> 165 dB
Other	90 dB	> 160 dB	> 180 dB

4.5 Indirect pressures

Changes in the substrate, vegetation and macrofauna can affect the habitat suitability of the different fish species in Fehmarnbelt. These types of pressure are described as indirect pressures.

The habitat choice of an organism depends on a combination of factors such as habitat structure and availability, food supply, predation and inter- and intraspecific competition. Specific requirements for feeding, shelter or spawning often determine the dependence on a habitat. Additionally, for some fish species habitat choice vary between season and life stages.

Especially the shallow water fish communities depend on the occurrence of vegetation. However, vegetation is important for specific life stages of other fish species such as benthic herring eggs which are attached to the vegetation. Other species use these protected, shallow and vegetated areas as nursery grounds. The macrofauna associated with the coastal habitats constitutes a major food source for the fish communities presented in these areas.

Few of the German redlisted species prefers vegetated habitats and is thus vulnerable to indirect pressure from changes in the vegetation which will cause changes in the habitat suitability.

Furthermore, changes in prey availability due to e.g. change in hydrological conditions will cause an indirect pressure to the predatory fish species. Especially fish larvae are vulnerable to changes in the occurrence of their main food items copepods.

The habitat suitability of fish in Fehmarnbelt were analysed and mapped during the present assessment. The analysis compares the distribution of fish species with environmental variables. Data from the catches in the shallow water communities together with information of the habitat (coverage of macroalgae and eelgrass) the fish were caught in were used for the analysis of suitability.

4.5.1 Environmental indicators

The environmental components that are relevant to assess regarding indirect pressure are shown in Figure 4.17. Especially small fish species are associated to vegetated habitats in all life stages whereas other species only utilize these areas as nursery grounds. Thus the impact differs between species and life stages. Some of the shallow water species generally prefer areas with macroalgae during the entire life cycle and these species has been selected as indicators.

Impacts on nursery and feeding of the pelagic species herring and sprat are not assessed as they are pelagic and primarily planktivorous. Thus, these environmental components are not expected to be affected by changes in the coverage of macroalgae and eelgrass. Furthermore, no spawning grounds for herring were identified and the potential spawning grounds are only estimated from the backtracking of few larvae. Thus, the impact of indirect pressures on herring spawning will not be assessed. Cod, sprat and flatfish eggs are pelagic and it is thus not relevant to assess the impairment of indirect pressures such as changes in vegetation on pelagic spawning species.

For many of the fish species present in Fehmarnbelt indirect impacts caused by sediment spill are likely to have far greater consequences than direct impacts on the fish themselves. For a number of protected species like salmon, seatrout, lampreys etc. the knowledge is not comprehensive enough to make a detailed assessment. For these species the assessment will be performed more extensively.

Table 4.17: Environmental indicators selected for the assessment of indirect pressures. (-) indicates no relevans of assessment in Fehmarnbelt.

Environmental indicators	Spawning	Egg-larvae drift	Nursery	Feeding	Migration
Atlantic cod			x	x	
Whiting	-	-	x		
Herring					
European sprat					
Flatfish			x	x	
Shallow water species	x	-	x	x	-
Protected species:					
European eel	-	-			
Redlisted species					
Sea stickleback	x	-	x	x	-
Snake blenny					
Protected species					

4.5.2 Sensitivity to pressure

Many small fish species prefers shallow and vegetated habitats as these areas provide shelter and protection. Additionally, this is the reason several species utilize these areas as nursery grounds. Thus, these fish species are sensitive to changes in the coverage of eelgrass and macroalgae.

The sensitivity to decrease in vegetation is expected to be highest for the small resident species which is restricted to the same type of habitat during the entire life cycle compared to other species only using these areas as nursery grounds. However, this implies that nearby habitats suitable for nursery are found in the adjacent areas.

On the other hand, a very dense vegetated habitat is not optimal for most fish species. In fact, macroalgal blooms are considered to have the potential to change the structure and function of shallow soft substratum habitats reducing the suitability as nursery and feeding grounds for commercial fish species (Wennhage, et al., 2007).

Shallow water fish communities:

Small fish like sticklebacks, gobies and sandeels are dominating in the shallow water communities along the coast of Fehmarn and Lolland. Additionally, juvenile fish were abundant in these areas. The small fish species in the shallow water communities are primarily resident living their entire life cycle in the same area.

Sheltered conditions and a fairly stable environment with good access to food are generally acknowledged to enhance small fish recruitment (Nellen, et al., 1996). In this respect the environmental basic settings of Orther Bight, Binnensee and Rødsand Lagoon are more optimal compared to the open exposed coast of Fehmarnbelt.

Many shallow water fish species are substrate-spawners practising brood care and are thus associated to highly structured habitats. Although many small fish may spawn on a wide variety of substrata, macrophytes often seem to be preferred. A reduction in water transparency will in general reduce macrophyte vegetation, and hence reduce potential spawning sites.

Males of threespined stickleback nest in vegetated habitats and Candolin et al. (2006) showed that they prefer to nest in habitats with sparse vegetation compared to dense vegetation. This indicates a negative effect of vegetation on visibility and mate encounter and thus the reproductive success. The same behaviour is seen for sea stickleback.

Species of the family *Pomatoschistus* (e.g. sand goby) are one of the main preys for several fish species utilizing shallow water sediment habitats. They are mainly found in areas with bare sand or in habitats with low algal biomass. To avoid predators these prey species buries in the sediment (Wennhage, et al., 2007).

Flatfish and gobies are dominating in the sandy habitats whereas sticklebacks are found in macroalgae habitats (Wennhage, et al., 2007).

Examples of mapping of habitat suitability of shallow water species can be seen on Figure 4.14 - Figure 4.15.

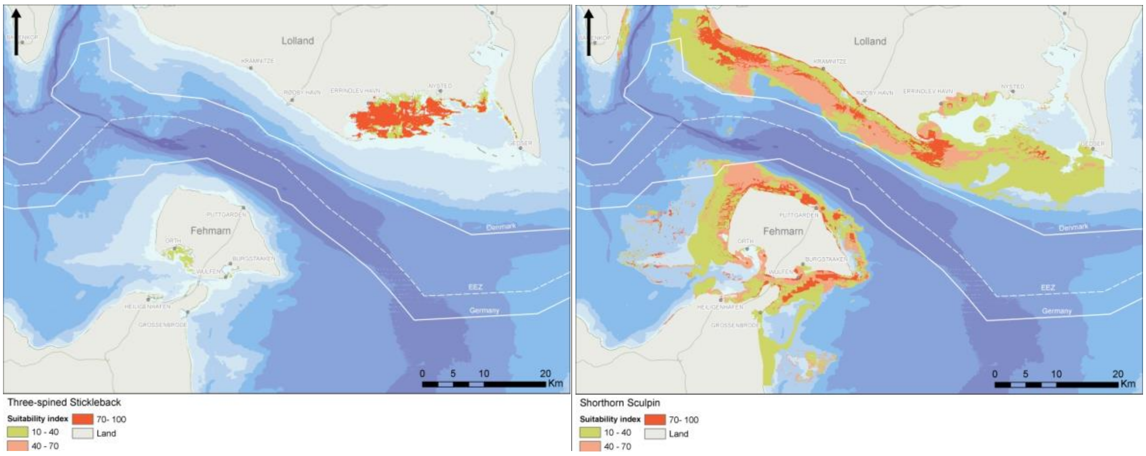


Figure 4.14: Habitat suitability for three-spined stickleback and shorthorn sculpin in the shallow water fish community in Fehmarnbelt.

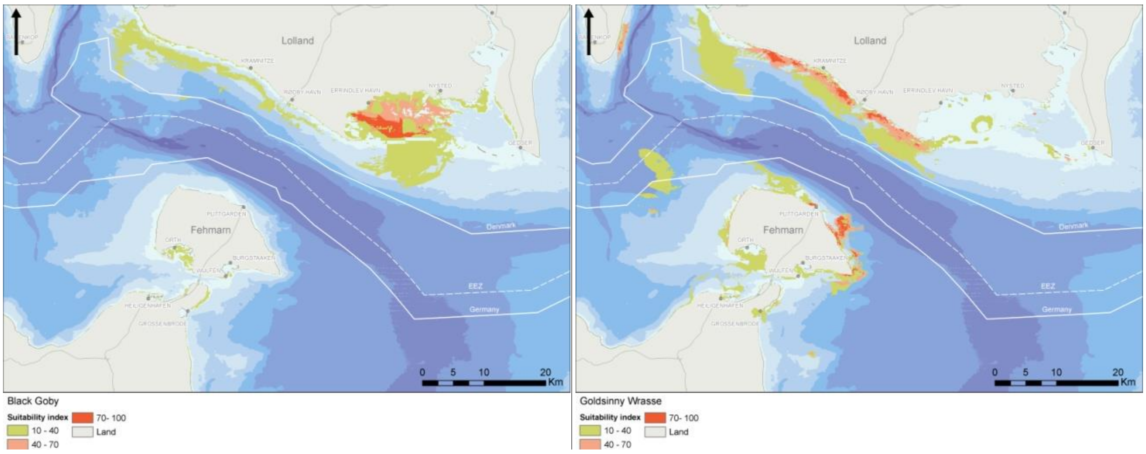


Figure 4.15: Habitat suitability for black goby and goldsinny wrasse in the shallow water fish community in Fehmarnbelt.

Juvenile species:
Juvenile species of a number of important fish species prefers sheltered, vegetated areas as nursery areas. These habitats provides ideal refuges from predation and good food resources as these shallow coastal areas often are associated with a high production of benthos. Finding a suitable habitat for settling might be crucial for the survival of newly recruited juveniles.

The vegetated habitats are important nursery grounds for young juvenile cod as they offer rich food resources in combination with protection against predation. During the first two years juvenile cod remains within the coastal zone. They undertake nocturnal migrations and utilize the rich food resources at shallow (1-2 m) soft bottoms (Borg, et al., 1997). The distribution and survival of juveniles might be affected by structural changes of the nursery habitats which will influence the recruitment. During daytime juvenile cod prefers vegetated habitats providing shelter whereas open sandy areas are important for feeding during nighttime (Borg, et al., 1997).

Some species utilize heterogenous habitats e.g. sand and vegetation in a mosaic pattern in order to minimize predation risk while maximizing foraging. Then the fish can forage in the unvegetated areas while being in close proximity to protected vegetated habitats.

The coast of Lolland seems to be an important nursery ground for juvenile cod in the western Baltic Sea (e.g Bauer et al., 2010). Furthermore, locations around the coast of Fehmarn also act as nursery grounds for juvenile cod. During the baseline study the majority of juvenile cod were caught at 5–10 m depth in habitats consisting of a mix of sand, stones, mytilus and vegetation where they can seek shelter and feed. The lowest abundance was found in areas with eelgrass and/or sand (without stones, vegetation, mytilus etc.).

Isaksson et al. (1994) found that 30 % cover of green macroalgae on the sediment results in significantly lower foraging success of juvenile (1-group) cod when feeding in their natural prey *Crangon crangon* and *Carcinus maenas* compared to an unvegetated bottom.

There are indications that juvenile whiting are using the shallow water areas of Fehmarnbelt and other areas in the Baltic Sea as nursery areas. During the baseline studies the majority of the juvenile whiting were caught at habitats with sand indicating that whiting prefer shallow coastal sandy h as nursery areas.

The baseline studies indicated that the coastal waters of Fehmarnbelt are little utilized by herring for feeding and nursery. Herring is a pelagic planktivorous species. Furthermore, juvenile herring preferred sandy habitats in shallow water compared to habitats with vegetation and sandy habitats at greater depth. However, the vegetation is important for the spawning of herring as the eggs are attached to the vegetation.

The habitat suitability of juvenile cod and flounder are illustrated on Figure 4.16.

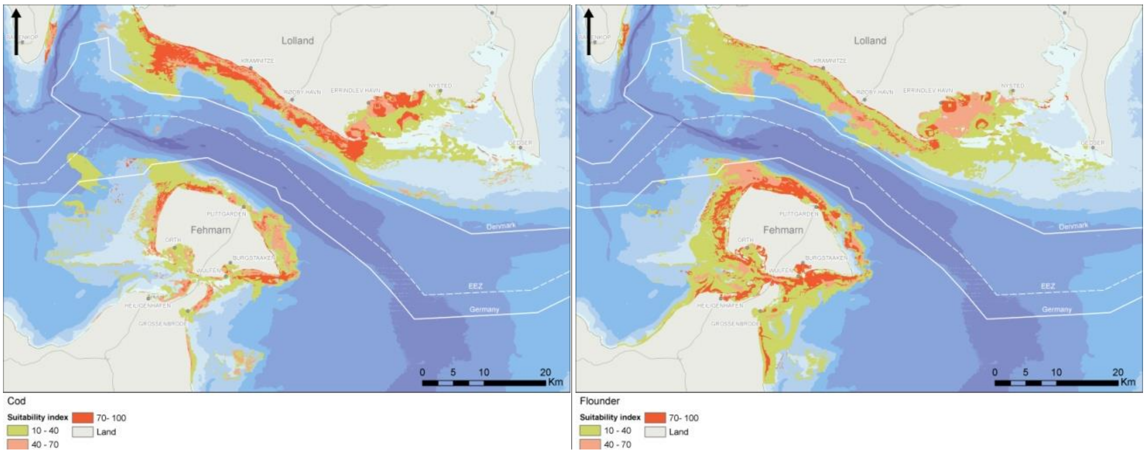


Figure 4.16: Habitat suitability for juvenile cod and juvenile flounder in the shallow water fish community in Fehmarnbelt.

<u>Redlisted species:</u>
Sea stickleback:
The sea stickleback is an essential part of the fish communities in the coastal regions of Lolland and Fehmarn. The main threats are eutrophication (oxygen depletion) and loss of habitats. Sea stickleback prefers habitats covered with vegetation, where it can nest (Kaiser, et al., 1992). During the baseline study, sea stickleback was relatively common at the coast of Fehmarn and Lolland. It was present in all types of habitats but mainly in habitats with eelgrass

meadows. Especially the eelgrass meadow habitats at the southern coast of Fehmarn and in the lagoon of Rødsand were preferred by the sea stickleback. The habitat suitability in the zero-alternative was mapped and illustrated on Figure 4.17.

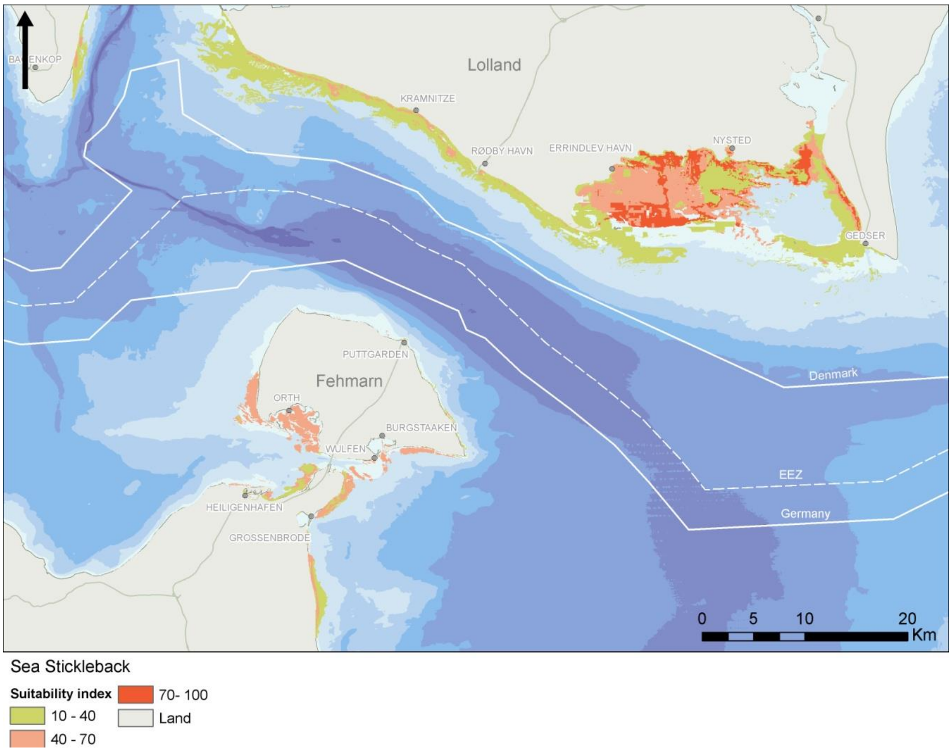


Figure 4.17: Habitat suitability for sea stickleback in the shallow water fish community in Fehmarnbelt.

4.5.3 Pressure indicators

The entire life cycle of shallow water species is restricted to one habitat and thus spawning, eggs and larvae as well as nursery and feeding are selected as pressure indicators. These stationary species are more sensitive to changes in vegetation compared to migratory species.

The shallow vegetated habitats are used as nursery areas by several species as they offer protection and food items. Vegetated habitats are also important as feeding areas for predatory migrating fish species. Herring eggs are benthic and thus depending on the cover of vegetation. However, flatfish mainly prefer sandy habitats and thus a decrease in vegetation would enhance the suitability of the habitat to these species.

The response to indirect pressure as change in vegetation can be decrease in egg survival probability of benthic spawners, avoidance behaviour or deterioration of habitats.

A decrease in the coverage of benthic vegetation is considered as a change in the suitability of habitats to different pressure indicators. The sensitivity towards indirect pressures is not established upon thresholds values but by comparing the habitat suitability in the baseline year with the habitat suitability modelled on the basis of the expected changes in coverages of eelgrass and macroalgae.

4.6 Other pressures

4.6.1 Electromagnetic fields (cables)

There are three primary natural sources of electromagnetic fields (EMFs) in the marine environment, the earth's geomagnetic field, electric fields induced by the movement of charged objects (e.g. water currents or organisms) through a magnetic field and bioelectric fields produced by organisms (Tricas and Gill, 2011*)*. The term EMF covers two fundamental different types of field, the electric field and the magnetic field. The strength of the electrical field is measured in volts per metre (V/m) and the unit of measurement of the magnetic field is tesla (T). The natural geomagnetic field of the earth varies with the latitude and reaches about 50 µT in the latitude of Fehmarnbelt. Naturally occurring electrical fields in the areas of Fehmarnbelt are expected to be around 25 µV/m (OSPAR Commision, 2008).

Anthropogenic electromagnetic fields in the marine environment are typically generated when electric energy is transmitted from one point to another, and are therefore generally related to operative submarine power cables. The expected EMF levels from undersea power cables are dependent on the source creating the field. The EMF from an AC cable will differ from the EMF from a DC cable.

The magnetic field

A modelling study describing the magnetic field along the seabed of existing and proposed power cables provided information of the characteristics the fields (Tricas and Gill, 2011*). Most* of the AC cables used in the modelling were designed to provide connection between land and offshore wind mills. The cables where operating at 33 kV to 345 kV. The average magnetic field at the seabed surface for the modelled cables is shown in Figure 4.18.

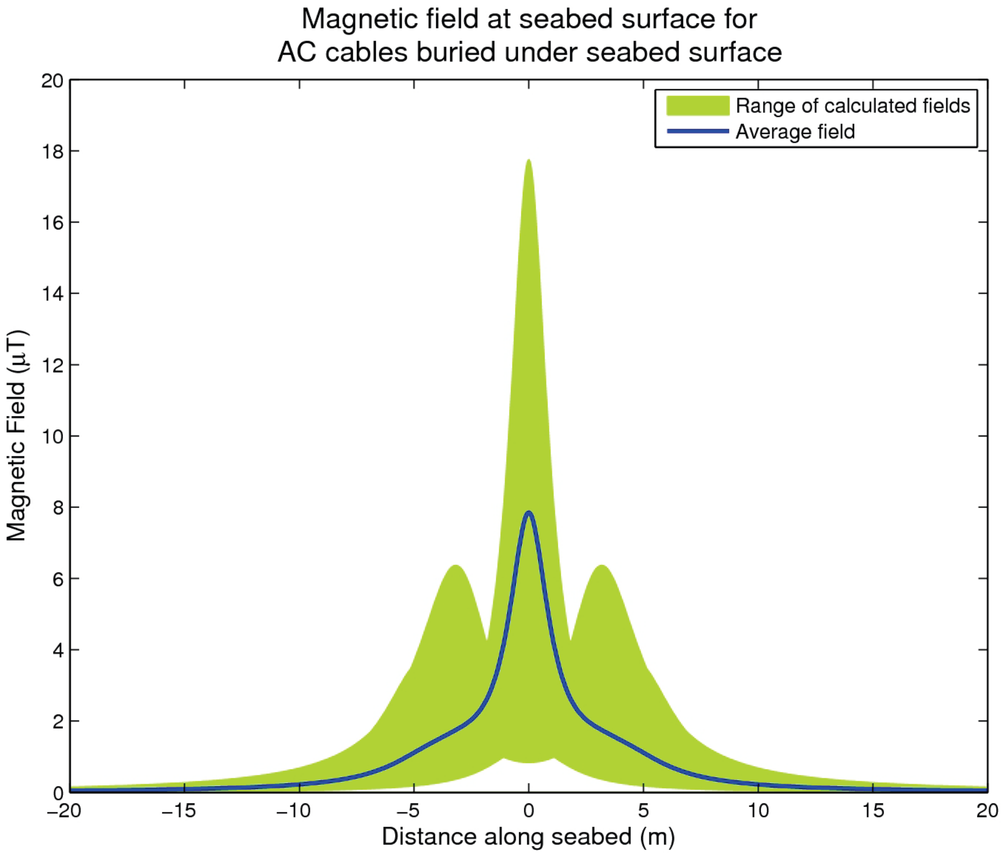


Figure 4.18: The average magnetic field calculated at seabed surface for AC cables assuming 1 m burial. Source: Tricas and Gill, 2011.

The magnetic field in the water column above the cables also varies with distance. Table 4.18 shows the average value of the magnetic field as a function of both horizontal and vertical distance to the cable.

Table 4.18: Calculated magnetic field at different vertical and horizontal distances to an AC cable buried one meter in the seabed (from Tricas and Gill, 2011).

Distance (m) Above Seabed	Field Strength (µT) Horizontal Distance (m) from AC Cable 0	4	10
0	7.85	1.47	0.22
5	0.35	0.29	0.14
10	0.13	0.12	0.08

The strength of the magnetic field created by an AC cable will not reach the level of the geomagnetic field, and it will decrease rapidly with distance to the cable. Due to the low strength of the field generated by the AC cable it is unlikely that it can interfere with the local geomagnetic field (Tricas and Gill, 2011).

Figure 4.19 shows the average DC magnetic field at the seabed surface for the modelled DC cables.

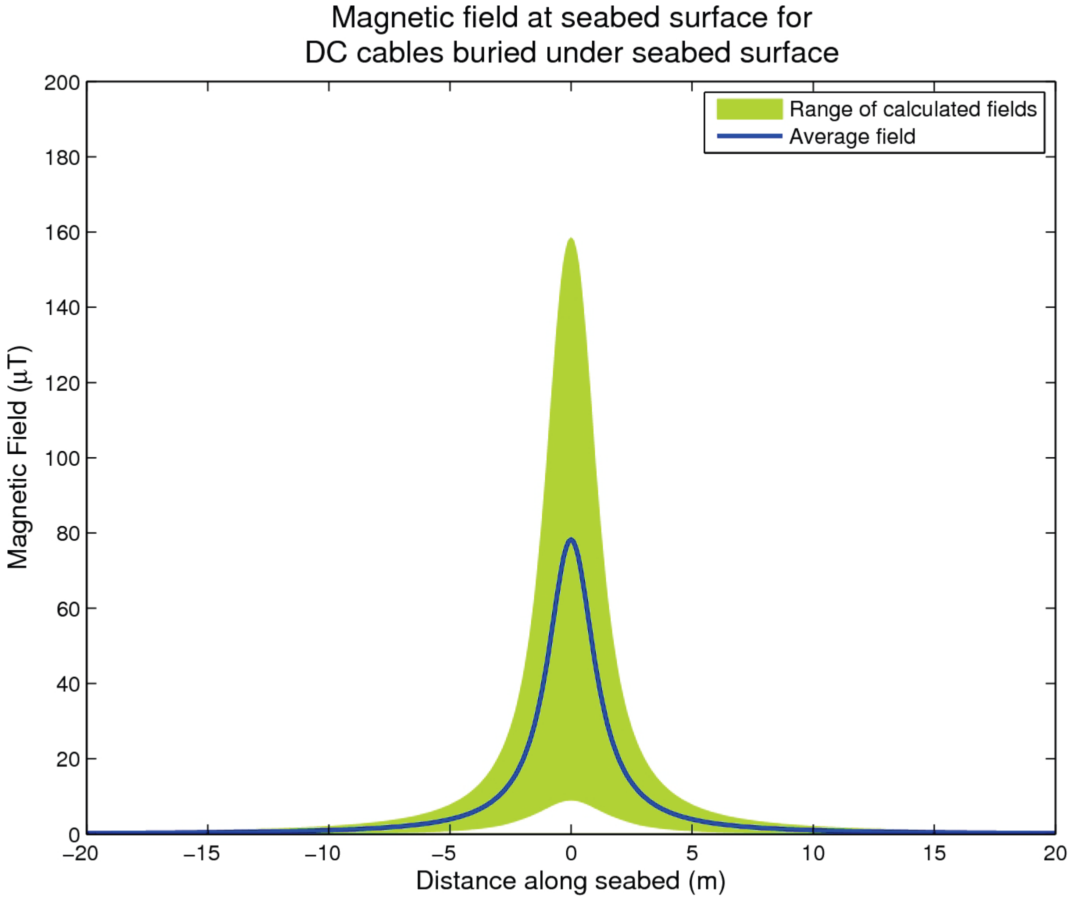


Figure 4.19: The average magnetic field calculated at seabed surface for DC cables assuming 1 m burial. Source: Tricas and Gill (2011).

The strength of the magnetic fields generated by DC cables is expected to be stronger than the natural geomagnetic field. Therefore it is possible that the magnetic field from DC cables can influence the intensity of the local geomagnetic field, and the orientation of the cable relative to the geomagnetic field should be accounted for when considering the effects of DC cables (Tricas and Gill, 2011).

Due to the rapidly decrease in intensity with distance to the cable the influence of the magnetic field from the DC cables on the geomagnetic field will be restricted to a very local area. At 4 mhorizontal or 5 m vertical distance to the cable the strength of the field is only 10 to 20 % of the naturally occurring geomagnetic field and at distances more than 10 m the field strength will be less than 5 % of the geomagnetic field (Table 4.19).

Table 4.19: Calculated magnetic field at different vertical and horizontal distances to a DC cable buried 1 m in the seabed (from Tricas and Gill, 2011).

Distance (m) Above Seabed	Field Strength (µT)		
	Horizontal Distance (m) from DC Cable		
	0	**4**	**10**
0	78.27	5.97	1.02
5	2.73	1.92	0.75
10	0.83	0.74	0.46

In general the magnetic field surrounding high voltage cables are stronger around DC cables than around AC cables. DC cables are monopolar or dipolar. In monopolar DC cables the strength of the magnetic field is dictated by the current, and in dipolar cables both the current and the distance between the two conductors dictate the strength and range of the magnetic field. Monopolar DC cables produce the strongest magnetic fields with field strength as much as 50 µT at a distance of 5 m from the line and 5 µT 60 m from the line as in the 450 kV monopolar Baltic Cable (Westerberg et al., 2000).

The electrical field

A water current or organism moving perpendicular to a cable magnetic field will generate an induced electric field and the field strength will be a function of the current's or organism's speed, its exact orientation relative to the cable magnetic field, and the strength of the magnetic field (Tricas and Gill, 2011). The induced electric field strength generated by a 5 knot current running perpendicular to a DC cable is shown in Table 4.20.

Table 4.20: Modelled average induced electric field from DC submarine cables (V/m) at distances above seabed and horizontally along seabed for cables buried 1m below seabed for a 5 knot current (from Tricas and Gill, 2011).

Distance (m) Above Seabed	Field Strength (V/m)		
	Horizontal Distance (m) from DC Cable		
	0	**4**	**10**
0	1.94E-04	3.15E-05	7.85E-05
5	1.75E-05	1.62E-05	1.39E-05
10	8.80E-06	8.52E-06	7.13E-06

Magnetic fields from AC cables can also induce electric currents. The polarity of the induced current would reverse at the same frequency as that of the AC magnetic field, potentially reducing the likelihood that the induced field from AC rotation would be detectable by organisms (Tricas and Gill, 2011). In general the induced electrical fields from AC cables are significantly lower than those arising from DC cables.

The intensity of the electrical field induced by the DC cables is expected to be stronger than the natural electrical field within 1 to 5 m from the DC cable, but with a distance of more than 10 m to the cable the induced electrical field will be significantly lower than the naturally occurring field (Tricas and Gill, 2011).

Environmental indicators

The biological processes of magnetoreception are not fully understood, but there is sufficient evidence that the magnetic information is important for the orientation of a variety of marine animals (OSPAR Commision, 2008). Marine fish use the magnetic field and field anomalies for orientation especially when migrating (Fricke, 2000). The best known use of the geomagnetic field is among elasmobranchs (sharks and rays). The use of magnetic fields among teleost fish (bony fish) is still under discussion, but some studies report that changes in the magnetic field resulted in a change in swimming behaviour in eels and salmonid fishes (OSPAR Commision, 2008). Fricke (2000) assumes magnetic orientation and thus a potential impact of artificial anomalies of the earth's magnetic field for allis shad (*Alosa alosa*), twait shad (*Alosa fallax*), herring (*Clupea harengus*) and sprat (*Sprattus sprattus*), and eel (*Anguilla anguilla*) showed orientating reactions to relatively weak fields under laboratory conditions (Westerberg, 2000).

Benthic fish are more exposed to magnetic fields around bottom cables and are thus expected to be stronger affected than pelagic species. A possible effect of an anthropogenic change of the magnetic field will be expected in the migration of fish due to their use of the magnetic field to navigation. Further the effect is expected to be strongest among the benthic species.

Electroreception has been reported for a number of fish species. Electroreception is best known among elasmobranchs (sharks and rays) and freshwater fish (OSPAR Commision, 2008). The information on marine fish and electroreception is scarce. Laboratory tests with lampreys (*Petromyzontiformes*) show behavioural responds to fields of 1 - 10 µV/cm (OSPAR Commision, 2008). According to Fricke (2000) induced electrical fields may have an effect on orientation of marine fishes during their migration.

Sensitivity to pressure

The investigations into electro- or magnetosensory capabilities have been conducted for only a few marine species and knowledge of the sensitivity of the fish in the western Baltic waters to electromagnetic fields is therefore restricted to a few observations. Table 4.21 shows the sensitivity and responds of some western Baltic fish species to changes in the magnetic field and Table 4.22 shows the sensitivity and response to induced electrical fields.

Table 4.21: Sensitivity and response for some selected western Baltic fish species to changes in magnetic field (from Tricas and Gill, 2011)

Fish species	Sensitivity (Magnetic field)	Response	References
Europaen eel	Geomagnetic Field	Behavioural, change of swimming direction when magnetic field changes.	Tesch (1974)
Europaen eel (elvers)	NA	Elvers to some degree hesitate to enter an anomalous magnetic field.	Westerberg (2000)
Europaen eel (silver)	5µT	Might have some effect on the orientation of the eel, but it is not likely that the cable acts as a permanent obstacle to the migration.	Westerberg (2000)
Plaice	Geomagnetic Field	Field observation. A possible use of geomagnetic field in navigation. Not proven.	Metcalfe et al. (1993)
Flounder	3.7mT	Test for response to magnetic fields. No response to increased magnetic exposure	(Bochert et al. (2004)
Sea trout	NA	Egg permeability to water increased with increased magnetic field.	Sadowski et al. (2007)

Table 4.22: Sensitivity and response for some selected western Baltic fish species to changes in electrical field (from Tricas and Gill, 2011).

Fish species	Sensitivity (Electrical field)	Response	References
Europaen eel	0.4 – 0.6 mV/cm	Physiological, heart rate decreased	Enger et al., (1976)
River lamprey	0.1 - 20 µV/cm	Physiological, neural response	Muraveiko (1984)
Sea lamprey	1 – 10 mV/cm	Physiological, neural response	Bodznick et al. (1983)
Sturgeon	0.2 – 6 mV/cm	Behavioural response to increased electrical field.	Basov (1999)

Threshold levels for the sensitivity to electromagnetic fields are only known for a few of the species found in the western Baltic. The levels of the sensitivity compared to the levels of the fields due to power cables indicate that a possible effect will be restricted to a zone few meters from the cables. At greater distances the fields is predicted to be indistinguishable from the naturally occurring fields (Gill et al., 2005).

It can be concluded that the magnetic fields and induced electrical fields from power cables are detectable by a number of species and that many of these species may response to the fields. However, threshold values are only available for a few species and the responds on individual and population level is accordingly uncertain (Tasker et al., 2010).

4.6.2 **Artificial light**

Artificial light is known to influence fish behaviour either by phototaxi as with herring, mackerel and sprat or by photophobia with eel and salmon smolt (Cullen, et al., 2000; Westerberg, 1993). In the zero-alternative the main source of light pollution is the Rødby-Puttgarden ferries and the commercial shipping traffic in the T-line. The frequent departures of the ferries, each 30 minutes from both sites, during the night and the significant enlightening of the ferries causes a notable presence of light in the dark hours. However, with an absorption factor 0.27 m^{-1} (Jerlov, 1968 in: Westerberg, 1993) the reach of the light in the water would be rather small, limited to a few decametres.

On the other hand the silver eel migrates preferably in the dark hours in the surface, where the light from the ferries would be visible in a substantial distance. With the present time schedule the mean distance between the ferries would be 5 km, and it is questionable whether the eel would be affected by such a distant light source taken their often troublesome downstream migration in freshwater with frequent passages of artificial light sources into account.

Other existing pressures like commercial fishery, eutrophication and global warming will be out of scope or dealt with elsewhere in this report.

5. Assessment of zero-alternative

5.1 Hydrological regime

Hydrological changes are natural occurring pressure for fish in the Baltic Sea and marine species living here are specially adapted to the brackish water conditions with events of oxygen depletion in the deeper water layers. Important fish species such as cod, herring, sprat, plaice, dab and flounder spawns in the western Baltic. The salinity, temperature and oxygen content are important especially for species with pelagic eggs for e.g. the fertilisation success and buoyancy. These parameters are also important for the match-mismatch between copepods, the main larval prey and the predatory post yolk sac fish larvae. Furthermore, the water flow determines the dispersal of eggs and larvae. Thus, the hydrological conditions have a major impact on the recruitment success in the zero-alternative.

The hydrographic regime in the Baltic Sea is highly variable primarily due to the irregular inflow from the North Sea replenishing the deep water layers with oxygenrich high saline water. The magnitude of existing pressure from hydrological changes in the western Baltic Sea is highly variable both within and between years. The hydrographic parameter salinity has the largest impact on fish communities in Fehmarnbelt and thus the assessment is based on impacts from these.

The magnitude of pressure is based on baseline salinity measurements from station MS02 placed n the alignment corridor on the border between Germany and the German EEZ (Figure 5.1). This permanent moored station at 27 m depth measured the salinity hourly from surface to bottom at two m intervals from March 2009 to February 2011.

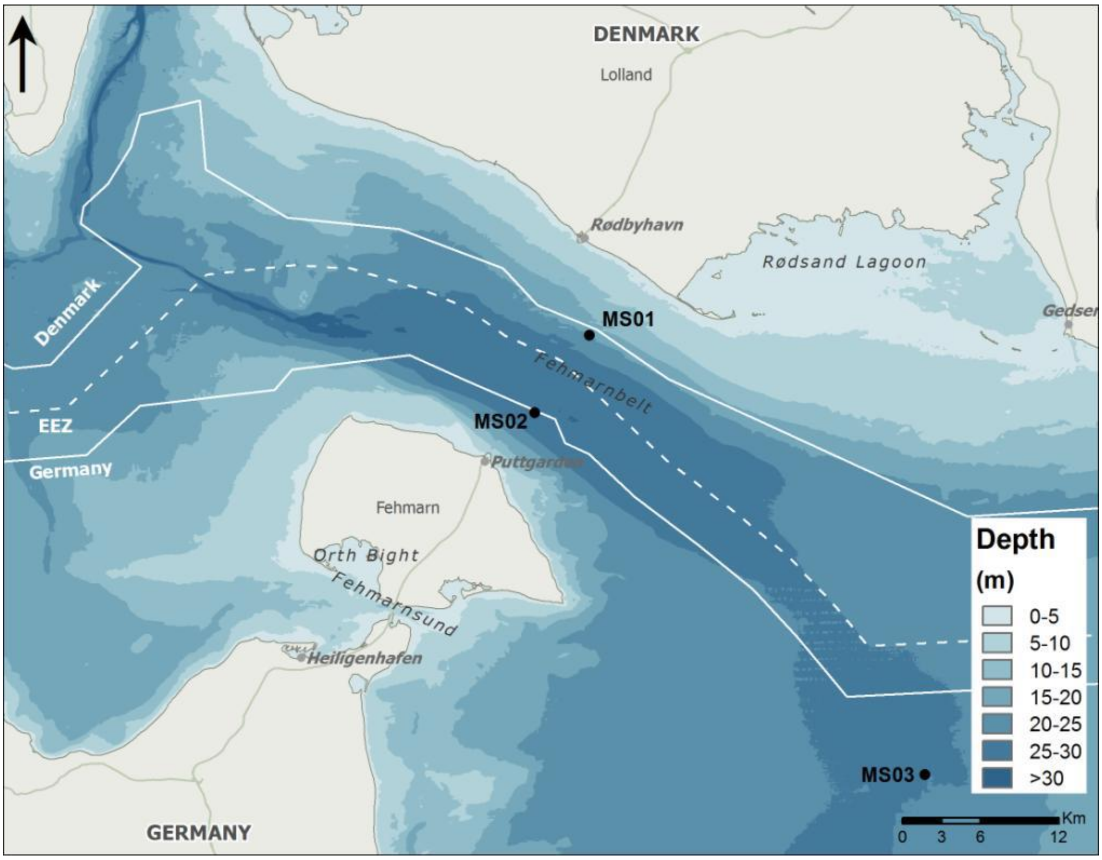


Figure 5.1: Map with the monitoring stations MS01, MS02 and MS03. Source: FEHY (2013b).

The buoyancy of cod, plaice and flounder eggs is studied in relation to this assessment. To stay buoyant in the water column pelagic eggs from cod, plaice and flounder are found to require salinities of 18.9, 17.6 and 20.7 psu, respectively. Figure 5.2 illustrates that especially flounder eggs are at risk of bottom contact and thus most sensitive to salinity changes or other parameters affecting the buoyancy. The salinity at station MS02 exceeded the threshold for cod 25 % of the time during winter (December-February 2010-2011), 20 % for plaice and 45 % for flounder. Flounder eggs are more sensitive to changes in salinity/buoyancy compared to other flatfish species.

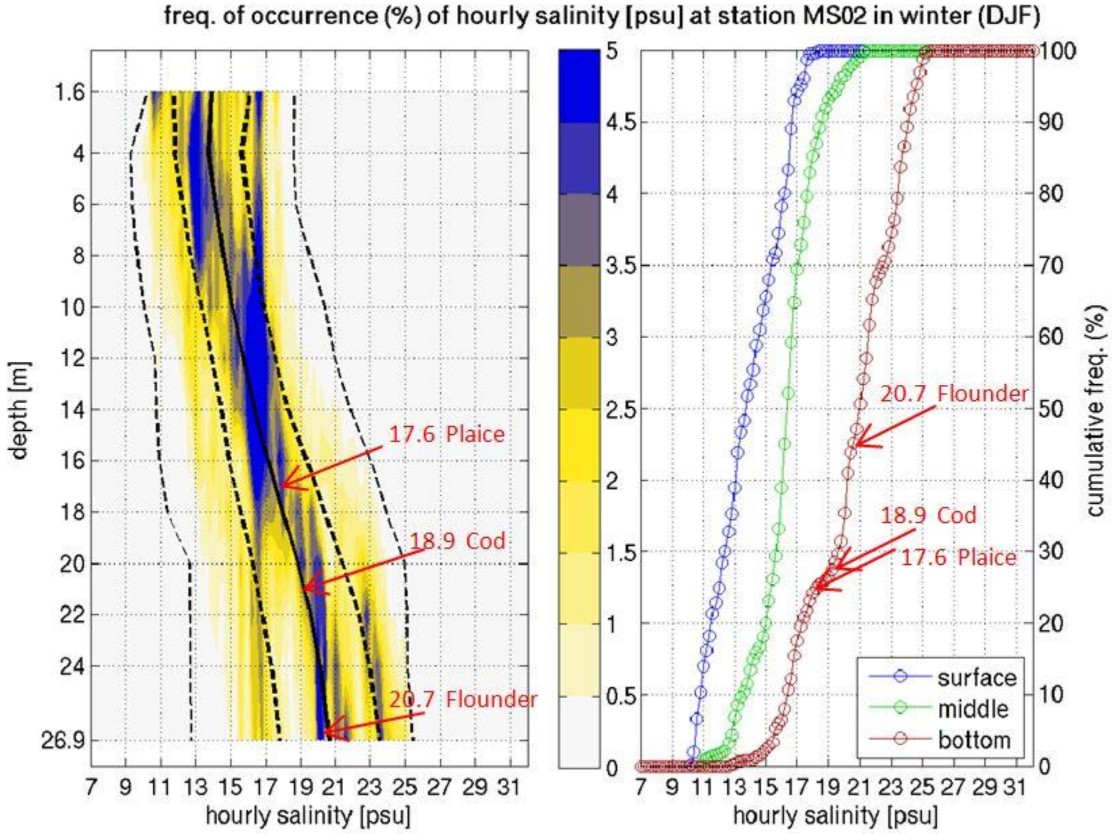


Figure 5.2: Frequency of occurrence (in % of time) of salinity (colour), temperature and buoyancy frequency MS02 in winter. Bold lines: averaged profile, bold dashed lines: averaged profile ± standard deviation, simple dashed lines: all-time minimum and maximum salinity at depth level, –o– : cumulative frequency of occurrence of salinity at uppermost, central and lowest observed depth levels (temperature and salinity interval when calculating percentage is 0.2 psu). Source: FEHY (2013b). Red figures correspond to salinities of neutral egg buoyancy found by experimental trials of plaice, cod and flounder to the present assessment, FeBEC.

Sprat eggs are limited by low temperature and the egg mortality increases at temperatures below 5ºC. The impact on sprat eggs was insignificant during the zero-alternative.

Periods of oxygen depletion in the deep water layers could impair the egg survival. During the baseline studies (FEHY, 2013b) the oxygen concentration at the bottom was below 2 ml/l from July to October 2010 in large areas of Fehmarnbelt. Thus, fish in the Baltic Sea experience oxygen depletion regularly during baseline conditions. This oxygen depletion at the bottom is critical for most fish species. However, juvenile and adult fish can avoid these areas whereas eggs are very sensitive to low oxygen concentrations. The main spawning seasons for plaice (winter), flounder (spring) and western Baltic cod (December-March) are outside the critical period where the oxygen concentration was below 2 ml/l.

In general eggs and larvae of pelagic spawning species such as cod and flatfish are highly affected by the hydrological conditions in the zero-alternative.

5.2 Suspended sediment and sedimentation

The amount of suspended sediments in the water column is a function of multitude parameters including sea bed material, water depth, current and wave conditions and loads from rivers and streams.

Sea bed
The central part of Fehmarnbelt and a large area towards the south-east are covered with layers of muddy sand and sandy mud. Mud is the dominating surface sediment in the Mecklenburg Bight, whereas sand and lag deposits dominate in the coastal areas around Rødbyhavn and Fehmarn. Surface sediment in Fehmarnbelt consists mainly of sand with relatively high content of fine-grained material. Contents of organic matter indicate accumulation of fine material and organic matter with highest values found along the Fehmarn coast while coarse sediments along the Lolland coast have only a low content of organic matter. Isotope dating of the sediment cores confirms that, in general, Fehmarnbelt is an accumulation area with rates of 1-2 mm/year.

Hydrographic conditions
Baseline analysis of hydrographic conditions and suspended sediment concentrations in Fehmarnbelt revealed that there were no fixed correlation between various hydrographic parameters and the level of suspended sediment concentrations (FEHY, 2013a).

Along the Danish coast and inside the Lagoon of Rødsand the concentration could be correlated to the wind speed and direction. However, identical wind conditions at specific sites did not always lead to the same level of sediment concentrations, which was assumed to be a result of limited availability of fine sediments. The measurements indicated an approximate threshold wind speed of 8 m/s before a significant increase in concentrations takes place at the Danish nearshore baseline stations.

In the deeper water of the Fehmarnbelt and at the near-shore baseline stations along the German coast the concentration of suspended sediment is suggested determined mainly by the general flow patterns in the region. The patterns can be very complex with upwellings and downwellings and it has therefore been difficult to relate the monitored sediment concentration to any hydrodynamic or meteorological situations (FEHY, 2013a).

Existing pressures
Until recently the concentration of suspended sediment in the area has been affected by dredging operations connected with the establishment of the wind farm at Rødsand 2. The dredging was performed mainly by backhoe dredgers that are known to spill about 2-5% of the dredged material (FEHY, 2013a). A large part of the sediment was coarser than 0.125 mm why only small amounts presumably left the work area. No measures of the suspended sediments from this activity have been obtained. The construction works started in spring 2009 and the park was opened 12. October 2010.

The ferries between Rødby and Puttgarden stir up sediment when they enter and leave the harbours. The amount is unknown but the effect in terms of suspended sediment plumes can be clearly seen on aerial photos. The ferries depart every half hour. Other ship traffic has similar effects in shallow water. The local fishing industry induces a pressure when trawling. Trawls will rip the bed and cause sediment resuspension. It will also loosen the top of the bed and make it more vulnerable for erosion.

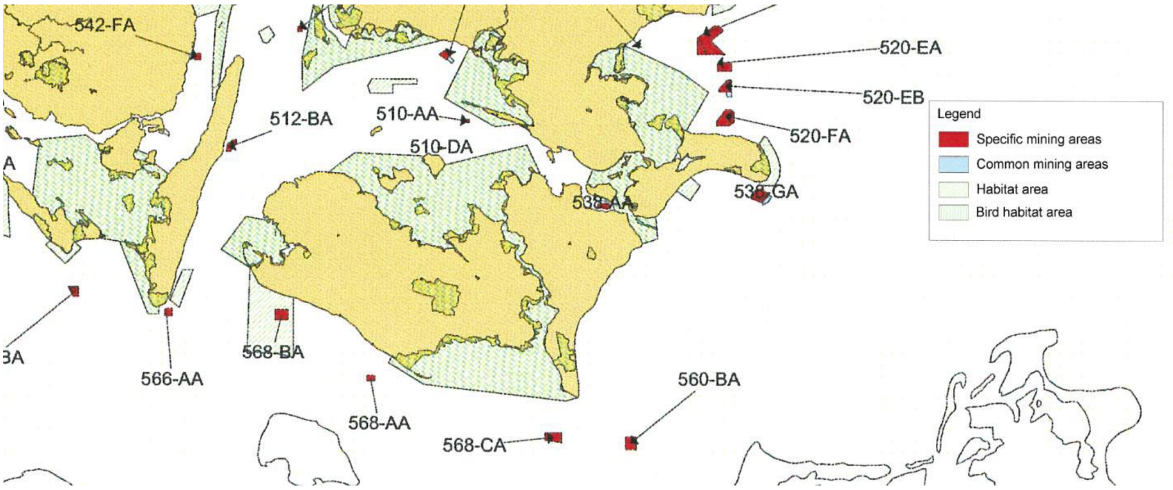


Figure 5.3: Human pressures in the Danish part of Fehmarnbelt . Source: modified from www. naturstyrelsen.dk in FEHY (2013a)

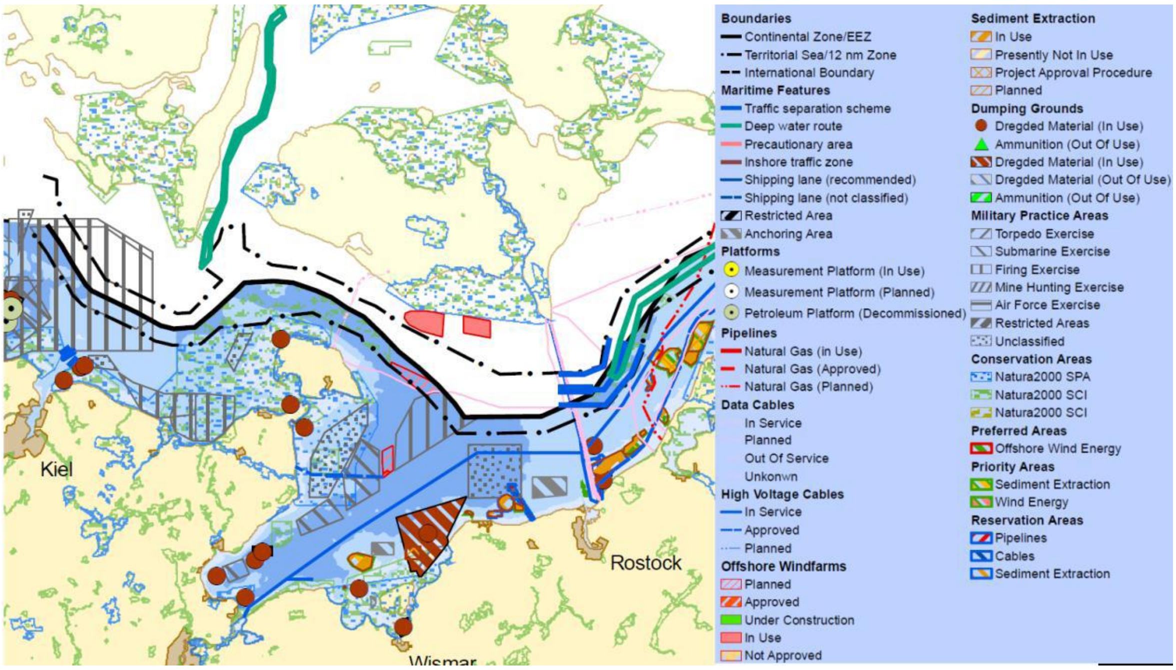


Figure 5.4: Known human pressures in the German part of Fehmarnbelt. Source: modified from www.bsh.de.

Background concentrations of suspended sediment

In general the average background levels of suspended sediment in the deeper parts of Fehmarnbelt were below 1 mg/l in the baseline years of 2009/2010. As shown in Figure 5.5 higher concentrations were measured at the coasts and particular in the Lagoon of Rødsand. Here the median concentrations reached 2.4 mg/l in the western part and 4.9 mg/l in the eastern part, mostly due to wind induced resuspension in the prevailing shallow waters.

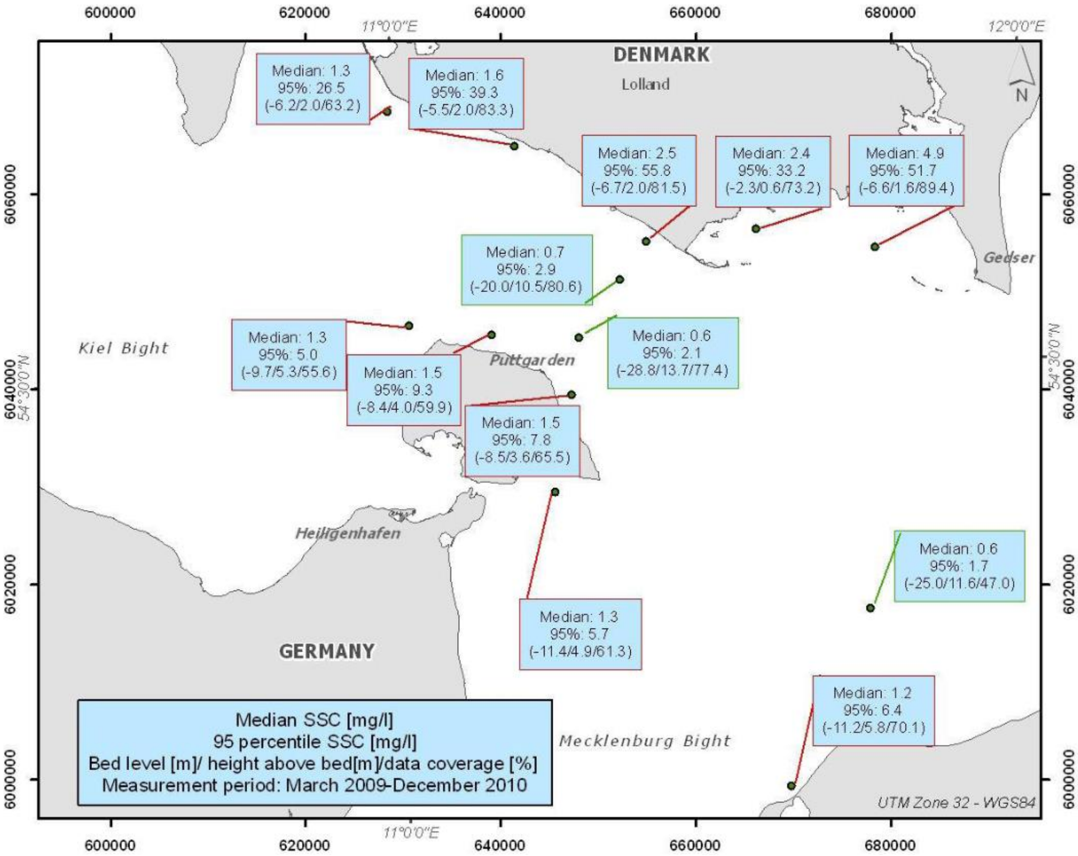


Figure 5.5: Overall statistics for suspended sediment concentration measured at baseline stations by FEHY 2009/2010. The values presented at the main stations (green stations) are from mid water measurements. Source: FEHY (2013a).

Although the medians at most stations during the baseline studies were below 2 mg/l the concentration exceeded 2 mg/l more than 20 % of the time at every coastal stations reaching 60-80 % in the lagoon of Rødsand (Figure 5.5). With respect to the two deep water stations 2 mg/l suspended sediment was exceeded 9.4 % respectively 6.4 % of the time (MS01 and MS02). In chapter 4.3.3 it is argued that a concentration of 2 mg suspended sediment/l might cause pelagic fish eggs to sink to the sea bottom, depending on the exposure time and the salinity of the sea water. From Table 5.1 follows that not only 2 mg/l but also 10 and 20 mg mg/l are exceeded at most stations some of the time, and it is therefore reasonable to presume that the background level of suspended sediment in Fehmarnbelt causes some mortality among pelagic fish eggs.

Table 5.1: Fractiles, fxx (xx %) in mg/l and exceedance times in %, Exx (xx mg/l) as measured at the measurement stations during 2009 and 2010. From FEHY (2013c).

Stations	f_{50} (mg/l)	F_{75} (mg/l)	F_{95} (mg/l)	E_2 (%)	E_{10} (%)	E_{20} (%)
NS01	1.1	1.9	12.5	24.2	6.7	2.3
NS02	1.5	3.8	28.0	38.2	13.8	7.9
NS03	2.2	6.4	23.9	52.9	16.5	6.6
NS04	2.4	6.0	33.2	60.1	17.4	9.2
NS05	5.0	15.3	51.9	79.9	33.5	19.8
NS06	1.3	1.9	5	22.6	1.3	0.2
NS07	1.5	2.7	9.6	34.2	4.7	1.3
NS08	1.5	2.4	7.9	32.4	3.8	1.4
NS09	1.3	1.9	5.8	22.4	2.6	0.9
NS10	1.2	2	6.5	24.6	2.1	0.6
MS01	0.7	1.1	3.0	9.4	0.3	0.0
MS02	0.7	1.0	2.3	6.4	0.3	0.0

It is noteworthy that the background concentrations measured in 2009-2010 are considerable higher than the modelled scenarios of the excess concentration of suspended sediment from the construction of the proposed link solutions. Even compared to the construction of the main tunnel solution, which according to the scanarios will cause most sediment spill, the background level is estimated to be more than 5 times higher at every apart from one station. In fact, according to the assessment methodology described in chapter 3.1.11, the exceedance percentages in Table 5.1 represent the reduction/loss of function of environmental factors with threshold values towards suspended sediment of 2 mg, 10 mg and 20 mg. In this view the natural background levels of suspended sediment in Fehmarnbelt potentially impacts fish in the area, which presumably particularly applies to the egg- and larvae drift in the area.

5.3 Noise and vibration

Noise scenarios in the zero-alternative are mostly restricted to noise emitted from commercial ships and ferries. ITAP measured the ambient noise as well as noise from a drilling rig and the prevailing ship traffic, and found that both the ambient noise and the noise from the drilling activity drowned in the substantial noise emitted from ships and ferries (ITAP, 2011). The measured noise from ships and ferries peaks at frequencies between 50-500 Hz which is within the hearing range of fish.

Measurements of the shipping noise were conducted using measurement buoys deployed at different locations in Fehmarnbelt. From the measured noise and from AIS data on ship traffic, noise maps were produced (Figure 5.6). There was very little variation in time in the noise scenarios, both during the day and during the year. The variation in space though was substantial. As expected, the highest underwater noise levels were measured near the main shipping routes, i.e. the T-route crossing the Fehmarnbelt from northwest to southeast and the Puttgarden-Rødby ferry.

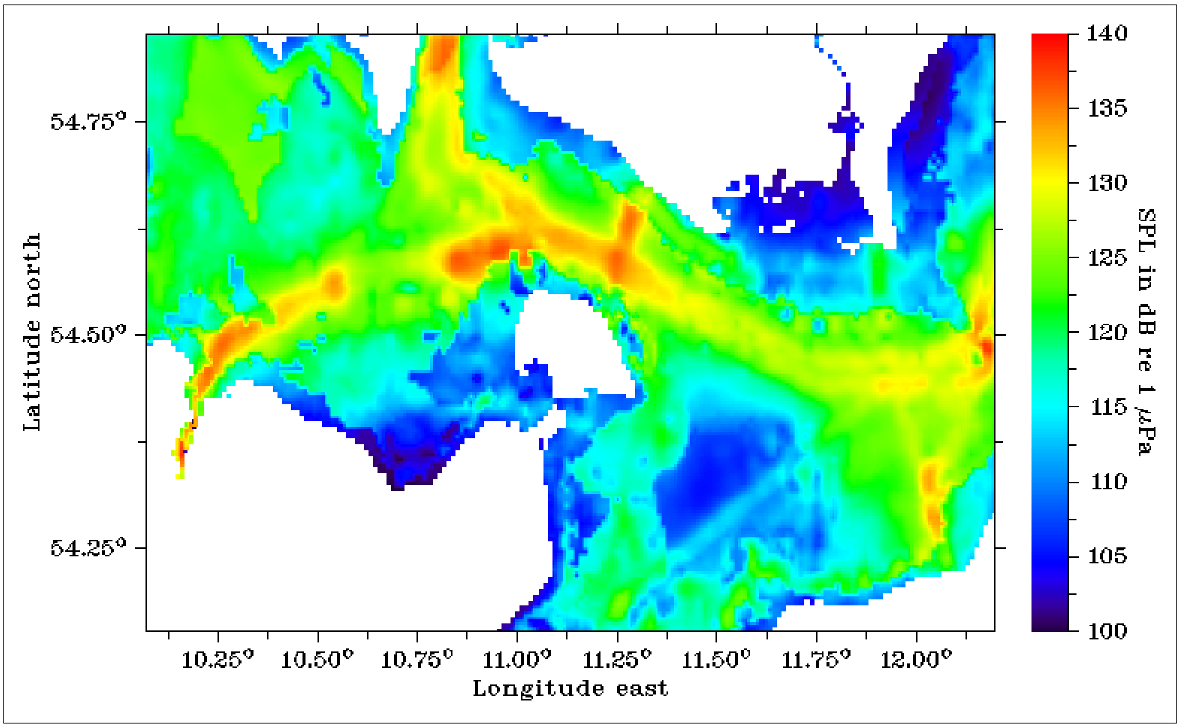


Figure 5.6: Noise map (median values) based on 12 months of shipping data for 2010. Source: ITAP (2011).

The magnitude of the area with noise exceeding the threshold limit for avoidance behaviour was calculated from the registered traffic and the emitted noise from ships and ferries. The traffic was measured by Rambøll (2011) using AIS and radar registrations. They estimated the yearly traffic to 46.200 ships in the east-west T-route and 38.400 ferry departures between Rødby and Puttgarden (Figure 5.7).

The average number of vessels present in Fehmarnbelt is dependent on the number of vessels entering the Fehmarnbelt and the speed of the vessels. Distributions for the speed over ground (SOG) based on AIS data at the T-route in Fehmarnbelt are shown in Figure 5.8. The mean speed was 12.85 nm.

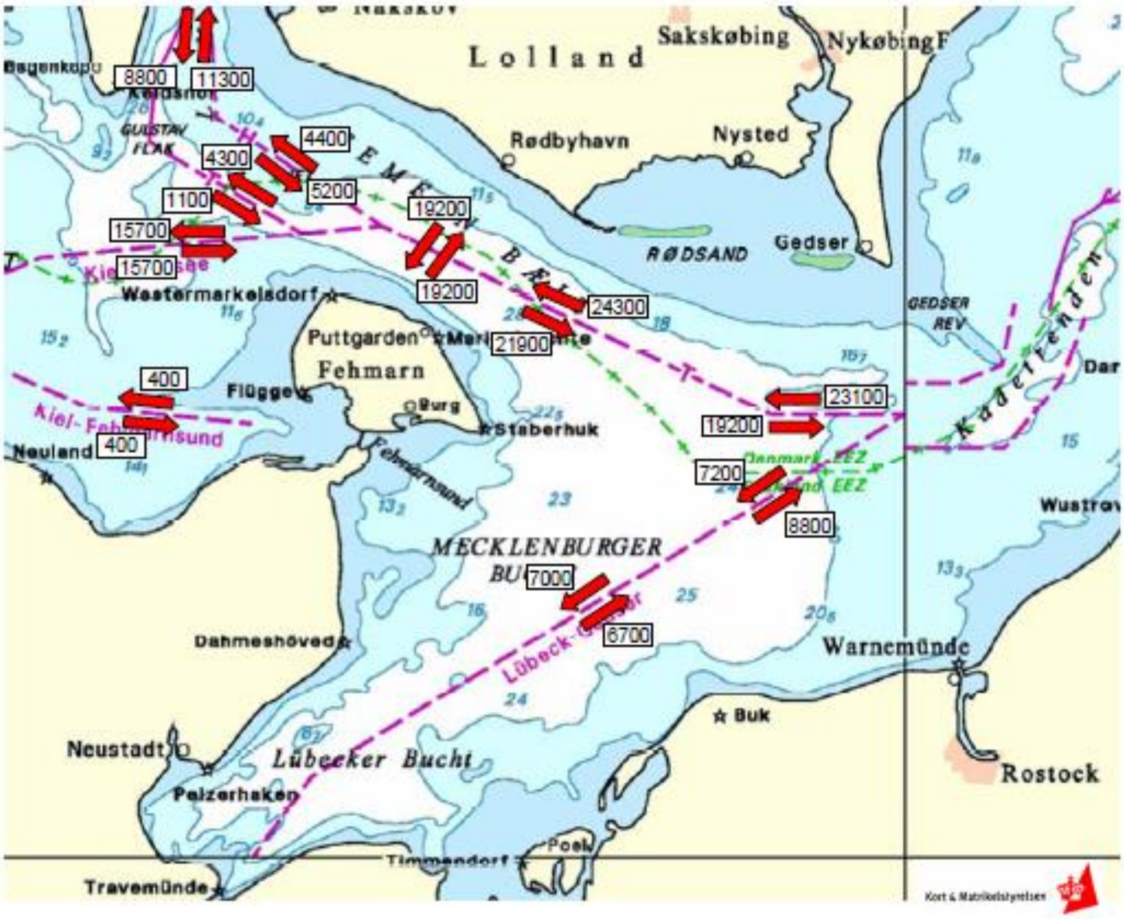


Figure 5.7: Estimated annual number of ship movements on main navigational routes in Fehmarnbelt determined on the basis of AIS data. Source: Rambøll (2011).

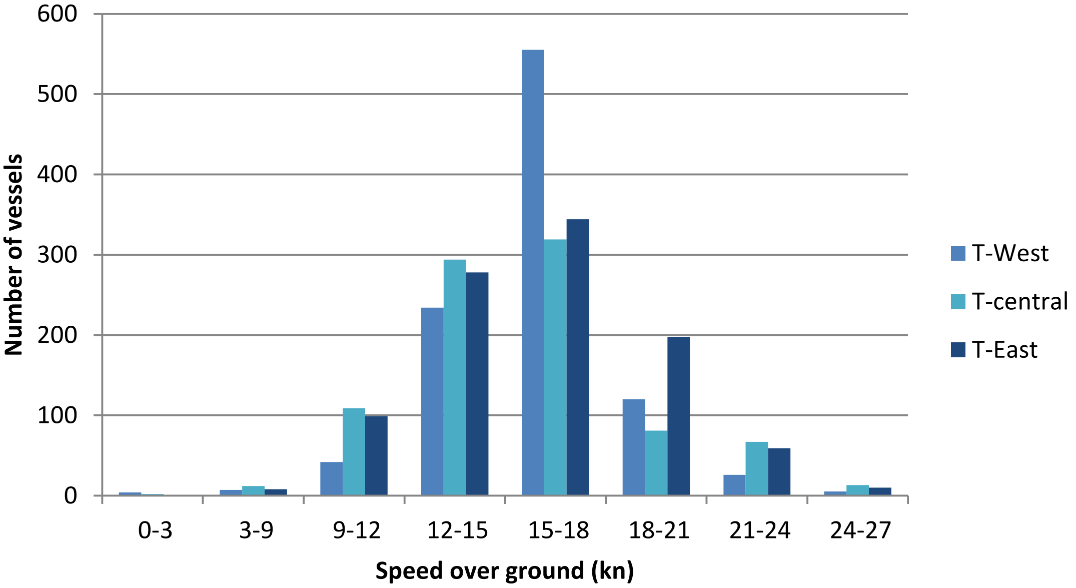


Figure 5.8: Distribution of the speed over ground based on AIS data at the T-route in Fehmarnbelt. Source: Rambøll (2011).

From the annual traffic, the calculated speed and the length of the specific areas, the mean number of vessels present in the specific areas in Fehmarnbelt was calculated as shown in Table 5.2.

Table 5.2: Mean number of vessels present in the specific areas in Fehmarnbelt.

Number of vessels present	Local area +/- 10 km			Near zone +/- 0.5 km	
	DK	EEZ	DE	DK	DE
Ferries				1.64	1.64
Other vessels		4.21		0.11	0.11

The messuremens performed by ITAP (2011) of the noise emitted from the ships in Fehmarnbelt showed a pronounced variation. In the summer the measured broadband ship noise varied in a distance of 1.000 m between 130-140 dB and in the winter between 123-133 dB re 1 µPa (Figure 5.9 and Figure 5.10). With a measured transmission loss of 60 dB in the summer period and 65 dB in the winter in a distance of 1000 m the source sound level could be estimated to 189-200 dB re 1 µPa. For the calculations of the range of the noise exceeding the threshold value a source level of 195 dB (all vessels) and a measured geometric loss factor of 22 were used (ITAP, 2011).

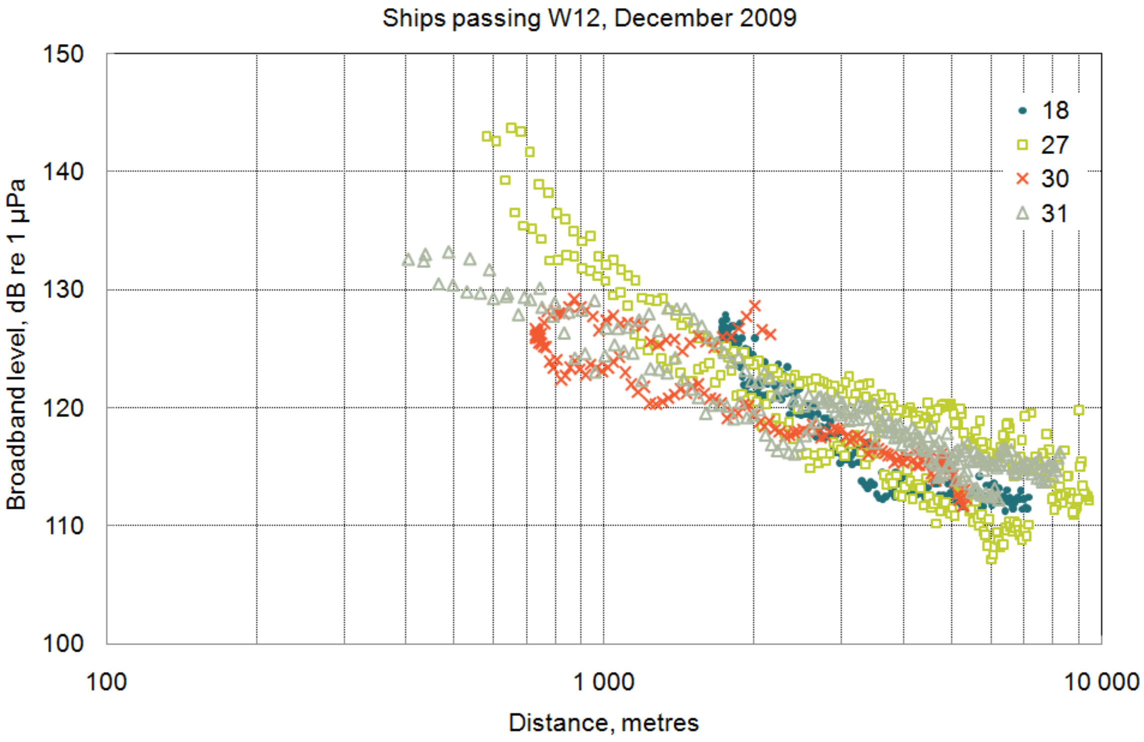


Figure 5.9: Broadband noise levels of ship passages in the winter as a function of distance between ship and measurement buoy for selected ship passages at position W12, December 2009. Source: ITAP (2011).

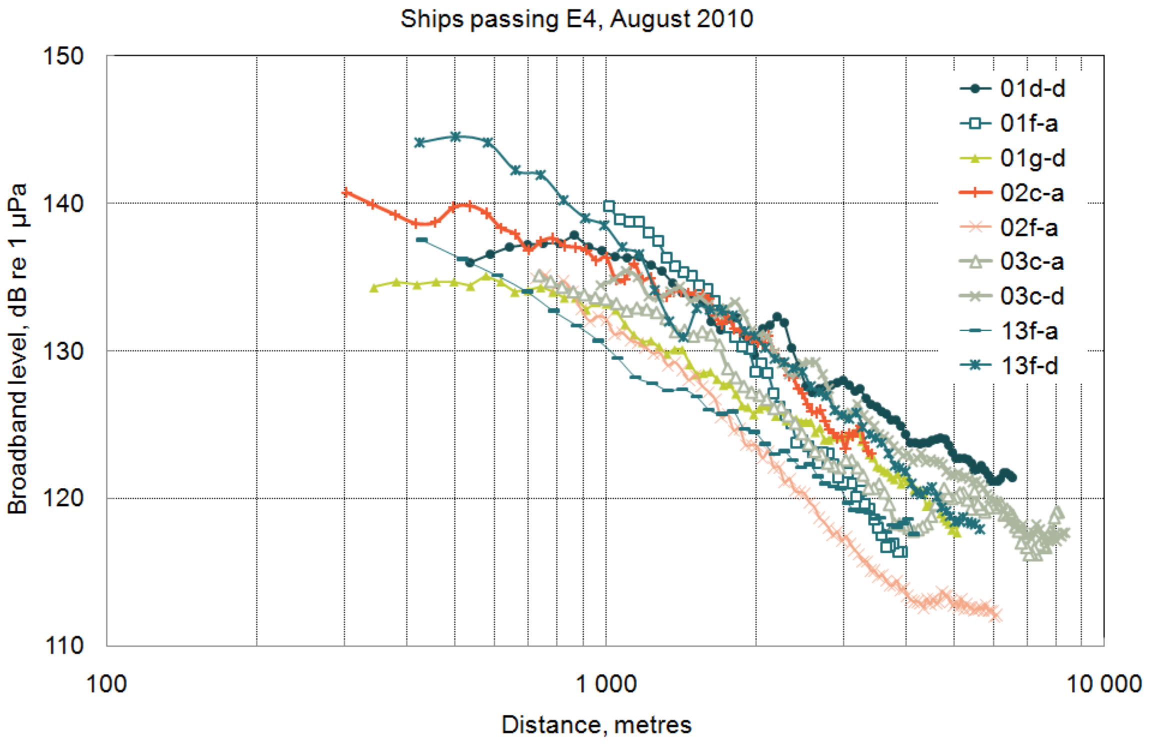


Figure 5.10: Broadband noise levels of ship passages as a function of distance between ship and measurement buoy for selected ship passages at position E4. Source: ITAP (2011).

The reduction of migration was calculated as the percentage of loss due to noise in the transection at the planned alignment corresponding to the near zone, and the reduction of the spawning, nursery and feeding areas were calculated as the percentage of area impacted. In total 4 % of the migration of gadoids/clupeids and less than 1 % of the migration of other species is potentially lost due noise from primarily the Rødby-Puttgarden ferries.

Other sources of noise and vibration.
The two offshore wind farms south of the Lagoon of Rødsand (Nysted and Rødsand 2) are considered a part of the zero-scenario. The emission of noise and vibration from offshore wind farms have been measured at several places (Figure 5.11) including Nysted and most noise have been recorded in the low frequency bands below 300 Hz.

There are no measurements to suggest that source levels of an operating wind turbine exceed 145 dB re 1 µPa (RMS), and such levels are the absolute highest back calculated from any reported measurements (Wahlberg, et al., 2005).

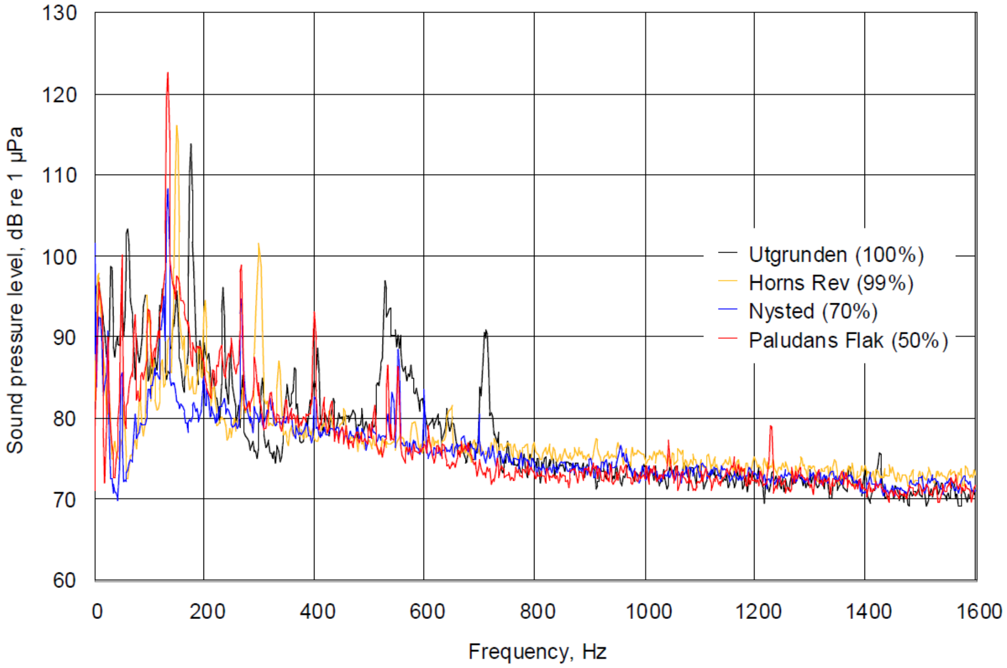


Figure 5.11: Narrowband spectra (2 Hz resolution) of noise radiated from offshore wind turbines. All measurements were made at 100 m distance. Values in brackets are approximate operating powers of the turbine during the measurement, with respect to its maximum power. Source: ISD et al. (2007) in BioConsult SH (2008).

In Nysted the peak sound pressure was 110 dB measured at 135 Hz 100 m from the mill corresponding to 140 dB at source level (BioConsult SH, 2008). This level is well below the threshold level for significant avoidance reactions of all the present fish species.

Even though most fish are sensitive to low frequent noise, the noise level from the operating turbines is too low to provoke any avoidance reactions except for the very close area within 4-7 m from the windmills, where vibrations might provoke avoidance reactions (Wahlberg, et al., 2005).

Thus, noise and vibrations from the offshore wind farms are not likely to have any significant impact on the fish migration or the fish communities in Fehmarnbelt.

Underwater noise and vibrations in the zero-alternative are predominantly caused by the heavy traffic by the Rødby-Puttgarden ferries. The only potential significant impact is on the spawning and feeding migration of cod, whiting, herring and sprat. These species will be able to hear the noise from the ships at any time throughout the alignment, but noise level exceeds only the threshold for avoidance reactions in a very limited part of the area. Furthermore it is highly questionable whether the fish actually would flee or just swim around to pass the alignment in a more quiet place.

6. Assessment of impacts of main tunnel alternative

6.1 Hydrological changes

Primarily the underwater structure of a Fehmarnbelt fixed link will impact the hydrodynamics causing changes in the water flow. However, as it is an immersed tunnel no impacts on the hydrographic parameters are expected. During the construction phase small temporary changes might occur, but these will only have a minor, if any, impact on the important fish species in the Baltic Sea. Especially, spawning, egg and larval drift and feeding (larvae) are sensitive to pressure from hydrological changes and are thus used as environmental indicators for these types of pressure.

6.1.1 **Magnitude of pressure**

The reduction of environmental components is determined as the difference between the background level and the duration and range of the hydrological pressures exceeding the specific threshold value for the specific environmental indicators.

The local area corresponding to a zone covering 10 km on each side of the alignment has been assessed. However, if worst case scenario for hydrological pressures is identified in an adjacent area this area will be assessed as well.

The natural hydrological conditions in the Baltic Sea vary greatly both between years and within a year. The impact from an immersed tunnel on the hydrology is very limited and the magnitude of pressure is very close to the fluctuations occurring in the zero-alternative.

Hydrological pressures will mainly be caused by the structure of a fixed link. The pressure of the structure is permanent. However, the sensitivity will vary throughout the year, because especially eggs and larvae are sensitive to hydrological changes. Additionally, the present hydrological conditions in the Baltic Sea are highly variable.

The blocking effect from reclamation areas and other parts of an immersed tunnel is extremely low and the flow blocking is only 0.01 % (FEHY, 2013b).

At the work harbour at Puttgarden and the immediate vicinity of the reclamation areas and the production facility access channel at the Lolland side there will be local effects to currents, but these effects are limited to very local areas. Thus the effects of salinities and temperature in Fehmarnbelt are very local and limited of size. Furthermore, there are no indications of effects from a tunnel on concentration of local dissolved oxygen (FEHY, 2013b).

The effects on local water quality in the Baltic Sea are assessed as non-existing due to the very limited permanent effects on the hydrography (FEHY, 2013b).

The temporary work during the construction period and the production facility structures does not add to the limited blocking effect seen in the permanent solution (FEHY, 2013b).

In summary, the regional effects of a tunnel are assessed to be insignificant based on the modelling of local effects showing no blocking of flow. Furthermore, the local effects to water quality are assessed to be insignificant as a result of the local model of the hydrodynamic (FEHY, 2013b).

As the effects of hydrography and water quality is assessed to be insignificant, the effects of a tunnel solution to the fish communities in Fehmarnbelt and adjacent areas are assessed to be insignificant.

Furthermore, the magnitude of hydrological pressures is insignificant compared to the current conditions. The mortality of pelagic eggs is already high due to the low salinity which prevents the eggs to stay buoyant in water layers with sufficient oxygen and not reach the bottom.

6.1.2 Degree of impairment

The assessment considers the reduction of environmental components relative to the background hydrological conditions.

The degree of impairment to fish communities due to effects to the hydrography will not be fully assessed as the effects are very local and limited.

The effects to salinity and water temperature in the water column in Fehmarnbelt are very local and of limited size and the effects on the Baltic Sea can be assessed as non-existing in practice. The impairment of spawning, eggs and larvae are only classified as minor.

The hydrography only has a minor impact on cod recruitment west of Fehmarnbelt and Mecklenburg Bight (Vitale, et al., 2008; Hüssy, 2011). Thus, a tunnel in Fehmarnbelt will mainly affect, if any impact, cod spawning east of the fixed link especially the Arkona Basin and the deep basins of the central Baltic Sea and not have any impact on the spawning areas west of Fehmarnbelt and Mecklenburg Bight.

It is assumed that the limited changes in salinity caused by a bridge will have an insignificant large-scale impact on the eastern Baltic cod recruitment through reduced abundance of larval prey (see chapter 7.1). It is assumed that a tunnel will have a smaller impact on salinity than a bridge. Thus a tunnel solution will not impact cod recruitment through decrease in larval abundance. Knowledge on the link between larval survival and prey availability in the western Baltic is lacking but it is expected that the salinity is less important for the copepod production in this area. Thus, an effect of a tunnel on the copepod production is assumed to be lower. Furthermore, the effect of climate change on zooplankton community is expected to be order of magnitude higher than the effects of a bridge in Fehmarnbelt.

The degree of the impairment caused by hydrological changes due to a tunnel in each area of investigation on each indicator selected for the present assessment is presented in Table 6.1.

Table 6.1: The degree of impairment among environmental subfactors concerning fish caused by changes in hydrological conditions in Fehmarnbelt due to a tunnel.

Degree of impairment of Hydrological regime, tunnel	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**	**Rødsand lagoon**
Cod							
Spawning (>15 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Herring							
Spawning (mod)	Minor		Minor	Minor		Minor	Minor
Sprat							
Spawning (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Flatfish							
Spawning (>15 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-

6.1.3 Severity and significance

The severity of impairment of hydrography from the construction of the E-ME tunnel solution is assessed as minor for all indicators selected for the present assessment (Table 6.2). Therefore, no impacts among fish and fish communities of the physical structures are expected.

Table 6.2: The severity of impariment caused by hydrological changes due to the structure of the E-ME-tunnel solution in Fehmarnbelt.

Severity of impairment/loss of Hydrological regime, tunnel, structure	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**	**Rødsand lagoon**
Cod							
Spawning (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Herring							
Spawning (mod)	Insignif.		Insignif.	Insignif.		Insignif.	Insignif.
Sprat							
Spawning (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Flatfish							
Spawning (>15 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-

6.2 Seabed reclamation

The construction of a Fehmarnbelt fixed link causes loss of marine habitats due to the physical structures. The loss partly occurs temporary but also permanent. A more temporary loss is expected in regard to the tunnel alternative. Construction harbours will be built in Rødbyhavn and Puttgarden. Furthermore, a temporary loss is expected to occur when lowering and inserting the tunnel elements to the seabed. After completion of the tunnel the construction based infrastructure will be scaled back. Along the construction corridor the original seabed structure will be restored by natural sedimentation. Based on the footprints of the tunnel alternative, a permanent loss of marine habitats will occur within those coastal areas of Lolland and Fehmarn in which the tunnel entrances will be build (approach to the landworks) and by the reclamation areas.

In relation to migration behaviour of fish (e.g. cod, herring, eel or salmon) it is assumed that the physical structures by the immersed tunnel do not create avoidance reactions like suspended sediment, noise or light does. Physical structures like approach ramp or access channel do not impair fish and fish are not negatively sensitive to any physical structures. Actually, physical structures tend to attract fish. Barrier effects in relation to physical structures only exist if they in any way impair fish migration. This only occur if the physical structure gives rise to entrapment in dead ends or if openings are so narrow that the passage is hampered by crowding or by high water currents or turbulence.

A physical structure, like the immersed tunnel, comprising of approach ramps, access channel does not give rise to neither dead ends nor any specific narrowing. In fact, as already described, the impairment from a tunnel on the flow regime is insignificant.

Since fish are not sensitive to physical structures and the physical structures are not creating any pressures in relation to migration (no blockage) the degree of impairment is minor.

6.2.1 **Magnitude of pressure**

The magnitude of pressure in terms of seabed reclamation (loss) is defined by the spatial size of footprint or by the direct loss of area caused by the physical structures.

Permanent changes caused by the protection layer will only occur within the areas of the access channels (near-shore areas). Reclamation areas are planned for both coasts. Within these areas the major part of the seabed material from the tunnel trench will be used (see Femern A/S, 2011). The planned reclamation areas at Fehmarn and Lolland cause new shorelines and thus permanently alter the original structure and function of the seabed. For the benthic fish communities the whole tunnel trench is classified as temporary long-term because the recovering of the protection layer with original substrate is not part of the construction process. It will be recovered with original substrate sometime after completion of the project by currents, wind and waves. Within small areas (Germany 7.3 ha, Denmark 7.2 ha) of the working harbours the recovering of the protection layer with original substrate is part of the construction process. The changes are therefore temporary short-term. For the pelagic species the changes in the entire tunnel trench is regarded as temporary short-term.

In total, an area of 584.2 ha will be lost by the construction of the immersed tunnel within the Femarnbelt region. This includes the permanent loss of seabed area as a result of the “permanent” physical structures as well as the temporary loss of seabed area resulting from the installation of the “temporary long-term” and the “temporary short-term” physical tunnel structures during the construction phase (see Table 6.3).

Table 6.3: Footprint area for the different physical tunnel structures and footprint categories for benthic and pelagic fish species.

Footprint category	Tunnel structures	Area loss (ha) Benthic		Pelagic
1 ("permanent"; ≥8 years)	Reclamation areas Elevated protection reefs Access channel to working harbour at Lolland coast	Danish waters	367.5	367.5
		German waters	20.3	20.3
		German EEZ	-	-
		German national	20.3	20.3
		Overall	387.8	387.8
2 ("temporary long-term" 3 – 8 years)	Tunnel trench	Danish waters	77.5	
		German waters	104.2	
		German EEZ	55.9	
		German national	48.5	
		Overall	181.9	
3 ("temporary short-term", ≤3 years)	Physical tunnel structures at landfall areas. For pelagic species the entire tunnel trench.	Danish waters	7.2	84.7
		German waters	7.3	111.5
		German EEZ		55.9
		German national	7.3	55.8
		Overall	14.5	196.4
		Total	584.2	584.2

As shown in Table 6.3, the installation of permanent physical tunnel structures along the alignment will cause the largest loss of seabed area within the Fehmarnbelt region. A total area of 387.8 ha will be lost by the installation of the permanent physical tunnel structures: the access channel at the coast of Lolland, the elevated protection reefs and the reclamation areas at the coast of Fehmarn and Lolland. The reclamation area at the coast of Lolland (329.1 ha) is about 23 times larger than the reclamation area at the coast of Fehmarn (14.3 ha). Furthermore, an access channel will only be installed at the coast of Lolland. Thus, the loss of seabed area due to permanent physical tunnel structures will be markedly higher in Danish waters than in German waters.

The construction of temporary long-term and temporary short-term physical tunnel structures will also lead to a temporary loss of seabed area (Table 6.3). However, the loss of seabed area due to temporary long-term and temporary short-term physical tunnel structures is relatively low compared to permanent physical tunnel structures. Similar to the permanent components, differences in the level of seabed area loss between German and Danish waters is expected. The loss of seabed area caused by temporary long- and short-term physical tunnel structures will be larger in German waters compared to Danish waters.

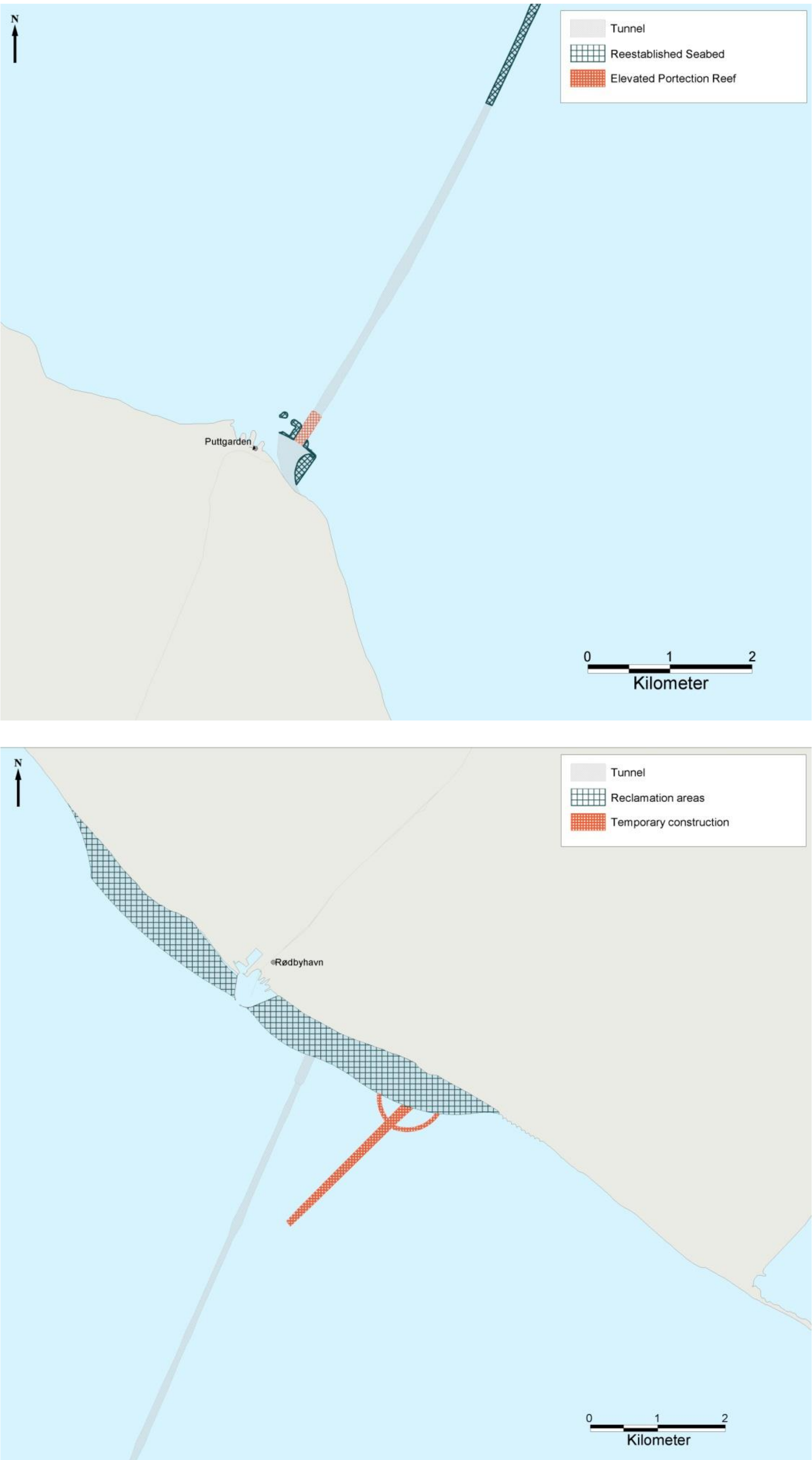


Figure 6.1: Overview of the various footprints (Fehmarn above; Lolland below).

According to the general assessment methodology, severity of loss and severity of impairment is used to describe the impact of permanent and temporary seabed reclamation on the respective environmental component and associated indicators. Both severities were determined by the ecology of the respective species and the resulting consequences of seabed reclamation on their population dynamic. For species which depends directly on the availability of seabed habitats, the severity of loss was applied when installations of permanent construction components leads to a habitat loss. For all other species, the severity of impairment was used.

For the impact assessment of temporary construction components, only the severity of impairment was used assuming that temporary habitat losses lead to temporary impairment only.

The degree of impairment for the respective construction components (category 1-3) was derived from estimated habitat loss (% of the total important area within in the near zone).

6.2.2 Degree of impairment

The impacts of footprints related to the physical tunnel structures (category 1-3) were assessed by comparing the footprints with the importance maps compiled for the respective component (species) and the associated indicator (spawning, egg-larvae drift, nursery, feeding and migration). The results of the analyses of the reduction of environmental components and the degree of impairment are separately presented for the three tunnel construction components (category 1-3).

Habitat loss caused by seabed reclamation is only expected in the near zone (German 500 m zone, German 500 m EEZ zone and Danish 500 m zone) as all structures are found within the near zone.

Permanent physical tunnel structures:
The permanent physical tunnel structures (category 1) will cause a permanent habitat loss for almost all components and associated indicators (Table 6.4). The habitat loss was only relatively high for shallow water species (including sea stickleback) as well as for species which use shallow waters as nursery area (e.g. cod, whiting and herring). In contrast, the habitat loss was relatively low for all other species. The permanent physical structures will not cause any permanent habitat loss for snake blenny.

A low degree of impairment (0 %) in relation to the migratory species cod, herring, eel and salmon (protected species) is expected, as described in chapter 6.2.

Table 6.4: Estimated area loss for the respective component and associated indicator resulting from the permanent physical tunnel structures in the Fehmarnbelt region (in % (ha) of the total importance area within the near zone).

Reduction of environmental subcomponents by seabed reclamation permanent, tunnel	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (3.1)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (3.1)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	15.2 (20.1)	0.0 (0.0)	32.9 (362.9)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.9 (10.4)	0.0 (0.0)	5.7 (84.8)
Migration (> 5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0))
Whiting						
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.5 (20.1)	0.0 (0.0)	19.3 (366.2)
Migration (>5m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Herring						
Spawning (mod)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.4 (20.1)	0.0 (0.0)	30.6 (37.2)
Egg-larvae drift (>2 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.7 (16.7)	0.0 (0.0)	15.1 (286.5)
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.5 (20.1)	0.0 (0.0)	19.3 (366.2)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.9 (10.4)	0.0 (0.0)	5.7 (84.8)
Migration (>5m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Sprat						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (3.1)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (3.1)
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.5 (20.1)	0.0 (0.0)	19.3 (366.2)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.9 (10.4)	0.0 (0.0)	5.7 (84.8)
Migration (>5m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Flatfish						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (3.1)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (3.1)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	15.2 (20.1)	0.0 (0.0)	32.9 (362.9)
Feeding (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.5 (20.1)	0.0 (0.0)	19.3 (366.2)
Migration (>5m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Shallow water species						
Spawning (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	15.2 (20.1)	0.0 (0.0)	32.9 (362.9)
Egg-larvae drift (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	15.2 (20.1)	0.0 (0.0)	32.9 (362.9)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	15.2 (20.1)	0.0 (0.0)	32.9 (362.9)
Feeding (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	15.2 (20.1)	0.0 (0.0)	32.9 (362.9)
Eel						
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	15.2 (20.1)	0.0 (0.0)	32.9 (362.9)
Feeding (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	15.2 (20.1)	0.0 (0.0)	32.9 (362.9)
Migration (>2m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Sea stickleback						
Spawning	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	41.7 (327.9)
Egg-larvae drift	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	41.7 (327.9)
Nursery	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	41.7 (327.9)
Feeding	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	41.7 (327.9)
Snake blenny						
Spawning (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Egg-larvae drift (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Nursery (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Feeding (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Protected species						
Migration (>5m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Temporary long-term physical tunnel structures:
The temporary long-term physical structures will cause a temporary habitat loss for all benthic components and associated indicators (Table 6.5). The level of habitat loss, however, is relatively small for all components and associated indicators (below 12 % of important area within the near zone).

Table 6.5: Estimated area loss for the respective component and associated indicator resulting from the temporary long-term physical tunnel structures in the Fehmarnbelt region (in % (ha) of the total importance area within the near zone).

Reduction of environmental subcomponents by seabed reclamation temporary long-term, tunnel	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	10.0 (44.8)	11.4 (55.9)	8.2 (64.9)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	10.0 (44.8)	11.4 (55.9)	8.2 (64.9)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (3.7)	0.0 (0.0)	1.1 (12.4)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.8 (48.5)	11.4 (55.9)	5.2 (77.3)
Migration (> 5 m)	-	-	-	-	-	-
Whiting						
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.4 (48.5	11.4 (55.9)	4.1 (77.3)
Migration (>5m)	-	-	-	-	-	-
Herring						
Spawning (mod)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.1 (4.3)	0.0 (0.0)	0.0 (0.0)
Egg-larvae drift (>2 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Migration (>5m)	-	-	-	-	-	-
Sprat						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Migration (>5m)	-	-	-	-	-	-
Flatfish						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	10.0 (44.8)	11.4 (55.9)	8.2 (64.9)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	10.0 (44.8)	11.4 (55.9)	8.2 (64.9)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (3.7)	0.0 (0.0)	1.1 (12.4)
Feeding (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.4 (48.5	11.4 (55.9)	4.1 (77.3)
Migration (>5m)	-	-	-	-	-	-
Shallow water species						
Spawning (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (3.7)	0.0 (0.0)	1.1 (12.4)
Egg-larvae drift (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (3.7)	0.0 (0.0)	1.1 (12.4)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (3.7)	0.0 (0.0)	1.1 (12.4)
Feeding (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (3.7)	0.0 (0.0)	1.1 (12.4)
Eel						
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (3.7)	0.0 (0.0)	1.1 (12.4)
Feeding (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (3.7)	0.0 (0.0)	1.1 (12.4)
Migration (>2m)	-	-	-	-	-	-
Sea stickleback						
Spawning	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.6 (4.8)
Egg-larvae drift	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.6 (4.8)
Nursery	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.6 (4.8)
Feeding	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.6 (4.8)
Snake blenny						
Spawning (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	9.4 (21.5)	11.4 (55.9)	8.0 (18.0)
Egg-larvae drift (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	9.4 (21.5)	11.4 (55.9)	8.0 (18.0)
Nursery (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	9.4 (21.5)	11.4 (55.9)	8.0 (18.0)
Feeding (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	9.4 (21.5)	11.4 (55.9)	8.0 (18.0)
Protected species						
Migration (>5m)	-	-	-	-	-	-

Temporary short-term:
The temporary short-term physical tunnel structures will cause a temporary habitat loss for all components and associated indicators (Table 6.6). The level of habitat loss, however, is relatively small for most of the components and the associated indicators (below 10 % of important area within the near zone). Only for the pelagic species herring and sprat, a higher level of habitat loss (55.4 ha = 11.4 % of important area within the near zone) was assessed.

Table 6.6: Estimated area loss for the respective component and associated indicator resulting from the temporary short-term physical tunnel structures in the Fehmarnbelt region (in % (ha) of the total importance area within the near zone).

Reduction of environmental subcomponents by seabed reclamation temporary short-term, tunnel	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	5.5 (7.3)	0.0 (0.0)	0.7 (7.2)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.1 (5.9)	0.0 (0.0)	0.5 (6.8)
Migration (> 5 m)	-	-	-	-	-	-
Whiting						
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.3 (7.3)	0.0 (0.0)	0.4 (7.2)
Migration (>5m)	-	-	-	-	-	-
Herring						
Spawning (mod)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	5.3 (7.3)	0.0 (0.0)	2.8 (3.4)
Egg-larvae drift (>2 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	9.7 (55.8)	11.4 (55.9)	4.5 (84.5)
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	9.7 (55.8)	11.4 (55.9)	4.5 (84.5)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	9.9 (54.4)	11.4 (55.9)	5.7 (84.1)
Migration (>5m)	-	-	-	-	-	-
Sprat						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	10.0 (44.8)	11.4 (55.9)	8.2 (64.9)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	10.0 (44.8)	11.4 (55.9)	8.2 (64.9)
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	9.7 (55.8)	11.4 (55.9)	4.5 (84.5)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	9.9 (54.4)	11.4 (55.9)	5.7 (84.1)
Migration (>5m)	-	-	-	-	-	-
Flatfish						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	5.5 (7.3)	0.0 (0.0)	0.7 (7.2)
Feeding (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.3 (7.3)	0.0 (0.0)	0.4 (7.2)
Migration (>5m)	-	-	-	-	-	-
Shallow water species						
Spawning (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	5.5 (7.3)	0.0 (0.0)	0.6 (7.2)
Egg-larvae drift (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	5.5 (7.3)	0.0 (0.0)	0.6 (7.2)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	5.5 (7.3)	0.0 (0.0)	0.6 (7.2)
Feeding (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	5.5 (7.3)	0.0 (0.0)	0.6 (7.2)
Eel						
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	5.5 (7.3)	0.0 (0.0)	0.7 (7.2)
Feeding (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	5.5 (7.3)	0.0 (0.0)	0.7 (7.2)
Migration (>2m)	-	-	-	-	-	-
Sea stickleback						
Spawning	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.9 (7.1)
Egg-larvae drift	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.9 (7.1)
Nursery	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.9 (7.1)
Feeding	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.9 (7.1)
Snake blenny						
Spawning (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Egg-larvae drift (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Nursery (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Feeding (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Protected species						
Migration (>5m)	-	-	-	-	-	-

According to general assessment methodology, the impact was determined for all physical tunnel structures. These include the permanent, the temporary long-term as well as the temporary short-term physical tunnel structures. Only for species which depend on the availability of "seabed" habitats, the "severity of loss" was determined.

Permanent physical tunnel structures:

The permanent physical tunnel structures within the German National waters will cause a low impairment for all species and associated indicators (Table 6.7). In contrast, the permanent physical tunnel structures in Danish waters will cause variable degrees of impairment, due to the small size of the considered area. The degree of impairment is "very high" for the indicators "larvae drift" (herring), "nursery" (whiting, herring and sprat), "medium" for the indicator "feeding" (cod, herring and sprat) and "low" for all remaining indicators.

Table 6.7: The degree of impairment (permanent) for each environmental component based on the pressure indicators and the loss of seabed (%) for the near (500 m on both sides of the middle of the alignment corridor) and the local zone (10 km on both sides of the middle of the alignment corridor).

Degree of impairment by seabed reclamation permanent, tunnel	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Spawning (> 10 m)	-	-	-	-	-	Minor
Egg-larvae drift (>10 m)	-	-	-	-	-	Minor
Feeding (>5 m)	-	-	-	Minor	-	Medium
Migration (> 5 m)	-	-	-	Minor	-	Minor
Whiting						
Nursery (>0 m)	-	-	-	Minor	-	Very high
Migration (>5m)	-	-	-	Minor	-	Minor
Herring						
Larvae drift (>2 m)	-	-	-	Minor	-	Very high
Nursery (>0 m)	-	-	-	Minor	-	Very high
Feeding (>5 m)	-	-	-	Minor	-	Medium
Migration (>5m)	-	-	-	Minor	-	Minor
Sprat						
Spawning (> 10 m)	-	-	-	-	-	Minor
Egg-larvae drift (>10 m)	-	-	-	-	-	Minor
Nursery (>0 m)	-	-	-	Minor	-	Very high
Feeding (>5 m)	-	-	-	Minor	-	Medium
Migration (>5m)	-	-	-	Minor	-	Minor
Flatfish						
Egg-larvae drift (>10 m)	-	-	-	-	-	Minor
Migration (>5m)	-	-	-	Minor	-	Minor
Eel						
Migration (>2m)	-	-	-	Minor	-	Minor
Protected species						
Migration (>5m)	-	-	-	Minor	-	Minor

Temporary long-term physical tunnel structures:

Physical tunnel structures and associated temporary habitat loss will have a medium or low impact on the population dynamics of the different species (Table 6.6). Only for species residing in the deeper areas of the Fehmarnbelt region, a medium impact was assessed.

Table 6.8: The degree of impairment (temporary long-term) for each environmental component based on the pressure indicators and the loss of seabed (%) for the near (500 m on both sides of the middle of the alignment corridor) and the local zone (10 km on both sides of the middle of the alignment corridor).

Degree of impairment by seabed reclamation temporary long-term, tunnel	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Spawning (> 10 m)	-	-	-	Medium	Medium	Medium
Egg-larvae drift (>10 m)	-	-	-	Medium	Medium	Medium
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (>5 m)	-	-	-	Medium	Medium	Minor
Migration (> 5 m)	-	-	-	-	-	-
Whiting						
Nursery (>0 m)	-	-	-	Medium	Medium	Minor
Migration (>5m)	-	-	-	-	-	-
Herring						
Spawning (mod)	-	-	-	Minor	-	-
Egg-larvae drift (>2 m)	-	-	-	-	-	-
Nursery (>0 m)	-	-	-	-	-	-
Feeding (>5 m)	-	-	-	-	-	-
Migration (>5m)	-	-	-	-	-	-
Sprat						
Spawning (> 10 m)	-	-	-	-	-	-
Egg-larvae drift (>10 m)	-	-	-	-	-	-
Nursery (>0 m)	-	-	-	-	-	-
Feeding (>5 m)	-	-	-	-	-	-
Migration (>5m)	-	-	-	-	-	-
Flatfish						
Spawning (> 10 m)	-	-	-	Medium	Medium	Medium
Egg-larvae drift (>10 m)	-	-	-	Medium	Medium	Medium
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (>0 m)	-	-	-	Medium	Medium	Minor
Migration (>5m)	-	-	-	-	-	-
Shallow water species						
Spawning (<10 m)	-	-	-	Minor	-	Minor
Egg-larvae drift (<10 m)	-	-	-	Minor	-	Minor
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (<10 m)	-	-	-	Minor	-	Minor
Eel						
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (<10 m)	-	-	-	Minor	-	Minor
Migration (>2m)	-	-	-	-	-	-
Sea stickleback						
Spawning	-	-	-	-	-	Minor
Egg-larvae drift	-	-	-	-	-	Minor
Nursery	-	-	-	-	-	Minor
Feeding	-	-	-	-	-	Minor
Snake blenny						
Spawning (>20 m)	-	-	-	Medium	Medium	Medium
Egg-larvae drift (>20 m)	-	-	-	Medium	Medium	Medium
Nursery (>20 m)	-	-	-	Medium	Medium	Medium
Feeding (>20 m)	-	-	-	Medium	Medium	Medium
Protected species						
Migration (>5m)	-	-	-	-	-	-

Temporary short-term tunnel construction components:

Physical tunnel structures and associated temporary short-term habitat loss will have only a low impairment on the different species (Table 6.9).

Table 6.9: The degree of impact (temporary short-term) for each environmental component based on the pressure indicators and the loss of seabed (%) for the near (500 m on both sides of the middle of the alignment corridor) and the local zone (10 km on both sides of the middle of the alignment corridor).

Degree of impact by seabed reclamation seabed temporary short-term, tunnel	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Spawning (> 10 m)	-	-	-	-	-	-
Egg-larvae drift (>10 m)	-	-	-	-	-	-
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (>5 m)	-	-	-	Minor	-	Minor
Migration (> 5 m)	-	-	-	-	-	-
Whiting						
Nursery (>0 m)	-	-	-	Minor	-	Minor
Migration (>5m)	-	-	-	-	-	-
Herring						
Spawning (mod)	-	-	-	Minor	-	Minor
Egg-larvae drift (>2 m)	-	-	-	Minor	Minor	Minor
Nursery (>0 m)	-	-	-	Minor	Minor	Minor
Feeding (>5 m)	-	-	-	Minor	Minor	Minor
Migration (>5m)	-	-	-	-	-	-
Sprat						
Spawning (> 10 m)	-	-	-	Minor	Minor	Minor
Egg-larvae drift (>10 m)	-	-	-	Minor	Minor	Minor
Nursery (>0 m)	-	-	-	Minor	Minor	Minor
Feeding (>5 m)	-	-	-	Minor	Minor	Minor
Migration (>5m)	-	-	-	-	-	-
Flatfish						
Spawning (> 10 m)	-	-	-	-	-	-
Egg-larvae drift (>10 m)	-	-	-	-	-	-
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (>0 m)	-	-	-	Minor	-	Minor
Migration (>5m)	-	-	-	-	-	-
Shallow water species						
Spawning (<10 m)	-	-	-	Minor	-	Minor
Egg-larvae drift (<10 m)	-	-	-	Minor	-	Minor
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (<10 m)	-	-	-	Minor	-	Minor
Eel						
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (<10 m)	-	-	-	Minor	-	Minor
Migration (>2m)	-	-	-	-	-	-
Sea stickleback						
Spawning	-	-	-	-	-	Minor
Egg-larvae drift	-	-	-	-	-	Minor
Nursery	-	-	-	-	-	Minor
Feeding	-	-	-	-	-	Minor
Snake blenny						
Spawning (>20 m)	-	-	-	-	-	-
Egg-larvae drift (>20 m)	-	-	-	-	-	-
Nursery (>20 m)	-	-	-	-	-	-
Feeding (>20 m)	-	-	-	-	-	-
Protected species						
Migration (>5m)	-	-	-	-	-	-

6.2.3 Severity and significance

In the following chapter, the severity of loss and the severity of impairment by the different physical tunnel structures are presented.

Permanent physical tunnel structures (severity of loss):
As shown in Table 6.10, the severity of loss by the permanent physical tunnel structures (Category 1) will be high for all life stages of sea stickleback (spawning, egg-larvae drift, nursery and feeding). For all other species and indicators, the severity of loss was assessed as minor or medium only.

Although the severity of loss was determined as high for sea stickleback, it has to be considered that the level of severity was directly derived from the importance status of the respective component (species) and associated indicators independently from the level of habitat loss (area size). Considering the relatively small size of area lost by the installation of a tunnel (compare Table 6.4-Table 6.6) and the small size of the "near zone"-area, no strong impact on these species is expected.

Therefore, no significant loss of function from the installation of a permanent tunnel construction on the population dynamics of all species is expected.

Table 6.10: Severity of loss (permanent) for each environmental component based on the pressure indicators and the loss of seabed (%) for the near (500 m on both sides of the middle of the alignment corridor) and the local zone (10 km on both sides of the middle of the alignment corridor).

Severity of loss by seabed reclamation permanent, tunnel	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Nursery (<10 m)	-	-	-	Medium	-	Medium
Herring						
Spawning (mod)	-	-	-	Minor	-	Minor
Egg drift (>2 m)	-	-	-	Minor	-	Minor
Flatfish						
Spawning (> 10 m)	-	-	-	-	-	Medium
Nursery (<10 m)	-	-	-	Medium	-	Medium
Feeding (>0 m)	-	-	-	Medium	-	Medium
Shallow water species						
Spawning (<10 m)	-	-	-	Medium	-	Medium
Egg-larvae drift (<10 m)	-	-	-	Minor	-	Minor
Nursery (<10 m)	-	-	-	Medium	-	Medium
Feeding (<10 m)	-	-	-	Medium	-	Medium
Eel						
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (<10 m)	-	-	-	Minor	-	Minor
Sea stickleback						
Spawning	-	-	-	-	-	High
Egg-larvae drift	-	-	-	-	-	High
Nursery	-	-	-	-	-	High
Feeding	-	-	-	-	-	High

Permanent tunnel construction components (Severity of impairment):
According to the results (Table 6.11), the permanent physical structures will have insignificant or a minor impairments on most of the components and associated indicators. Only for the indicator feeding (cod), a medium impact was assessed.

Therefore, no significant impairment for all species (i.e. components) and associated indicators (i.e. spawning, egg-larvae-drift, nursery, feeding and migration) are expected.

Table 6.11: Severity of impairment (permanent) for each environmental component based on the pressure indicators and the loss of seabed (%) for the near (500 m on both sides of the middle of the alignment corridor) and the local zone (10 km on both sides of the middle of the alignment corridor).

Severity of impairment/ by seabed reclamation permanent, tunnel	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Spawning (> 10 m)	-	-	-	-	-	Minor
Egg-larvae drift (>10 m)	-	-	-	-	-	Minor
Feeding (>5 m)	-	-	-	Minor	-	Medium
Migration (> 5 m)	-	-	-	Minor	-	Minor
Whiting						
Nursery (>0 m)	-	-	-	Insignif.	-	Minor
Migration (>5m)	-	-	-	Minor	-	Minor
Herring						
Larvae drift (>2 m)	-	-	-	Insignif.	-	Minor
Nursery (>0 m)	-	-	-	Insignif.	-	Minor
Feeding (>5 m)	-	-	-	Insignif.	-	Minor
Migration (>5m)	-	-	-	Minor	-	Minor
Sprat						
Spawning (> 10 m)	-	-	-	-	-	Minor
Egg-larvae drift (>10 m)	-	-	-	-	-	Minor
Nursery (>0 m)	-	-	-	Insignif.	-	Minor
Feeding (>5 m)	-	-	-	Insignif.	-	Minor
Migration (>5m)	-	-	-	Minor	-	Minor
Flatfish						
Egg-larvae drift (>10 m)	-	-	-	-	-	Minor
Migration (>5m)	-	-	-	Insignif.	-	Insignif.
Eel						
Migration (>2m)	-	-	-	Minor	-	Minor
Protected species						
Migration (>5m)	-	-	-	Minor	-	Minor

Temporary long-term physical tunnel structures (Severity of impairment):
Physical tunnel structures and associated temporary habitat loss will have insignificant, minor and medium impairments on the components and associated indicators (Table 6.12). For the indicators spawning (cod, flatfish and snake blenny), egg-larvae drift (cod, flatfish and snake blenny), nursery (snake blenny) and feeding (cod, flatfish and snake blenny), a medium impact was assessed. Therefore, no significant impairment for all species (i.e. components) and associated indicators (i.e. spawning, egg-larvae-drift, nursery and feeding) is expected.

Table 6.12: Severity of impairment (temporary long-term) for each environmental component based on the pressure indicators and the loss of seabed (%) for the near (500 m on both sides of the middle of the alignment corridor) and the local zone (10 km on both sides of the middle of the alignment corridor).

Severity of impairment by seabed reclamation temporary long-term, tunnel	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Spawning (> 10 m)				Medium	Medium	Medium
Egg-larvae drift (>10 m)				Medium	Medium	Medium
Nursery (<10 m)				Minor		Minor
Feeding (>5 m)	-	-	-	Medium	Medium	Minor
Migration (> 5 m)	-	-	-	-	-	-
Whiting						
Nursery (>0 m)	-	-	-	Minor	Minor	Insignif.
Migration (>5m)	-	-	-	-	-	-
Herring						
Spawning (mod)	-	-	-	Insignif.	-	-
Egg-larvae drift (>2 m)	-	-	-	-	-	-
Nursery (>0 m)	-	-	-	-	-	-
Feeding (>5 m)	-	-	-	-	-	-
Migration (>5m)	-	-	-	-	-	-
Sprat						
Spawning (> 10 m)	-	-	-	-	-	-
Egg-larvae drift (>10 m)	-	-	-	-	-	-
Nursery (>0 m)	-	-	-	-	-	-
Feeding (>5 m)	-	-	-	-	-	-
Migration (>5m)	-	-	-	-	-	-
Flatfish						
Spawning (> 10 m)	-	-	-	Medium	Medium	Medium
Egg-larvae drift (>10 m)	-	-	-	Medium	Medium	Medium
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (>0 m)	-	-	-	Medium	Medium	Minor
Migration (>5m)	-	-	-	-	-	-
Shallow water species						
Spawning (<10 m)	-	-	-	Minor	-	Minor
Egg-larvae drift (<10 m)	-	-	-	Insignif.	-	Insignif.
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (<10 m)	-	-	-	Minor	-	Minor
Eel						
Nursery (<10 m)	-	-	-	Insignif.	-	Insignif.
Feeding (<10 m)	-	-	-	Insignif.	-	Insignif.
Migration (>2m)	-	-	-	-	-	-
Sea stickleback						
Spawning	-	-	-	-	-	Minor
Egg-larvae drift	-	-	-	-	-	Minor
Nursery	-	-	-	-	-	Minor
Feeding	-	-	-	-	-	Minor
Snake blenny						
Spawning (>20 m)	-	-	-	Medium	Medium	Medium
Egg-larvae drift (>20 m)	-	-	-	Medium	Medium	Medium
Nursery (>20 m)	-	-	-	Medium	Medium	Medium
Feeding (>20 m)	-	-	-	Medium	Medium	Medium
Protected species						
Migration (>5m)	-	-	-	-	-	-

Temporary short-term physical tunnel structures (Severity of impairment):
The temporary short-term physical tunnel structures will only have insignificant or minor impairments on all components and associated indicators (Table 6.13).

Therefore, no significant impairment is expected for all species (i.e. components) and associated indicators (i.e. spawning, egg-larvae-drift, nursery and feeding).

Table 6.13: Severity of impairment (temporary short-term) for each environmental component based on the pressure indicators and the loss of seabed (%) for the near (500 m on both sides of the middle of the alignement corridor) and the local zone (10 km on both sides of the middle of the alignment corridor).

Severity of impairment by seabed reclamation temporary short-term, tunnel	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Spawning (> 10 m)	-	-	-	-	-	-
Egg-larvae drift (>10 m)	-	-	-	-	-	-
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (>5 m)	-	-	-	Minor	-	Minor
Migration (> 5 m)	-	-	-	-	-	-
Whiting						
Nursery (>0 m)	-	-	-	Insignif.	-	Insignif.
Migration (>5m)	-	-	-	-	-	-
Herring						
Spawning (mod)	-	-	-	Insignif.	-	Insignif.
Egg-larvae drift (>2 m)	-	-	-	Insignif.	Insignif.	Insignif.
Nursery (>0 m)	-	-	-	Insignif.	Insignif.	Insignif.
Feeding (>5 m)	-	-	-	Insignif.	Insignif.	Insignif.
Migration (>5m)	-	-	-	-	-	-
Sprat						
Spawning (> 10 m)	-	-	-	Minor	Minor	Minor
Egg-larvae drift (>10 m)	-	-	-	Minor	Minor	Minor
Nursery (>0 m)	-	-	-	Insignif.	Insignif.	Insignif.
Feeding (>5 m)	-	-	-	Insignif.	Insignif.	Insignif.
Migration (>5m)	-	-	-	-	-	-
Flatfish						
Spawning (> 10 m)	-	-	-	-	-	-
Egg-larvae drift (>10 m)	-	-	-	-	-	-
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (>0 m)	-	-	-	Minor	-	Minor
Migration (>5m)	-	-	-	-	-	-
Shallow water species						
Spawning (<10 m)	-	-	-	Minor	-	Minor
Egg-larvae drift (<10 m)	-	-	-	insignif.	-	Insignif.
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (<10 m)	-	-	-	Minor	-	Minor
Eel						
Nursery (<10 m)	-	-	-	Insignif.	-	Insignif.
Feeding (<10 m)	-	-	-	Insignif.	-	Insignif.
Migration (>2m)	-	-	-	-	-	-
Sea stickleback						
Spawning	-	-	-	-	-	Minor
Egg-larvae drift	-	-	-	-	-	Minor
Nursery	-	-	-	-	-	Minor
Feeding	-	-	-	-	-	Minor
Snake blenny						
Spawning (>20 m)	-	-	-	-	-	-
Egg-larvae drift (>20 m)	-	-	-	-	-	-
Nursery (>20 m)	-	-	-	-	-	-
Feeding (>20 m)	-	-	-	-	-	-
Protected species						
Migration (>5m)	-	-	-	-	-	-

6.3 Sediment spill

The construction of the immersed tunnel solution is associated with several dredging activities such as dredging of the tunnel trench, the reclamations at Rødby and Puttgarden, the constructions of two work harbours and the back filling of the trench. With respect to the solution with production facilities at Rødby Havn the total amount of handled sediment is approximated to be 55.8 mill m^3. From this amount it is expected that 0.7 mill m^3 will be spilled.

The spilled sediment will consist of everything present in the dredged soil. Boulders and coarser sand fractions will settle close to the dredging site while finer sediment may be carried away. As is the case with natural sediment the transport and deposition of spilled sediment during dredging are determined by the hydrodynamic conditions. In periods with rough weather and currents the sediment will be kept in suspension and transported with the flow. In periods with calm weather the sediment will settle out on the seabed. Normally the weather is shifting with the irregular weather patterns and therefore the sediment transport happens in a series of events. The sediment will continue being resuspended and re-deposited until it reaches a final deposition area where the hydrodynamic forces, waves and currents are so weak that the sediment cannot be resuspended.

Similar to the background level the excess concentrations of suspended sediment and sedimentation may impact fish in various ways as described in detail in chapter 3.2.2. This may be either directly affecting the fish in one or the other way or indirectly by impairing the habitats of fish including their food resources.

The duration of the dredging activites is of importance for the magnitude of the impact. The dredging is planned to last six years but hereafter there will be no sediment spill associated with the tunnel. The impact assessment regarding sediment spill is therefore only related to the construction phase.

6.3.1 Magnitude of pressure

The pressure towards fish caused by sediment spill from the construction of the main tunnel solution is assessed upon spill scenarios established by FEHY. The simulations used in the present assessment are primarily the sediment spill budget for the immersed tunnel E-ME with production facility at Rødby Havn. The differences between the two tunnel solutions are minor with the Rødbyhavn production facility releasing about 12% more sediment.

The simulations are based on the average hydrographic year 2005, which is considered to represent average conditions, and assume that the timing and construction will follow the plan presented in the design project description (FEHY, 2013c).

In general the simulations show that the concentration of suspended sediment will vary during the construction period depending on the location of the dredging operations and the current and wave conditions. During the first construction of working harbours, access channels and the near coastal parts of the tunnel the concentrations will tend to be higher along the coast, but when the construction work moves offshore the levels of suspended sediment decreases in the nearshore areas. However, in coastal waters waves will prevent the spilled material from settling and resuspend material from the seabed. Relatively high concentrations are therefore in periods seen in the shallow waters and sediment is transported relatively far along the coastline before settling. Due to this effect sediment from the dredging is seen in the simulations to pass Gedser Odde and Nakskov Fjord and around Fehmarn both at the eastern and western fringe (Figure 6.2). In general excess concentrations on the German side are lower than at the Danish side consistent with the smaller amounts of spilled sediment and the milder wave climate here.

At the end of the construction period deposition will be present over large areas but in thin layers less than 1 mm. The overall sediment spill budget shows that the majority of the spilled sediment travels east into the Baltic Sea, consistent with the inflow of saline water from the Kattegat to the Baltic Sea, with final resting places in the Arkona Basin and the edges of Bay of Mecklenburg. About 45 % remains near the dredging area consisting mainly of sand fractions. Only 2.5 % of the spilled volume enters the Rødsand Lagoon.

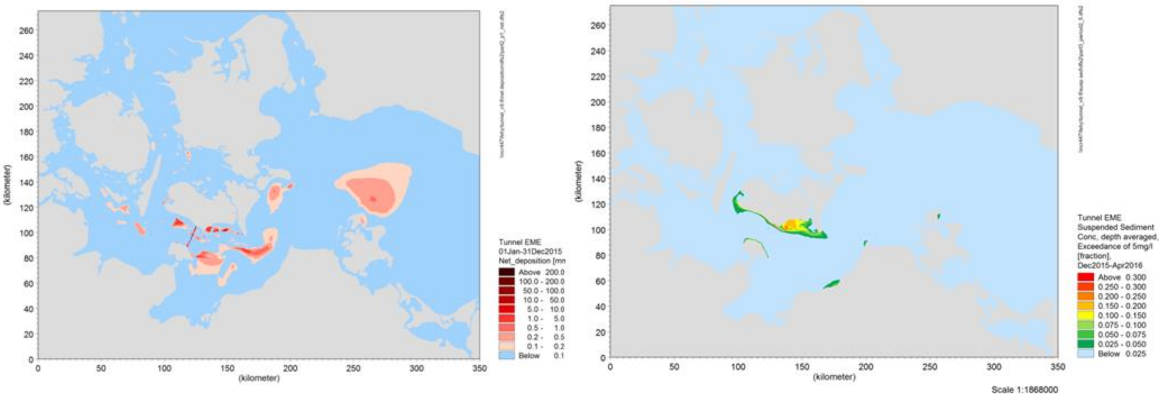


Figure 6.2: Sediment spill scenarios of net deposition in the period January-December 2015 and frequency of exceeding of 5 mg/l from in the period December 2015-April 2016 from the tunnel solution (modelled for FeBEC by FEHY 2011c).

Since spawning and migration among fish are highly seasonal the timing of the dredging activities is included in the assessment considering the relevant periods for each environmental indicator. Table 6.14 gives an overview of the sediment spill scenarios used in the assessment of each environmental indicator and Figure 6.2 shows examples of two scenarios of respective suspended sediment and sedimentation.

Table 6.14: Sediment spill scenarios used for the assessment of each environmental indicator in relevant periods.

Environmental Indicator	Species	Pressure	Threshold	Period	Years
Spawning	herring	net sedimentation	0.1 mm/d	Mar-May	2015-2019
	shallow water species, sea stickleback, snake blenny	"	0.1 mm/d	Jan-Dec	2015-2019
Egg-larvae drift	cod, flatfish (plaice), snake blenny	SS, frequency of exceedance	2 mg/l	Dec-Apr	2014-2019
	sprat, flounder, dab	"	2 mg/l	Mar-May	2015-2019
	turbot	"	2 mg/l	May-Aug	2015-2019
Nursery area	cod, whiting, herring, sprat	"	10 mg/l	Jan-Dec	2015-2019
	shallow water species, eel, sea stickleback, snake blenny	"	50 mg/l	Jan-Dec	2015-2019
Feeding area	cod, whiting, herring, sprat	"	10 mg/l	Jan-Dec	2015-2019
	shallow water species, eel, sea stickleback, snake blenny	"	50 mg/l	Jan-Dec	2015-2019
Migration	cod, sprat, whiting, flatfish	"	10 mg/l	Dec-Apr	2014-2019
	herring, flatfish	"	10 mg/l	Mar-May	2015-2019
	silver eel	"	50 mg/l	Oct-Dec	2015-2019

From simulations of net deposition and excess concentrations shown in Figure 6.2 and exceeding threshold values in the relevant periods given in Table 6.14 magnitude of pressures have been quantified. Thus, the area of occurrence of the specific indicator overlapping the area, where the specific threshold is exceeded, is considered the magnitude of pressure. With respect to suspended sediment each overlap is weighted according to the frequency of exceedance and the fractions represents either percentages of time or area. With respect to deposition the fractions represents only areas.

For each of the considered areas of investigation described in chapter 1.4 the year with the maximal magnitude of pressure as well as the maximal average of three successive years are used for the classification of the degree of impairment. Figure 6.3 shows the calculated percentages exceeding concentrations of suspended sediment of 2 mg/l used for impact assessment of egg and larvae drift among cod and flatfish.

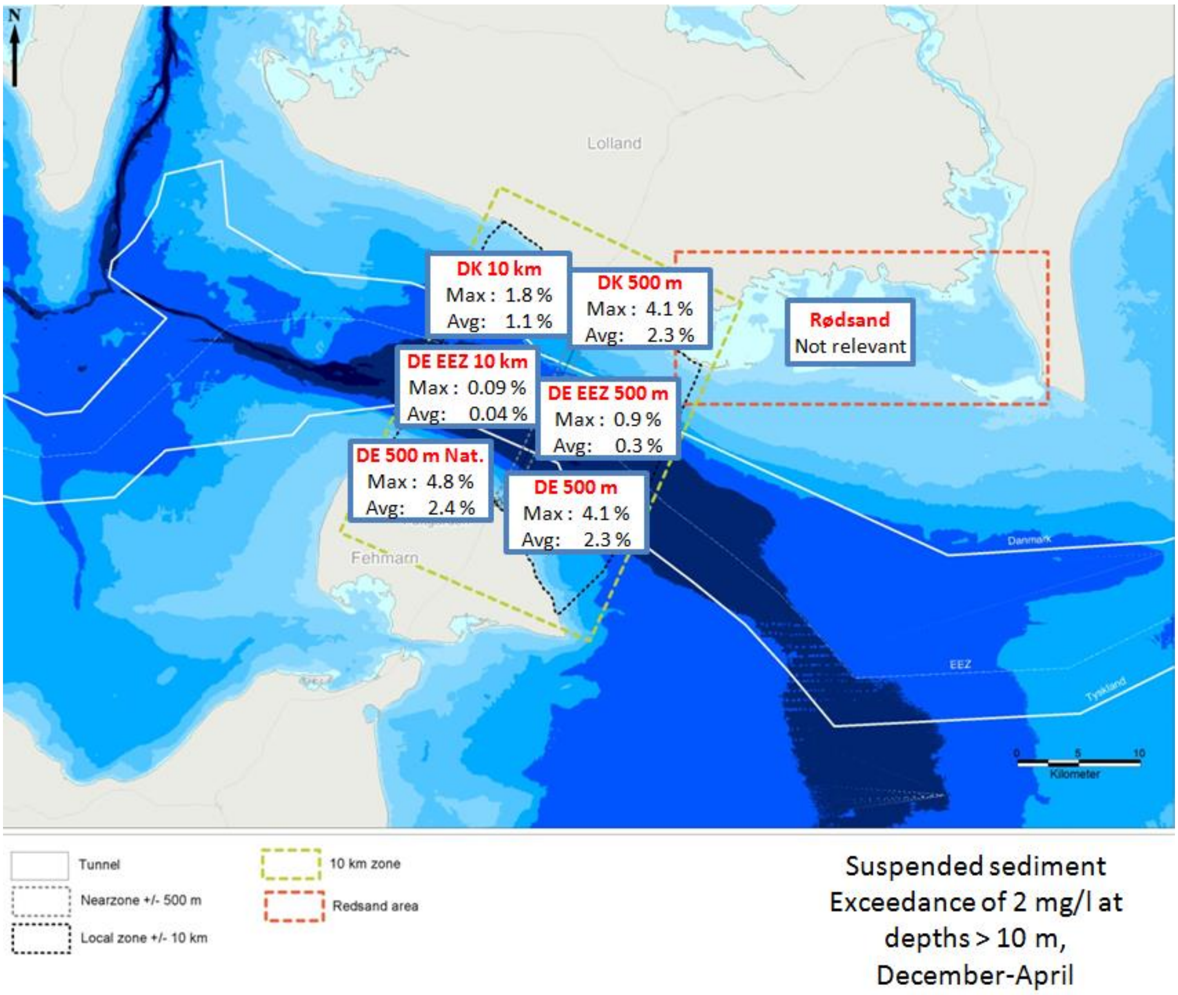


Figure 6.3: Weighted fractions exceeding concentrations of 2 mg/l at depths > 10 m in the period December-April for the year with maximal concentrations of suspended sediment and the maximal three successive years during construction of the main tunnel solution from 2014-2019. The fractions are used to assess impacts caused by sediment spill towards egg- and larvae drift among cod and flatfish in Fehmarnbelt.

As the spill scenarios are based on excess concentrations alone the present assessment has also considered the magnitude of pressure relative to the background concentration of suspended sediment. Average excess concentrations of suspended sediment from the tunnel solution relative to the background concentrations have been modelled for the year 2015 (FEHY, 2013c). At every station the background concentrations are considerable higher and the exceedance times much longer than the excess concentrations from the sediment spill (Table 6.15). Thus, background fractiles are generally five or more times higher than the excess concentrations due to spillage. Similarly, all exceedance times for background concentrations are higher than the exceedance times due to spillage.

Table 6.15: Fractiles and excedance times in % for excess concentrations modelled for the E-ME Tunnel solution with facility at Rødbyhavn in 2015. In FEHY (2013c).

E-ME tunnel Stations	f_{50} (mg/l)	F_{75} (mg/l)	F_{95} (mg/l)	E_2 (%)	E_{10} (%)	E_{20} (%)
NS01	0.1	0.3	0.8	3.9	0.4	0.0
NS02	0.2	0.7	1.3	4.6	0.1	0.1
NS03	0.3	0.7	1.5	5.8	0.1	0.0
NS04	0.4	0.7	8.5	24.9	9.0	4.5
NS05	0.2	0.0	1.8	8.7	0.8	0.2
NS06	0.0	0.0	0.1	0.2	0.0	0.0
NS07	0.0	0.0	0.3	0.3	0.0	0.0
NS08	0.0	0.0	0.2	0.6	0.0	0.0
NS09	0.0	0.0	0.0	0.0	0.0	0.0
NS10	0.0	0.0	0.0	0.0	0.0	0.0
MS01	0.0	0.1	0.2	0.2	0.0	0.0
MS02	0.0	0.1	0.3	1.2	0.0	0.0
Baseline 2009-2010 Stations	**f_{50} (mg/l)**	**F_{75} (mg/l)**	**F_{95} (mg/l)**	**E_2 (%)**	**E_{10} (%)**	**E_{20} (%)**
NS01	1.1	1.9	12.5	24.2	6.7	2.3
NS02	1.5	3.8	28.0	38.2	13.8	7.9
NS03	2.2	6.4	23.9	52.9	16.5	6.6
NS04	2.4	6.0	33.2	60.1	17.4	9.2
NS05	5.0	15.3	51.9	79.9	33.5	19.8
NS06	1.3	1.9	5	22.6	1.3	0.2
NS07	1.5	2.7	9.6	34.2	4.7	1.3
NS08	1.5	2.4	7.9	32.4	3.8	1.4
NS09	1.3	1.9	5.8	22.4	2.6	0.9
NS10	1.2	2	6.5	24.6	2.1	0.6
MS01	0.7	1.1	3.0	9.4	0.3	0.0
MS02	0.7	1.0	2.3	6.4	0.3	0.0

However, situations with high excess and baseline concentrations will generally occur simultaneously and excess concentrations can not give rise to a significant impact if the natural background concentration already exceeds the specific thresholds. Taken the latter into consideration, but assuming independently stochastic resuspension events for a worst case scenario, frequencies of exceedance which approximates the impact caused by the spillage alone have been calculated. The approximation is based on the premise that there are two occasions where spill from the tunnel is the impacting factor:

- when the background concentration is below and the excess concentration exceeds the threshold
- when both the background and the excess concentration are below but the sum of the concentrations exceeds the threshold

The specific frequencies have then been interpolated from the relation between fractiles and exceedance times given in Table 6.15 and shown for station NS01 in Figure 6.4. For each station new estimated exceedance times, where the background level of suspended sediment is considered, are presented in Table 6.16. Worthy of note is that these "new" values do not differ significantly from the modelled excess concentration, where background concentrations were not considered. This being the case, it has been found reasonable to perform the assessment alone on the excess concentrations which enables assessing both in time and space corresponding to relevant periods and areas where a specific species or function is present/occurs.

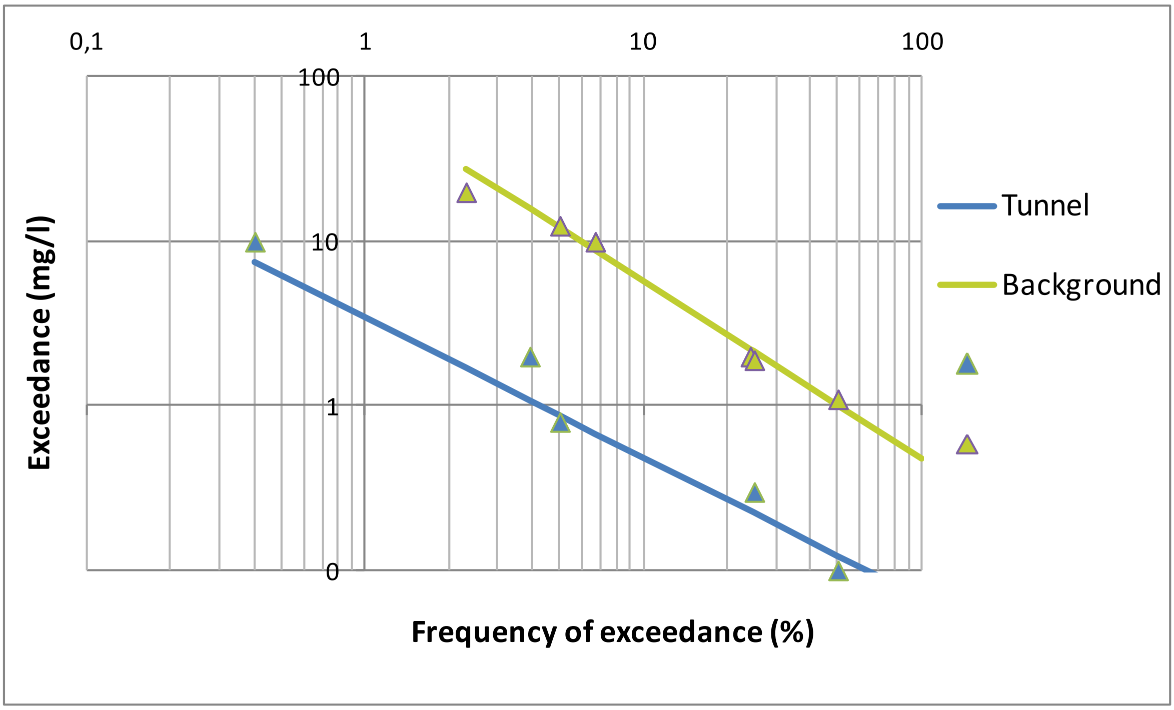


Figure 6.4: Relation between frequency of exceedance and exceedance concentration from measured background concentrations at station NS01 during 2009 and 2010 and modelled excess concentrations from the EME-tunnel solution. Data from FEHY (2013a).

Table 6.16: Estimated frequencies of exceedance of 2 mg/l, 10 mg/l and 20 mg/l of excess concentrations from the EME-tunnel solution with stochastic probability of acting isolated from background levels.

Stations	E - 2 mg	E - 10 mg	E - 20 mg
NS01	4.0	0.4	0.0
NS02	5.9	0.2	0.1
NS03	11.2	0.3	0.0
NS04	17.8	7.5	4.5
NS05	4.8	1.2	0.4
NS06	0.2	0	0
NS07	0.2	0	0
NS08	0.4	0	0
NS09	0	0	0
NS10	0	0	0
MS01	0.2	0	0
MS02	1.1	0	0

6.3.2 Degree of impairment

The estimated reductions of each area of investigation for each environmental indicator are presented in Table 6.17. The values represent the percentage reduction/ loss of function in the year with the maximal spillage and the corresponding area or, regarding migration, the length of the corridor. The reduction of environmental components from each construction year is not presented here, but is included in the overall project impact assessment.

In general the maximal reductions of most indicators are far less than 10 % apart for egg and larvae drift among herring in the near zone of the alignment in the Danish territory and the

Lagoon of Rødsand (Table 6.17). Compared to the natural levels of suspended sediment the magnitude of pressure from the construction of the proposed tunnel solution is expected to be insignificant.

Table 6.17: The reduction of environmental sub-components caused by sediment spill from the construction of the E-ME-tunnel solution in Fehmarnbelt.

Reduction of environmental subcomponents Sediment spill. % (ha or m) Tunnel Construction	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**	**Rødsand Lagoon**
Cod							
Egg-larvae drift (>10 m)	1.1 (95)	0.1 (8)	1.8 (237)	4.8 (21)	0.9 (4)	4.1 (32)	-
Nursery (<10 m)	1.4 (49)	-	1.6 (79)	3.2 (4)	-	8.2 (91)	4.8 (1482)
Feeding (>5 m)	0.2 (18)	1.6 (130)	0.3 (44)	0.6 (3)	3.0 (15)	4.3 (64)	5.6 (58)
Migration (>5m)	-	-	-	0.7 (33m)	0.1 (2m)	3.5 (314m)	-
Whiting							
Nursery (>0 m)	0.4 (51)	0.0 (2)	0.3 (56)	1.1 (7)	3.8 (0)	3.9 (75)	4.8 (1482)
Migration (>5m)	-	-	-	0.7 (33m)	0.1 (2m)	3.5 (314m)	-
Herring							
Spawning (mod)	0.0 (0)	-	0.0 (0)	0.0 (0)	-	0.9 (1)	0.0 (0)
Egg-larvae drift (>2 m)	1.8 (212)	0.1 (9)	6.9 (1227)	4.0 (23)	2.4 (12)	21.8 (388)	12.7 (2363)
Nursery (>0 m)	0.4 (51)	0.0 (2)	0.3 (56)	1.1 (7)	3.8 (19)	3.9 (75)	4.8 (1482)
Feeding (>5 m)	0.2 (18)	1.6 (130)	0.3 (44)	0.6 (3)	3.0 (15)	4.3 (64)	5.6 (58)
Migration (>5m)	-	-	-	0.5 (22m)	0.1 (6m)	7.3 (665m)	-
Sprat							
Egg-larvae drift (>10 m)	0.4 (31)	0.1 (9)	0.6 (75)	2.8 (12)	2.4 (12)	1.7 (13)	-
Nursery (>0 m)	0.4 (51)	0.0 (2)	0.3 (56)	1.1 (7)	3.8 (19)	3.9 (75)	4.8 (1482)
Feeding (>5 m)	0.2 (18)	1.6 (130)	0.3 (44)	0.6 (3)	3.0 (15)	4.3 (64)	5.6 (58)
Migration (>5m)	-	-	-	0.6 (29m)	3.0 (137m)	4.3 (394m)	-
Flatfish							
Egg-larvae drift (>10 m)	0.4 (31)	0.1 (9)	0.6 (75)	2.8 (12)	2.4 (12)	1.7 (13)	
Nursery (<10 m)	0.2 (5)	-	0.2 (12)	0.1 (0)	-	0.6 (7)	0.6 (181)
Feeding (>0 m)	0.0 (5)	0.0 (0)	0.1 (12)	0.0 (0)	0.0 (0)	0.4 (7)	0.6 (181)
Migration (>5m)	-	-	-	0.0 (1m)	0.0 (0m)	0.3 (26m)	-
Shallow water species							
Spawning (<10 m)	0.1 (3)	-	0.6 (30)	0.0 (0)	-	1.8 (20)	0.0 (0)
Nursery (<10 m)	0.2 (5)	-	0.2 (12)	0.1 (0)	-	0.6 (7)	0.6 (181)
Feeding (<10 m)	0.2 (5)	-	0.2 (12)	0.1 (0)	-	0.6 (7)	0.6 (181)
Eel							
Nursery (<10 m)	0.2 (5)	-	0.2 (12)	0.1 (0)	-	0.6 (7)	0.6 (181)
Feeding (<10 m)	0.2 (5)	-	0.2 (12)	0.1 (0)	-	0.6 (7)	0.6 (181)
Migration (>2m)	-	-	-	0.0 (1m)	0.0 (0m)	0.0 (4m)	-
Sea stickleback							
Spawning (habmap)	0.0 (0)	-	0.0 (0)	0.0 (0)	-	1.2 (9)	0.0 (0)
Nursery (habmap)	0.4 (0)	-	0.6 (11)	0.0 (0)	-	0.8 (6)	0.8 (134)
Feeding (habmap)	0.4 (0)	-	0.6 (11)	0.0 (0)	-	0.8 (6)	0.8 (134)
Snake blenny							
Spawning (>20 m)	0.0 (0)	0.1 (10)	0.0 (0)	6.1 (14)	0.0 (0)	0.0 (0)	-
Egg-larvae drift (>20 m)	0.5 (20)	0.1 (8)	0,7 (41)	3.4 (8)	0.9 (4)	3.3 (7)	-
Nursery (>20 m)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	-
Feeding (>20 m)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	-
Protected species							
Migration (>5m)	-	-	-	0.7 (33m)	0.1 (2m)	3.5 (314m)	-

In consequence of the small reductions the degree of impairment caused by sediment spill from the construction of the main tunnel solution is classified as minor to all indicators except for hering larvae drift in the Danish near zone and in the Lagoon of Rødsand (Table 6.18). Particularly considering the levels of natural suspended sediment the impairment caused by sediment spill by the construction of the tunnel is expected to be insignificant.

Table 6.18: The degree of impariment caused by sediment spill from the construction of the E-ME tunnel solution in Fehmarnbelt.

Degree of impairment Sediment spill Tunnel Construction	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**	**Rødsand Lagoon**
Cod							
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (>5 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor	
Whiting							
Nursery (>0 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor	
Herring							
Spawning (mod)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Egg-larvae drift (>2 m)	Minor	Minor	Minor	Minor	Minor	Medium	Medium
Nursery (>0 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Feeding (>5 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor	
Sprat							
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (>0 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Feeding (>5 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor	
Flatfish							
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (>0 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor	
Shallow water species							
Spawning (<10 m)	Minor		Minor	Minor		Minor	Minor
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (<10 m)	Minor		Minor	Minor		Minor	Minor
Eel							
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (<10 m)	Minor		Minor	Minor		Minor	Minor
Migration (>2m)				Minor	Minor	Minor	
Sea stickleback							
Spawning (habmap)	Minor		Minor	Minor		Minor	Minor
Nursery (habmap)	Minor		Minor	Minor		Minor	Minor
Feeding (habmap)	Minor		Minor	Minor		Minor	Minor
Snake blenny							
Spawning (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Egg-larvae drift (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Feeding (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Protected species							
Migration (>5m)				Minor	Minor	Minor	

6.3.3 Severity and significance

The severity of impairment of sediment spill from the tunnel solution is assessed minor for all indicators selected for the present assessment (Table 6.19). Fehmarnbelt plays thus a minor role for herring larvae drift, which is the only indicator with an expected medium degree of impairment. Therefore, no impacts among fish and fish communities of the dredging activities related to the construction of the E-ME tunnel are expected.

Table 6.19: The severity of impariment caused by sediment spill from the construction of the E-ME-tunnel solution in Fehmarnbelt.

Severity of impairment Sediment spill Tunnel Construction	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**	**Rødsand Lagoon**
Cod							
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (>5 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor	
Whiting							
Nursery (>0 m)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Migration (>5m)				Minor	Minor	Minor	
Herring							
Spawning (mod)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Egg-larvae drift (>2 m)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Minor	Minor
Nursery (>0 m)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Feeding (>5 m)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Migration (>5m)				Minor	Minor	Minor	
Sprat							
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (>0 m)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Feeding (>5 m)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Migration (>5m)				Minor	Minor	Minor	
Flatfish							
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (>0 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Insignif.	Insignif.	Insignif.	
Shallow water species							
Spawning (<10 m)	Minor		Minor	Minor		Minor	Minor
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (<10 m)	Minor		Minor	Minor		Minor	Minor
Eel							
Nursery (<10 m)	Insignif.		Insignif.	Insignif.		Insignif.	Insignif.
Feeding (<10 m)	Insignif.		Insignif.	Insignif.		Insignif.	Insignif.
Migration (>2m)				Minor	Minor	Minor	
Sea stickleback							
Spawning (habmap)	Minor		Minor	Minor		Minor	Minor
Nursery (habmap)	Minor		Minor	Minor		Minor	Minor
Feeding (habmap)	Minor		Minor	Minor		Minor	Minor
Snake blenny							
Spawning (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Egg-larvae drift (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Feeding (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Protected species							
Migration (>5m)				Minor	Minor	Minor	

6.4 Noise and vibration

The noise scenarios related to the construction of an immersed tunnel are primarily caused by ramming of piles and steel sheets during the construction of the harbour and fabrication area, dredging work and the traffic associated with work at sea. During the operation of the tunnel low frequent noise (vibrations) from passing trains and heavy traffic would be the major source of impact. Following activities will be assessed:

- Dredging – tunnel and reclamation
- Dredging – harbour and approaches
- Harbour construction – sheet piles (Rødby construction facility)
- Construction vessels
- Ship traffic (including changes to ferry service)
- Tunnel traffic [tunnel operation phase]

6.4.1 **Magnitude of pressure**

The noise scenarios associated with the construction and operation of an immersed tunnel are mostly related to the establishment of the construction and harbour area on the coast of Lolland and Fehmarn, the dredging and back filling of the track, the traffic of heavy vessels in connection with placement of the tunnel elements and the low frequency noise generated by trains and heavy vehicles in the tunnel tubes.

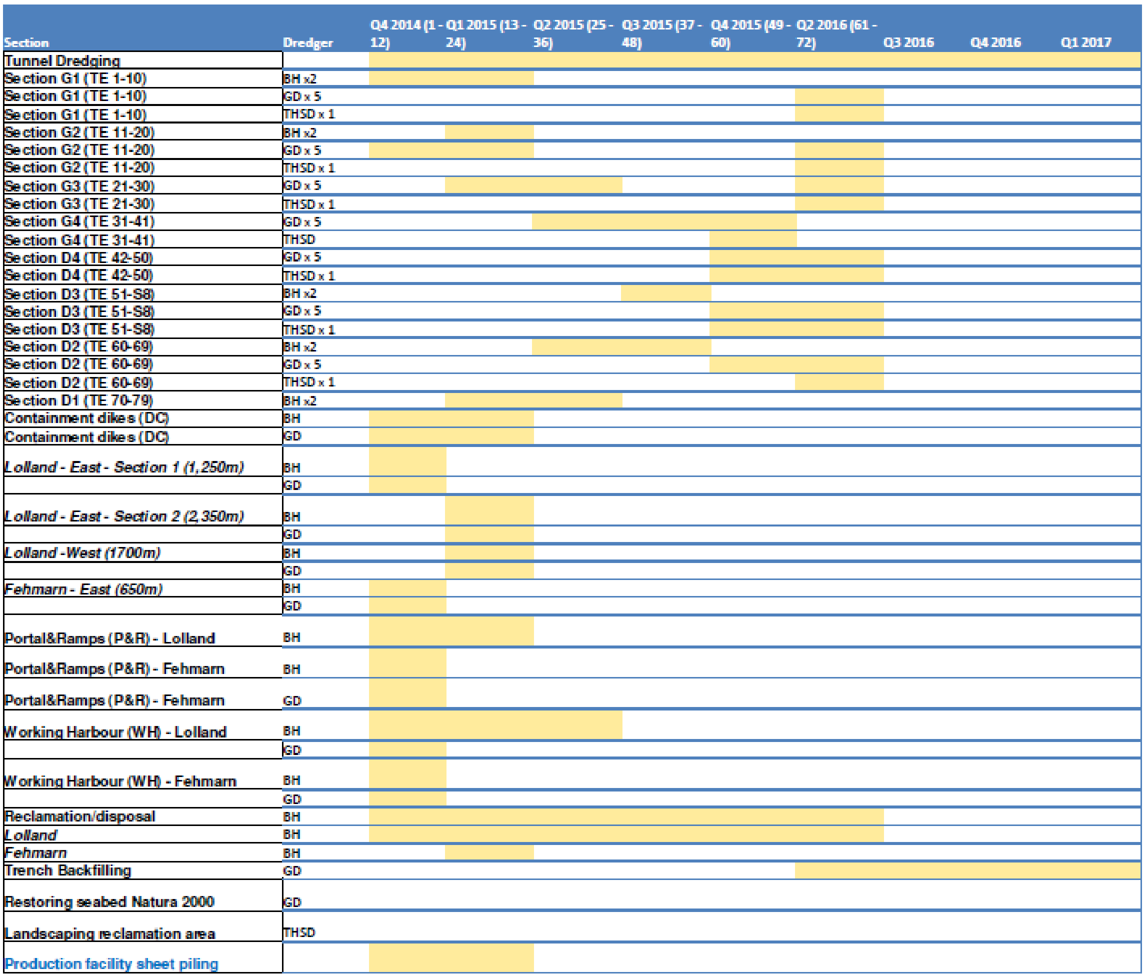
Construction

Dredging
Three different types of dredgers will be used in the construction works; one Trailer Suction Hopper Dredger (TSHD) with a capacity of 13,200 m^3, five Grab Dredgers (GD) with grabs of 10 m^3 and two Backhoe Dredgers (BD) with buckets of 15 m^3 and 25 m^3. The timing and location of dredging for the tunnel is shown in Figure 6.5. For the purpose of this assessment, the noise from the dredging and backfilling is being modelled as the same pressure.

All dredgers are modelled as Trailing Suction Hopper Dredgers with an SPL of 184 dB. That is a worst case assumption but for grab and backhoe dredgers there is only very few data published.

The dredging noise modelling has focused on sections G1 and G2 in the first instance. These are the only sections where dredging in adjacent blocks is planned, so they are taken as the worst case. Dredging in sections G1 and G2 is simulated with five dredgers distributed over the two sections. Tugs and barges in the area are neglected since they do not contribute too much to the overall level. A tug has a source level of about 175 dB, i.e. nearly 10 dB less than a dredger.

Noise maps during the seven stages of dredging are shown in Figure 6.6-Figure 6.9 (FEMM, 2011c).



Section	Dredger	Q4 2014 (1 - 12)	Q1 2015 (13 - 24)	Q2 2015 (25 - 36)	Q3 2015 (37 - 48)	Q4 2015 (49 - 60)	Q2 2016 (61 - 72)	Q3 2016	Q4 2016	Q1 2017
Tunnel Dredging		🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Section G1 (TE 1-10)	BH x2	🟨	🟨							
Section G1 (TE 1-10)	GD x 5						🟨			
Section G1 (TE 1-10)	THSD x 1						🟨			
Section G2 (TE 11-20)	BH x2		🟨							
Section G2 (TE 11-20)	GD x 5	🟨	🟨				🟨			
Section G2 (TE 11-20)	THSD x 1						🟨			
Section G3 (TE 21-30)	GD x 5		🟨	🟨			🟨			
Section G3 (TE 21-30)	THSD x 1						🟨			
Section G4 (TE 31-41)	GD x 5			🟨	🟨	🟨				
Section G4 (TE 31-41)	THSD					🟨				
Section D4 (TE 42-50)	GD x 5					🟨	🟨			
Section D4 (TE 42-50)	THSD x 1					🟨	🟨			
Section D3 (TE 51-S8)	BH x2				🟨					
Section D3 (TE 51-S8)	GD x 5					🟨	🟨			
Section D3 (TE 51-S8)	THSD x 1					🟨	🟨			
Section D2 (TE 60-69)	BH x2			🟨	🟨					
Section D2 (TE 60-69)	GD x 5					🟨	🟨			
Section D2 (TE 60-69)	THSD x 1						🟨			
Section D1 (TE 70-79)	BH x2		🟨	🟨						
Containment dikes (DC)	BH	🟨	🟨							
Containment dikes (DC)	GD	🟨	🟨							
Lolland - East - Section 1 (1,250m)	BH	🟨								
	GD	🟨								
Lolland - East - Section 2 (2,350m)	BH		🟨							
	GD		🟨							
Lolland -West (1700m)	BH		🟨							
	GD		🟨							
Fehmarn - East (650m)	BH	🟨								
	GD	🟨								
Portal&Ramps (P&R) - Lolland	BH	🟨	🟨							
Portal&Ramps (P&R) - Fehmarn	BH	🟨								
Portal&Ramps (P&R) - Fehmarn	GD	🟨								
Working Harbour (WH) - Lolland	BH	🟨	🟨	🟨						
	GD	🟨								
Working Harbour (WH) - Fehmarn	BH	🟨								
	GD	🟨								
Reclamation/disposal	BH	🟨	🟨	🟨	🟨	🟨	🟨			
Lolland	BH	🟨	🟨	🟨	🟨	🟨	🟨			
Fehmarn	BH		🟨							
Trench Backfilling	GD						🟨	🟨	🟨	🟨
Restoring seabed Natura 2000	GD									
Landscaping reclamation area	THSD									
Production facility sheet piling		🟨	🟨							

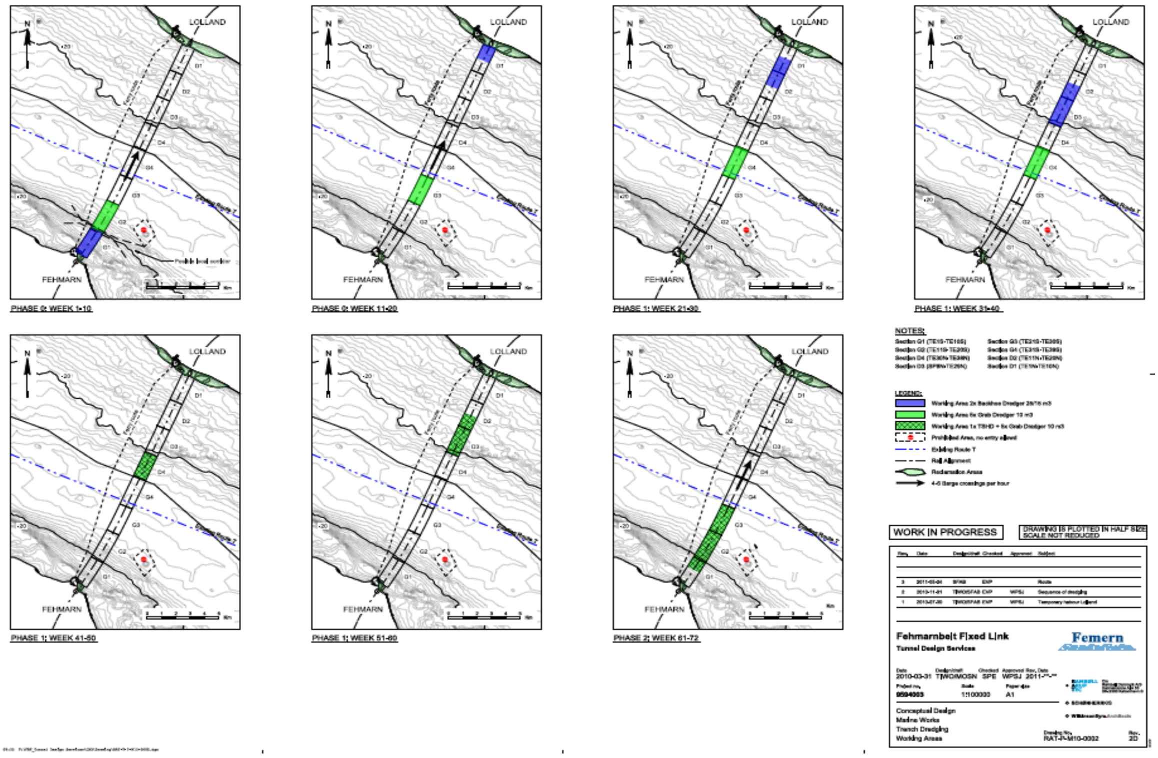
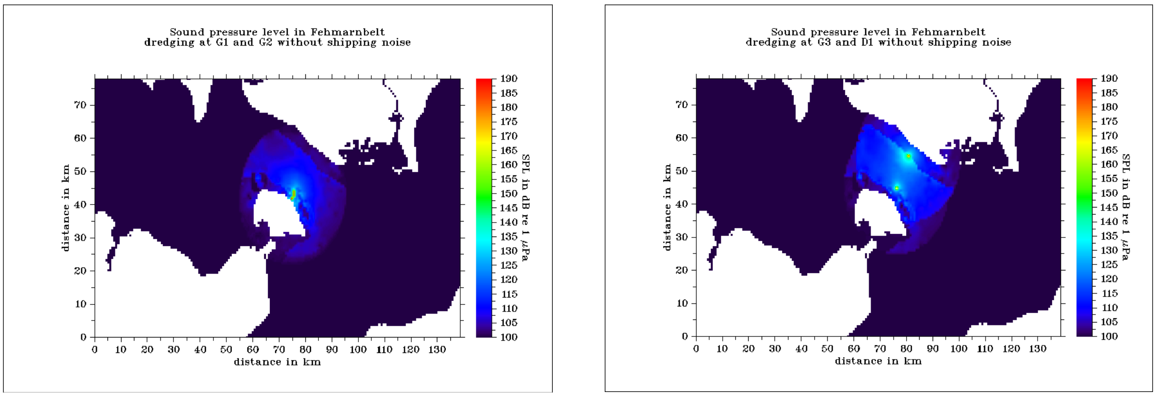
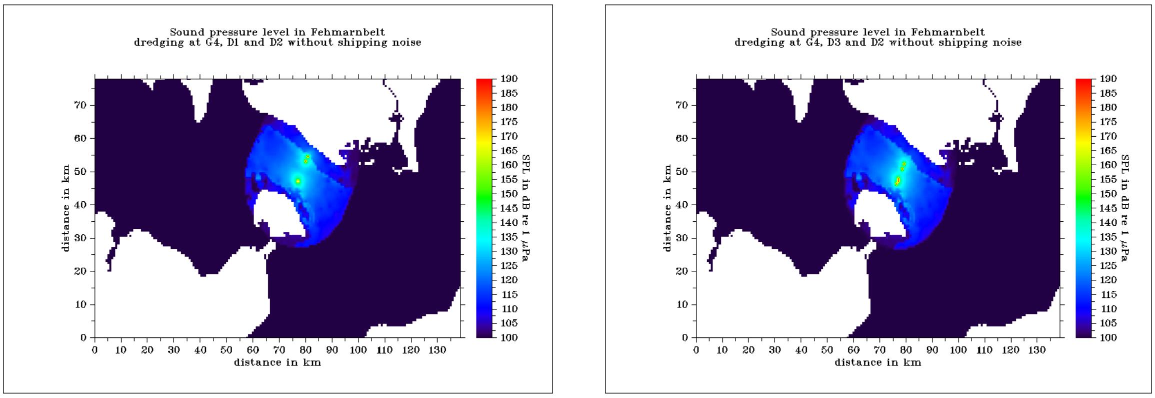

PHASE 0: WEEK 1-10
PHASE 0: WEEK 11-20
PHASE 1: WEEK 21-30
PHASE 1: WEEK 31-40
PHASE 1: WEEK 41-50
PHASE 1: WEEK 51-60
PHASE 2: WEEK 61-72

Figure 6.5: Time table for the dredging work for the tunnel.


Sound pressure level in Fehmarnbelt
dredging at G1 and G2 without shipping noise

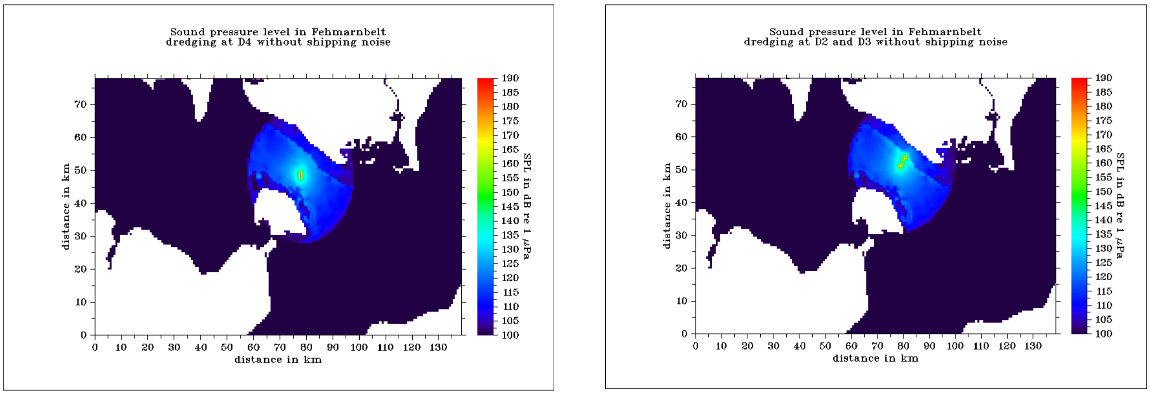
Sound pressure level in Fehmarnbelt
dredging at G3 and D1 without shipping noise

Figure 6.6: Sound Pressure Level during stage 1 (left) and stage 2 (right) of dredging (FEMM, 2011c).


Sound pressure level in Fehmarnbelt
dredging at G4, D1 and D2 without shipping noise

Sound pressure level in Fehmarnbelt
dredging at G4, D3 and D2 without shipping noise

Figure 6.7: Sound Pressure Level during stage 3 (left) and stage 4 (right) of dredging (FEMM, 2011c).


Sound pressure level in Fehmarnbelt
dredging at D4 without shipping noise

Sound pressure level in Fehmarnbelt
dredging at D2 and D3 without shipping noise

Figure 6.8: Sound Pressure Level during stage 5 (left) and stage 6 (right) of dredging (FEMM, 2011c).

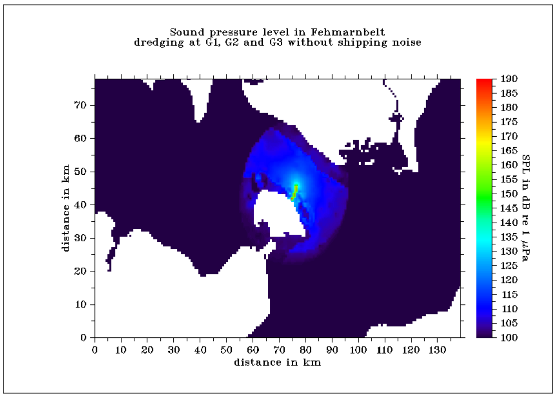

Sound pressure level in Fehmarnbelt
dredging at G1, G2 and G3 without shipping noise

Figure 6.9: Sound Pressure Level during stage 7 of dredging. Source: FEMM (2011c).

Pile ramming

Ramming of steel sheets and concrete pile in the construction area might produce severe noise. The production site requires harbour facilities to facilitate delivery of materials which are transported by ship (Rambøll, 2011). It is estimated that the required quay walls are in the range of 750 m. The quay walls could be constructed using sheet piles installed from the sea side. The location of the quay walls are shown on Figure 6.10.

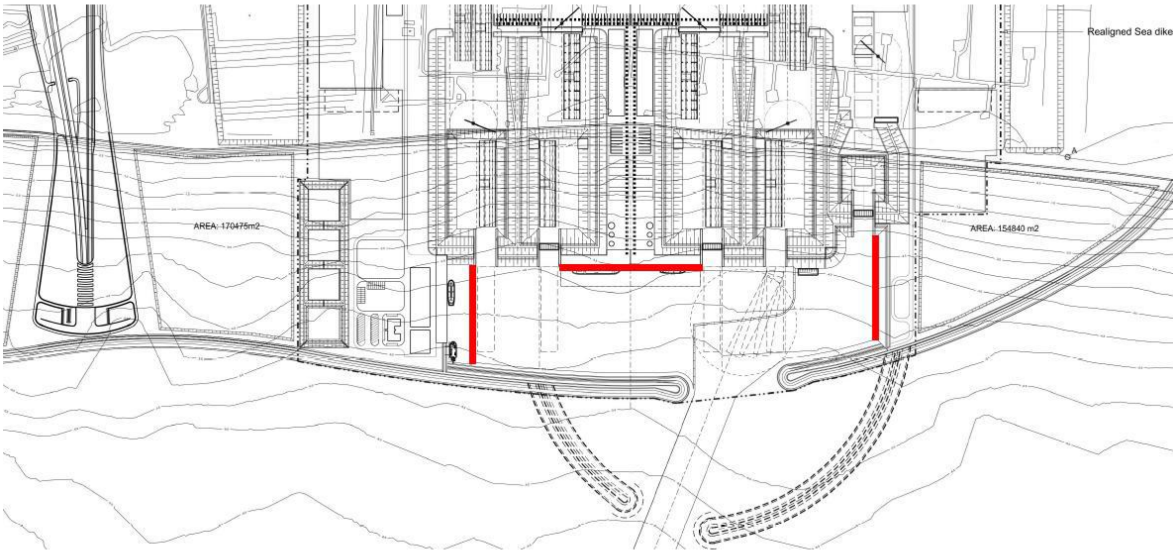


Figure 6.10: Piling quay walls from sea side. Source: Rambøll (2011)

To prevent water seepage through the dikes around the upper and lower basins these may be constructed with a sheet pile wall in the centre of the dike, shown with dotted light green on Figure 6.11. A total of app. 4150 m of sheet pile wall is required. Each sliding gate require app. 200 m of sheet pile wall and app. 700 m for the temporary dike used in the construction phase of the sliding gate. It is expected that the sheet piles are established using vibration piling equipment.

It is expected that concrete piles are used as part of the foundation for the skid beams on which the tunnel elements are transported during construction. The piles will be located in the areas marked with green on Figure 6.12. The concrete piles are expected to be driven by a traditionally piling hammer.

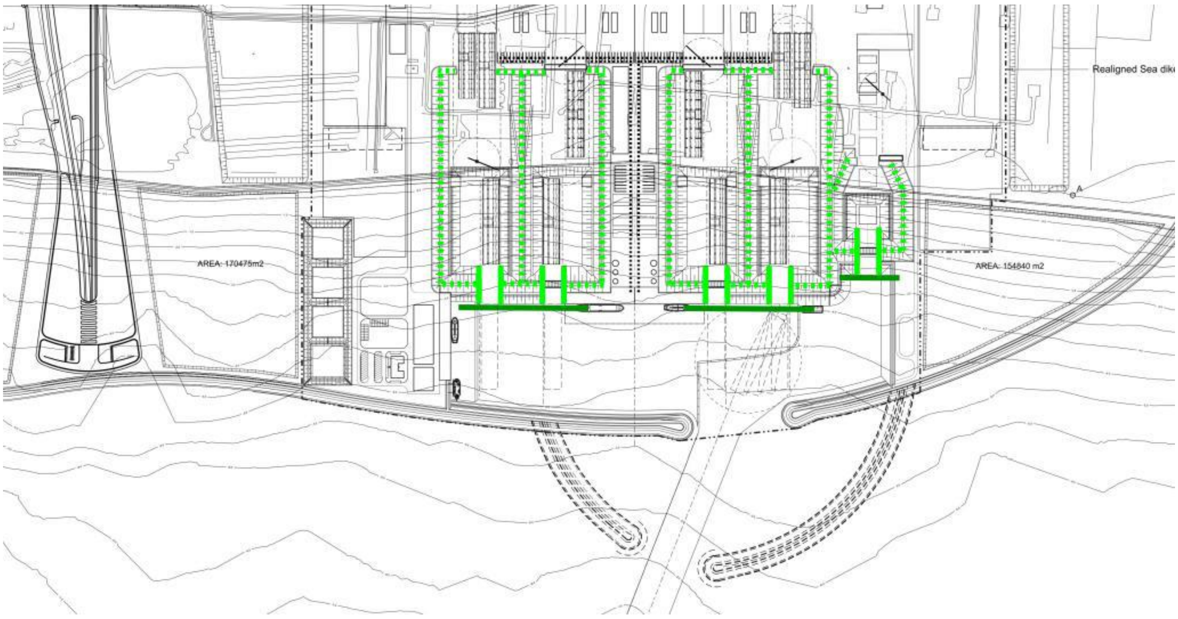


Figure 6.11: Piling from land, sheet piles (Rambøll, 2011).

Figure 6.12: Piling on land, piles for skid beams. Source: Rambøll (2011).

On Fehmarn a temporary harbour will be constructed east of Puttgarden harbour. This harbour is expected to have quay walls which may be constructed using sheet piles. The length of the quay wall is expected to be less than 250 m.

For the pile driving at Lolland, a worst case scenario of impact pile driving is assumed. The source level for piles of 1 m diameter was taken to be 202 dB SEL. This has previously been measured during port construction in Wilhelmshaven Jade-Weser-Port (Kibblewhite, 1989).

Vibratory hammers drive the pile into the ground by a push and pull action of counter-rotating weights. Vibratory action of the driver causes soil adjacent to the pile to be like a viscous fluid with little or no skin friction. The use of vibratory hammers may produce lower sound pressure levels, but may not be less disturbing than the use of an impact hammer. This depends upon the interaction of the pile and the soil, and whether the hammer and pile resonate in a fashion that produces high noise levels (U.S. Army Corps of Engineers, 2004).

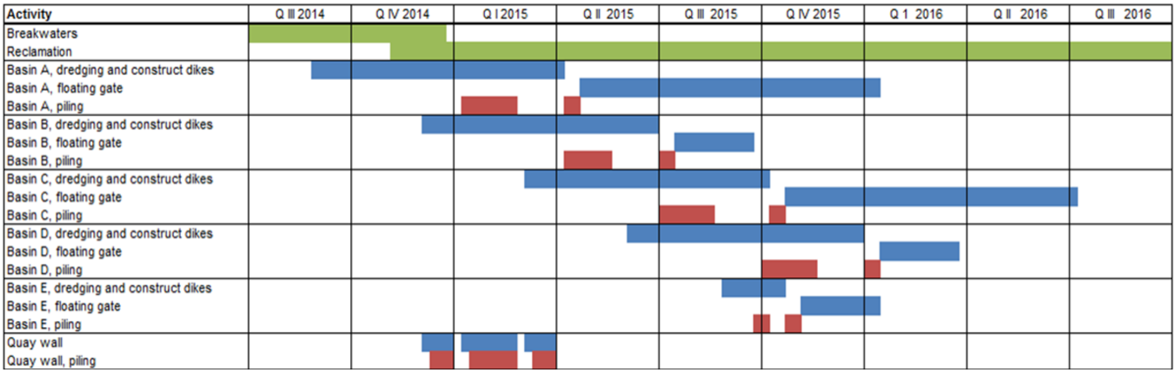
The majority of vibratory pile driving machines used for piling such as sheet piles and small pipe piles are medium-frequency machines with a vibrator frequency of 10 to 30 Hz, and the emitted noise level is typically 15-20 dB below a traditional pile hammer (U.S. Army Corps of Engineers, 2004). In a steel sheet ramming (24 inch AZ Steel Sheet) in Port of Oakland in San Francisco Bay the noise level was measured to 177 dB (peak level) and 163 dB (RMS) at 10 m distance at a water depth of 15 m, using a APE 600B Super Kong Vibrator (Illinworth, et al., 2007).

In the construction area at Rødby on the coast of Lolland the sheet ramming will take place in the harbour basin inside the dykes. The noise is expected to be significantly attenuated due to the phase shift between water-soil-water and due to the low water depth, which prevents the low frequency sound to propagate freely through the water.

No information is available at the moment of the noise scenarios associated with the establishment of the construction areas. For this assessment the noise due to pile ramming and sheet ramming is assumed to be 195 dB (source level) at the dykes and the propagation loss factor is set to 25 (FEMM, 2011a).

The ramming on the coast of Lolland is planned to take place from the fourth quarter of 2014 to the first quarter of 2016 (Table 6.20).

Table 6.20: Time schedule for the establishment of the construction and harbour area at Rødby. Source: Rambøll (2011).



Activity	Q III 2014	Q IV 2014	Q I 2015	Q II 2015	Q III 2015	Q IV 2015	Q 1 2016	Q II 2016	Q III 2016
Breakwaters	🟩	🟩							
Reclamation		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Basin A, dredging and construct dikes	🟦	🟦	🟦	🟦					
Basin A, floating gate				🟦	🟦	🟦	🟦		
Basin A, piling			🟥	🟥					
Basin B, dredging and construct dikes		🟦	🟦	🟦					
Basin B, floating gate					🟦				
Basin B, piling				🟥	🟥				
Basin C, dredging and construct dikes			🟦	🟦	🟦	🟦			
Basin C, floating gate						🟦	🟦	🟦	🟦
Basin C, piling					🟥	🟥			
Basin D, dredging and construct dikes				🟦	🟦	🟦			
Basin D, floating gate							🟦		
Basin D, piling						🟥	🟥		
Basin E, dredging and construct dikes					🟦	🟦			
Basin E, floating gate						🟦	🟦		
Basin E, piling					🟥	🟥			
Quay wall		🟦	🟦						
Quay wall, piling		🟥	🟥						

The numbers of support / construction vessels are not stated – it has been assumed that such vessels will be operating within the footprint of the bridge and tunnel. However, construction / support vessels are not modelled as they do not increase the noise levels having an SPL of 175 dB re 1 ųPa @ 1m, 5 dB lower than the TSHD.

Noise maps during pile ramming at Lolland is shown in Figure 6.13 including a worst case scenario (FEMM 2011).

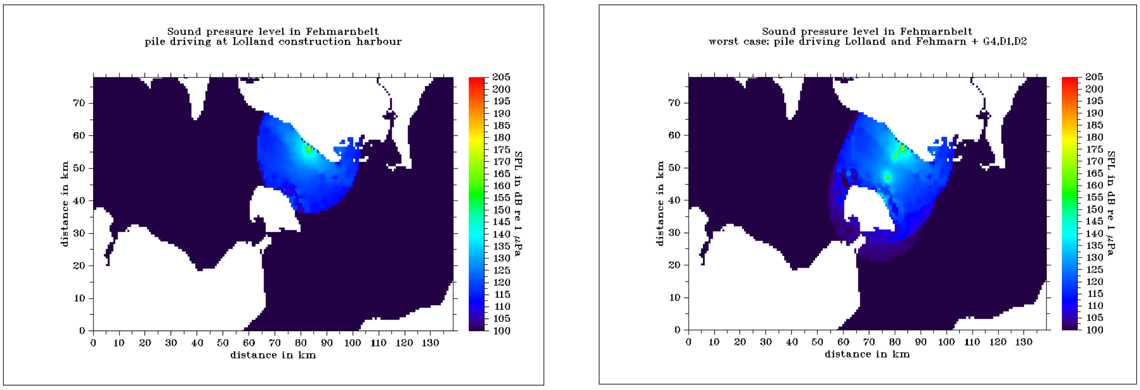


Figure 6.13: Sound Pressure Level during pile ramming at Rødby (left) and worst case scenario including dredging at G4, D1 and D2. Source: FEMM (2011c).

Operation

Heavy vehicles and cargo trains might produce significant low frequency noise or vibrations during the passage. Simultaneous measurements of underwater sound pressure and sea bottom vibrations directly above the Drogden tunnel trench in Øresund were conducted in order to evaluate the impact on the noise level caused by train passage induced vibrations (FEMM, 2011). A number of train passages were recorded including at least on cargo train (Figure 6.14). A typical train passage lasted approx. 10 seconds and caused an increase in sound level to about 140 dB directly above the tunnel. Cargo trains lead to comparable level increases for about 20 seconds.

The trains caused a level increase in a broad frequency range, with a broad maximum from 30 Hz to 1 kHz, and an absolute maximum near 50 Hz for most trains (Figure 6.15).

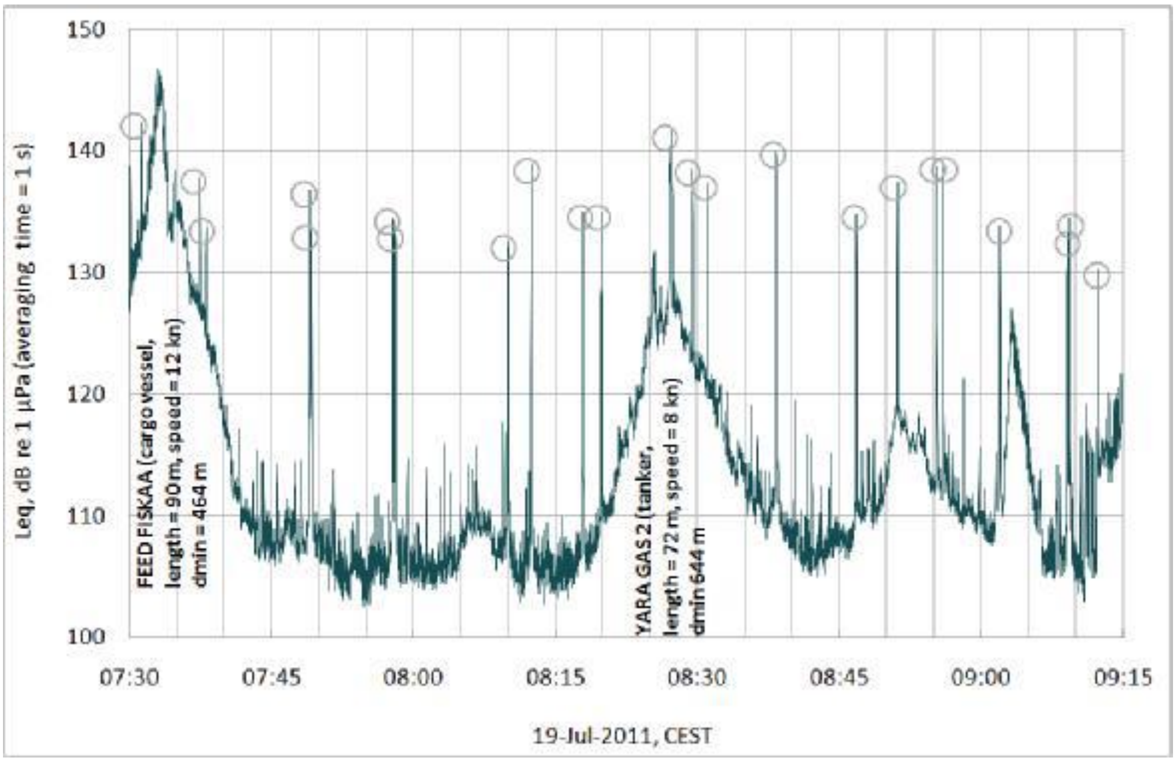


Figure 6.14: Broadband sound level recorded above the tunnel. The peaks marked by circles were identified as train passages. Source: FEMM (2011b).

In Øresund 20 trains with a passage time of ten seconds and three cargo trains with a passage time of 20 seconds passed in 105 minutes, which gives an average of train passage 4.0 % of the time on a specific location on the alignment.

Even though the measured sound frequencies in Øresund were within the hearing spectra of the fish present in Femarnbelt, the measured sound pressure levels were with at most 140 dB two meters above the sea bottom low compared to the threshold values for avoidance reactions for the present assessment.

Given the same traffic intensity as in Øresund no reactions are thus expected regarding fish in the free water column above the immersed tunnel solution in Fehmarnbelt, and only fish very close to the sediment like many flatfish species would be vulnerable to the vibrations from passing trains.

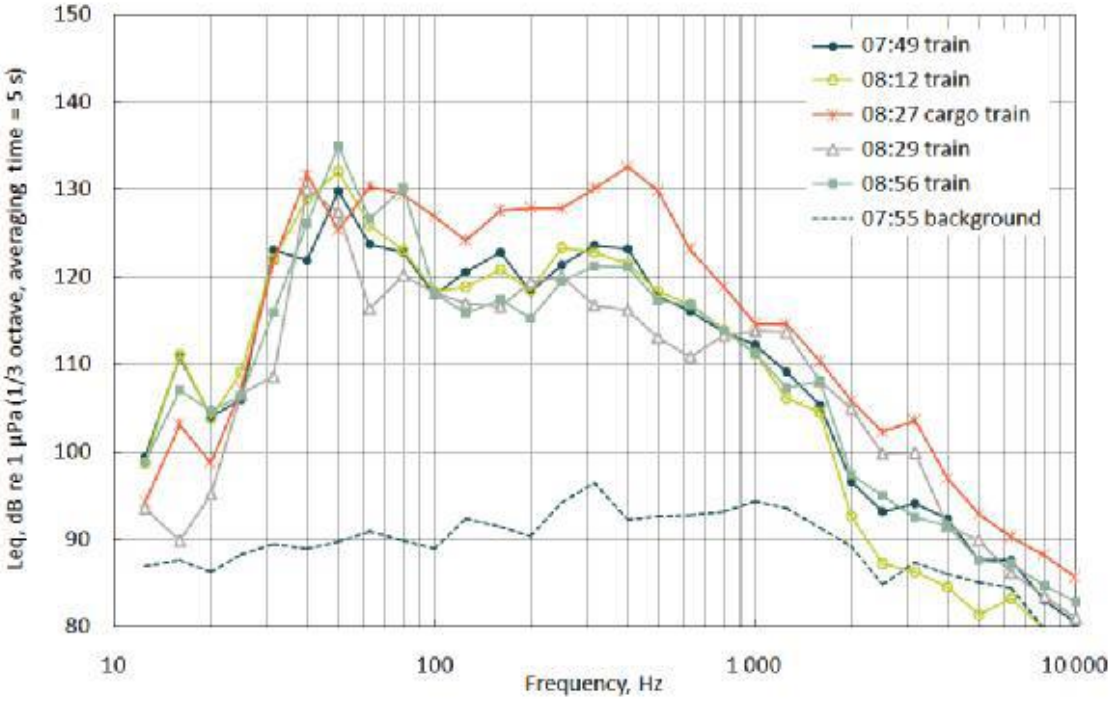


Figure 6.15: Sound spectra from passing trains measured 2 m above the sea bottom over the tunnel. Source: FEMM (2011b).

The vibrations measured by the geophone on the sea bottom showed a peak value of -115 dB re 1 m/s at 400 Hz equalizing a particle acceleration of 0.0045 m/s^2. This is below the threshold value for avoidance behavior for most fish (0.01 m/s^2) according to Wahlberg, et al. (2005).

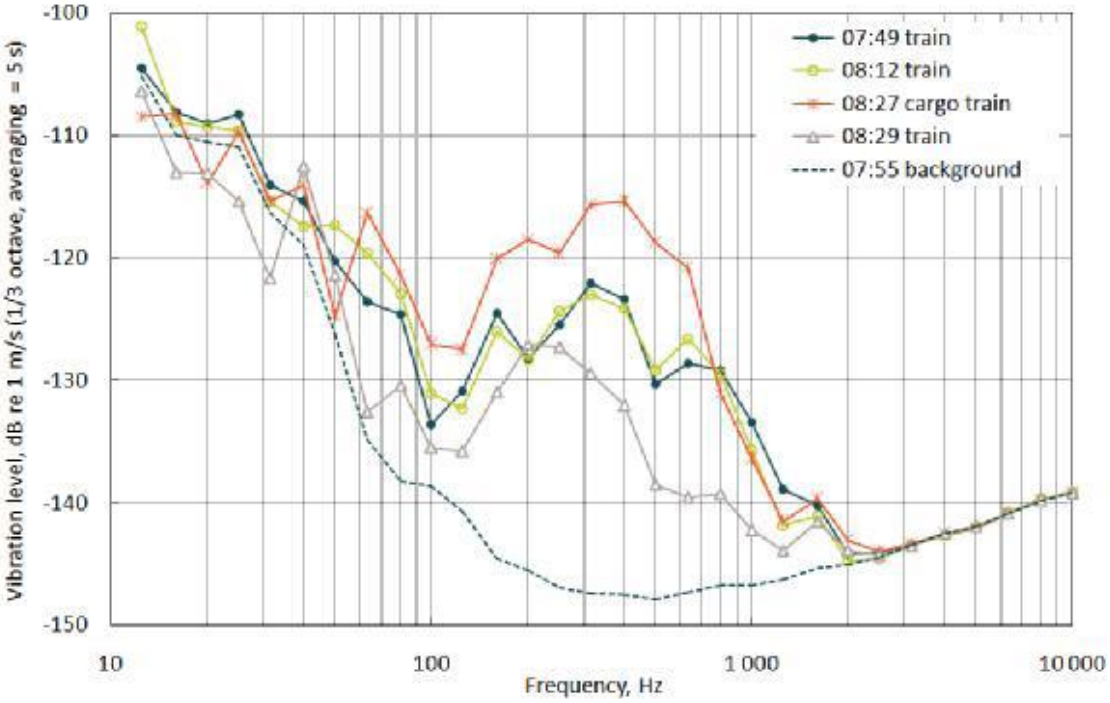


Figure 6.16: Vibration spectra of the sea bottom above the tunnel. Source: FEMM (2011b).

The higher level of vibration in the low frequency spectrum without trains passing was assumed to be an artifact, caused by wave-induced movements of the rope and surface marker buoy (FEMM, 2011b). In a similar measurement at the train tunnel in Great Belt with an electronic acceleration sensor, analysis of more than three hours of sea floor acceleration data revealed no sign of measureable vibration of the ground (FEMM, 2011b). Thus there is no evidence of vibrations causing avoidance reactions among fish in connection with the operation of an immersed tunnel.

6.4.2 Degree of impairment

Construction
5.5 % of the migration of gadoids and clupeids are estimated to be lost during construction activities due to noise in the near zone, while 1.1 % of the migration of other species is lost (Table 6.21). Only small areas of spawning, feeding and nursery grounds will be impaired due to noise. Most of the impacted areas are close to the construction harbours (12 ha for gadoids and clupeids near Rødby and 3 ha near Puttgarden). The impact on nursery and feeding areas ofother species is insignificant.

Operation
No measureable impact is expected due to noise and vibrations during operation of the tunnel.

Table 6.21: Estimated reduction of environmental sub-components from noise and vibrations during construction in % and ha (m for migration).

Reduction of environmental subcomponents of noise and vibrations (%-ha) Construction. Tunnel	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Nursery (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	2.20 (3.0)	0.00 (0.0)	1.12 (12.5)
Feeding (>5 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.42 (2.0)	0.39 (1.9)	0.38 (3.4)
Migration (>5m)				5.49 (255)	5.49 (245)	5.49 (445)
Whiting						
Nursery (>0 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.34 (2.0)	0.39 (1.9)	0.20 (3.9)
Migration (>5 m)				5.49 (255)	5.49 (245)	5.49 (445)
Herring						
Spawning (mod)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	2.20 (0.0)	0.00 (0.0)	1.12 (0.0)
Nursery (>0 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.34 (2.0)	0.39 (1.9)	0.20 (3.9)
Feeding (>5 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.42 (2.0)	0.39 (1.9)	0.38 (3.4)
Migration (>5 m)				5.49 (255)	5.49 (245)	5.49 (445)
Sprat						
Nursery (>0 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.34 (2.0)	0.39 (1.9)	0.20 (3.9)
Feeding (>5 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.42 (2.0)	0.39 (1.9)	0.38 (3.4)
Migration (>5 m)				5.49 (255)	5.49 (245)	5.49 (445)
Flatfish						
Nursery (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.54 (0.7)	0.00 (0.0)	0.26 (2.9)
Feeding (>0 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.01 (0.1)	0.02 (0.1)	0.01 (0.2)
Migration (>5 m)				1.14 (53)	1.14 (51)	1.14 (93)
Shallow water species						
Spawning (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.54 (0.7)	0.00 (0.0)	0.26 (2.9)
Nursery (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.54 (0.7)	0.00 (0.0)	0.26 (2.9)
Feeding (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.54 (0.7)	0.00 (0.0)	0.26 (2.9)
Eel						
Nursery (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.54 (0.7)	0.00 (0.0)	0.26 (2.9)
Feeding (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.54 (0.7)	0.02 (0.0)	0.26 (2.9)
Migration (>2 m)				1.14 (53)	1.14 (51)	1.14 (98)
Sea stickleback						
Spawning (habmap)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.54 (0.7)	0.00 (0.0)	0.26 (2.9)
Nursery (")	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.54 (0.7)	0.00 (0.0)	0.26 (2.9)
Feeding (")	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.54 (0.7)	0.00 (0.0)	0.26 (2.9)
Snake blenny						
Nursery (>20 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)
Feeding (>20 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)
Protected species						
Migration (>5 m)				1.14 (53)	1.14 (51)	1.14 (93)

Table 6.22: Estimated reduction of environmental sub-components caused by noise and vibrations during operation % and ha (m for migration).

Reduction of environmental subcomponents of noise and vibrations (%-ha/m) Operation, Tunnel	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Nursery (<10 m)	0 (0)	0 (0)		0 (0)		0 (0)
Feeding (>5 m)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Migration (>5m)				0 (0)	0 (0)	0 (0)
Whiting						
Nursery (>0 m)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Migration (>5 m)				0 (0)	0 (0)	0 (0)
Herring						
Spawning (mod)	0 (0)	0 (0)				
Nursery (>0 m)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Feeding (>5 m)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Migration (>5 m)				0 (0)	0 (0)	0 (0)
Sprat						
Nursery (>0 m)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Feeding (>5 m)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Migration (>5 m)				0 (0)	0 (0)	0 (0)
Flatfish						
Nursery (<10 m)	0 (0)	0 (0)		0 (0)		0 (0)
Feeding (>0 m)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Migration (>5 m)				0 (0)	0 (0)	0 (0)
Shallow water species						
Spawning (<10 m)	0 (0)	0 (0)				
Nursery (<10 m)	0 (0)	0 (0)		0 (0)		0 (0)
Feeding (<10 m)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)
Eel						
Nursery (<10 m)	0 (0)	0 (0)		0 (0)		0 (0)
Feeding (<10 m)	0 (0)	0 (0)		0 (0)		0 (0)
Migration (>2 m)				0 (0)	0 (0)	0 (0)
Sea stickleback						
Spawning (habmap)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)
Nursery (")	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)
Feeding (")	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)
Snake blenny						
Nursery (>20 m)				0 (0)	0 (0)	0 (0)
Feeding (>20 m)				0 (0)	0 (0)	0 (0)
Protected species						
Migration (>5 m)				0 (0)	0 (0)	0 (0)

The classification of impacts in accordance with the assessment criteria is given in table 6.23 and 6.24. No degree of impairment exceeding minor was found.

Table 6.23: Classification of impact from noise and vibrations during construction.

Degree of impairment of Noise and vibration, Tunnel, Construction	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Nursery (<10 m)				Minor		Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor
Whiting						
Nursery (>0 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Herring						
Nursery (>0 m)				Minor	Minor	Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Sprat						
Nursery (>0 m)				Minor	Minor	Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Flatfish						
Nursery (<10 m)				Minor		Minor
Feeding (>0 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Shallow water species						
Spawning (<10 m)						
Nursery (<10 m)				Minor		Minor
Feeding (<10 m)				Minor		Minor
Eel						
Nursery (<10 m)				Minor		Minor
Feeding (<10 m)				Minor		Minor
Migration (>2 m)				Minor	Minor	Minor
Sea stickleback						
Spawning (habmap)				Minor		Minor
Nursery (")				Minor		Minor
Feeding (")				Minor		Minor
Snake blenny						
Nursery (>20 m)				Minor	Minor	Minor
Feeding (>20 m)				Minor	Minor	Minor
Protected species						
Migration (>5 m)				Minor	Minor	Minor

Table 6.24: Classification of impact from noise and vibrations during operation.

Degree of impairment of Noise and vibration, Tunnel, Operation	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Nursery (<10 m)				Minor		Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor
Whiting						
Nursery (>0 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Herring						
Nursery (>0 m)				Minor	Minor	Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Sprat						
Nursery (>0 m)				Minor	Minor	Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Flatfish						
Nursery (<10 m)				Minor		Minor
Feeding (>0 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Shallow water species						
Spawning (<10 m)						
Nursery (<10 m)				Minor		Minor
Feeding (<10 m)				Minor		Minor
Eel						
Nursery (<10 m)				Minor		Minor
Feeding (<10 m)				Minor		Minor
Migration (>2 m)				Minor	Minor	Minor
Sea stickleback						
Spawning (habmap)				Minor		Minor
Nursery (")				Minor		Minor
Feeding (")				Minor		Minor
Snake blenny						
Nursery (>20 m)				Minor	Minor	Minor
Feeding (>20 m)				Minor	Minor	Minor
Protected species						
Migration (>5 m)				Minor	Minor	Minor

6.4.3 Severity and significance

The classification of the severity of impairment is given in Table 6.25 and Table 6.26. No severity exceeding minor was found.

Table 6.25: Estimated severity of noise and vibrations during construction.

Severity of impairment/loss of noise and vibration, Tunnel, construction	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Nursery (<10 m)				Minor		Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor
Whiting						
Nursery (>0 m)				Insignif.	Insignif.	Insignif.
Migration (>5 m)				Minor	Minor	Minor
Herring						
Nursery (>0 m)				Insignif.	Insignif.	Insignif.
Feeding (>5 m)				Insignif.	Insignif.	Insignif.
Migration (>5 m)				Minor	Minor	Minor
Sprat						
Nursery (>0 m)				Insignif.	Insignif.	Insignif.
Feeding (>5 m)				Insignif.	Insignif.	Insignif.
Migration (>5 m)				Minor	Minor	Minor
Flatfish						
Nursery (<10 m)				Minor		Minor
Feeding (>0 m)				Minor	Minor	Minor
Migration (>5 m)				Insignif.	Insignif.	Insignif.
Shallow water species						
Spawning (<10 m)						
Nursery (<10 m)				Minor		Minor
Feeding (<10 m)				Minor		Minor
Eel						
Nursery (<10 m)				Insignif.		Insignif.
Feeding (<10 m)				Insignif.		Insignif.
Migration (>2 m)				Minor	Minor	Minor
Sea stickleback						
Spawning (habmap)				Minor		Minor
Nursery (")				Minor		Minor
Feeding (")				Minor		Minor
Snake blenny						
Nursery (>20 m)				Minor	Minor	Minor
Feeding (>20 m)				Minor	Minor	Minor
Protected species				-		
Migration (>5 m)				Minor	Minor	Minor

Table 6.26: Estimated severity of noise and vibrations during operation.

Severity of impairment/loss of noise and vibration, Tunnel, operation	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	GE 500 m EEZ	DK 500 m
Cod						
Nursery (<10 m)				Minor		Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor
Whiting						
Nursery (>0 m)				Insignif.	Insignif.	Insignif.
Migration (>5 m)				Minor	Minor	Minor
Herring						
Nursery (>0 m)				Insignif.	Insignif.	Insignif.
Feeding (>5 m)				Insignif.	Insignif.	Insignif.
Migration (>5 m)				Minor	Minor	Minor
Sprat						
Nursery (>0 m)				Insignif.	Insignif.	Insignif.
Feeding (>5 m)				Insignif.	Insignif.	Insignif.
Migration (>5 m)				Minor	Minor	Minor
Flatfish						
Nursery (<10 m)				Minor		Minor
Feeding (>0 m)				Minor	Minor	Minor
Migration (>5 m)				Insignif.	Insignif.	Insignif.
Shallow water species						
Nursery (<10 m)				Minor		Minor
Feeding (<10 m)				Minor		Minor
Eel						
Nursery (<10 m)				Insignif.		Insignif.
Feeding (<10 m)				Insignif.		Insignif.
Migration (>2 m)				Minor	Minor	Minor
Sea stickleback						
Spawning (habmap)				Minor		Minor
Nursery (")				Minor		Minor
Feeding (")				Minor		Minor
Snake blenny						
Nursery (>20 m)				Minor	Minor	Minor
Feeding (>20 m)				Minor	Minor	Minor
Protected species						
Migration (>5 m)				Minor	Minor	Minor

The impact of underwater noise and vibrations on fish in the tunnel scenario is overall insignificant. The impact is limited to small areas close to the construction and harbour areas and to the near zone during the construction. In general, the impact is at worst of the same magnitude than the impact from the existing heavy traffic of ferries, and the establishment of a tunnel would presumably reduce the noise level in Fehmarnbelt if the ferry service stops.

Although heavy low frequency noise and vibrations from passing trains and heavy vehicles could impact the migration of several fish species, measurements on the Øresund tunnel indicates, that the noise and vibration level will not exceed the threshold level for avoidance behaviour.

6.5 Indirect pressures

The construction of a tunnel across Fehmarnbelt can affect the substrate, vegetation and macrofauna and thus the habitat suitability of the different fish species. These types of pressure are described as indirect pressures.

The vegetation in an area as Fehmarnbelt reduces the water currents and can act as a sediment trap. Resuspension of sediment increases the turbidity and thus sediment spill from the construction of a tunnel can affect the macroalgae and seagrass communities.

The habitat choice of an organism depends on a combination of factors such as habitat structure and availability, food supply, predation and inter- and intraspecific competition. Specific requirements for feeding, shelter or spawning often determine the dependence on a habitat. Additionally, for some fish species habitat choice vary between season and life stages.

Especially the shallow water fish communities depend on the occurrence of vegetation. However, vegetation is important for specific life stages of other fish species such as benthic herring eggs which are attached to the vegetation. Other species use these protected, shallow and vegetated areas as nursery grounds. The macrofauna associated with the coastal habitats constitutes a major food source for the fish communities presented in these areas.

Few of the German redlisted species prefers vegetated habitats and is thus vulnerable to indirect pressure from changes in the vegetation which will cause changes in the habitat suitability.

Furthermore, changes in prey availability due to e.g. change in hydrological conditions will cause an indirect pressure to the predatory fish species. Especially fish larvae are vulnerable to changes in the occurrence of their main food items copepods. However, changes in prey abundance due to the construction of a tunnel are not considered to impact the fish communities in Fehmarnbelt.

The habitat suitability of fish in Fehmarnbelt were analysed and mapped during the present assessment. The analysis compares the distribution of fish species with environmental variables. Data from the catches in the shallow waters of Fehmarnbelt (<20 m) together with information of the habitat (coverage of macroalgae and eelgrass) the fish were caught in were used for the analyses of suitability. Furthermore, changes in habitat suitability during the construction phase, based on data from FEMA modelling the changes in the cover of eelgrass and macroalgae, were analysed.

6.5.1 Magnitude of pressure

Different pressures such as sedimentation, increased concentration of suspended matter, footprint and additional solid substrates are expected to affect the benthic vegetation in relation to the construction of a tunnel in Fehmarnbelt. The most considerable impacts on the vegetation and thus the fish communities are expected to be the increase in suspended material and footprint.

Sand erosion and deposition are natural occurring processes in the shallow water exposed ecosystem and the benthic flora is adapted to these conditions. However, increase in these processes e.g. in relation to the construction of a tunnel will affect the flora. Macroalgae are more sensitive to sedimentation compared to angiosperms.

The expected impacts on the benthic flora in relation to the tunnel are (FEMA, 2011):

- Mainly the Danish areas are affected whereas only few and small impacts are predicted in the German areas.

- Small areas with minor to high degree of impairment or severity of loss due to sedimentation.
- Temporary decrease of biomass in large areas resulting in minor and medium degree of impairment as well as small areas with a high degree of impairment caused by suspended sediment.
- Permanent loss of vegetation in a large area along the coast of Lolland caused by footprints. This results in minor to high degree of loss on vegetation.

The benthic fauna is an important food resource for some fish species and changes in this fauna is considered as indirect pressure on fish. However, the impact on benthic fauna is minor, temporary and very local and the impairment on fish species is considered insignificant. Furthermore, changes in zooplankton composition and abundance caused by the tunnel will affect pelagic planktivorous species such as herring and sprat. Additionally, copepods are important food items for e.g. cod larvae. The plankton community in Fehmarnbelt is, however, only expected to be minor affected by the tunnel and thus the indirect pressure from changes in zooplankton is considered insignificant.

Habitat suitability mapping:
The reduction of environmental components caused by indirect pressure is estimated as the changes (reductions) in the suitability of habitat for the specific environmental indicator.

Habitat modelling has been done for a number of fish species in the coastal zone on the basis of two benthic fishing methods. The passive fishing methods gill nets and fyke nets are believed to provide valid data, proportional with the actual abundance of a number of species. Due to the nature of the selected fishing gear, which can never provide valid absence data, the modelling was carried out using a presence-only method.

The method, Ecological-Niche Factor Analysis (ENFA), is detailed described in (Hirzel, et al., 2002) (Hirzel, et al., 2006), but is a presence-only multifactorial analysis, comparing the distribution of the species in question with the distribution of a number of Eco-Geographical Variables (EGVs) believed to describe the habitat available for the species (Table 6.27). The EGVs are transformed into a smaller set of uncorrelated factorial axes, of which the first represents Marginality (how much a species' habitat differs from the mean available environmental conditions) and the rest contributes to Specialization (width of the ecological niche).

The coefficients of the EGV's on the factors give the importance of EGV's in describing each factorial axes. A Habitat Suitability (HS) index was calculated on the basis of the marginality factor and the first 2-4 specialization factors by comparison with a broken-stick distribution. All grid cells in the study area were allocated values by the habitat suitability algorithm proportional to the distance between the grid value and the value for the species optimum in factorial space. The geometric mean algorithm was used for computing the habitat suitability because of the algorithms improved estimation in situations with non-unimodal distributions (Hirzel, et al., 2003). Habitat Suitability Index (HSI) values ranging from 0 to 100 were calculated based on the habitat suitability values; cells near the geometric mean of an axis scoring the most.

In order to compare the habitat suitability in the baseline year with each of the following years, the HSI computations mentioned above was done by pairing information for each year with information from the baseline year in one “pseudo map”. Changes in habitat suitability was calculated by subtracting the baseline years HSI value in a given grid cell from the HSI value in the given year.

The only EGV's that change from the baseline year and the following years are coverage of eelgrass and coverage of macroalgae. Both of the variables are modelled on the basis of changing spill scenarios.

ENFA analyses were carried out using Biomapper 4.0 (Hirzel, et al., 2007) and IDRISI (Clarks University).

Table 6.27: The Eco-Geographical-Variables (EGV's) used for the habitat modelling.

EGV
Distance to Danish coastline (constant above 5000 m)
Distance to German coastline (constant above 500 m)
Distance to nearest mussel area (constant above 2000 m)
Current speed (yearly mean, direction into the Baltic, m/s)
Depth (negative numbers, m)
Coverage of eelgrass 0-100%
Coverage of macroalgae 0 – 100%
Distance to nearest coarse, mixed substrate (constant above 2000 m)
Distance to nearest mud, sandy mud or thin sandy mud substrate (constant above 2000 m)
Distance to nearest muddy sand or sand substrate (constant above 2000 m)
Density (yearly mean, current direction into the Baltic, g/cm^3)
Pycnocline strength (yearly mean, current direction into the Baltic, g/cm^3/m)

6.5.2 **Degree of impairment**

The degree of impairment is estimated as changes in habitat suitability due to changes in the coverage of macroalgae and eelgrass caused by e.g. sediment spill during the construction phase of the tunnel.

Figure 6.17-Figure 6.25 illustrates the changes in habitat suitability between the baseline situation and a specific year during the construction for juvenile cod, juvenile whiting, juvenile flatfish and shallow water species including sea stickleback. These are the environmental indicators of the shallow water fish community which might be affected by the indirect pressure from changes in the benthic vegetation.

Cod

A minor reduction (0.35 %) in habitat suitability for cod (nursery and feeding) in Rødsand lagoon is expected in the first year (2015) of the construction of the tunnel. However, in 2017 the reduction is only 0.05 % and insignificant (Figure 6.17). No impairment is expected in neither the near zone (500 m zone) nor the local area (10 km zone).

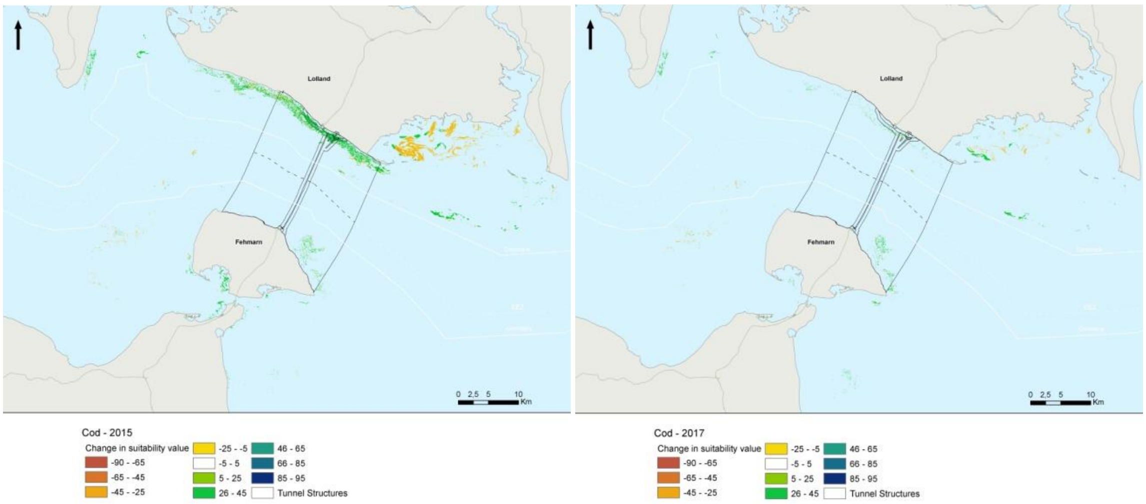


Figure 6.17: Changes in habitat suitability for cod in the shallow water fish community in Fehmarnbelt during the construction year 2015 and 2017 of the E-ME tunnel.

Whiting

The suitability of nursery areas for juvenile whiting in Fehmarnbelt is not reduced by the construction of the tunnel (Figure 6.18). Even the most suitable area along the southern coast of Lolland does not seem to be affected.

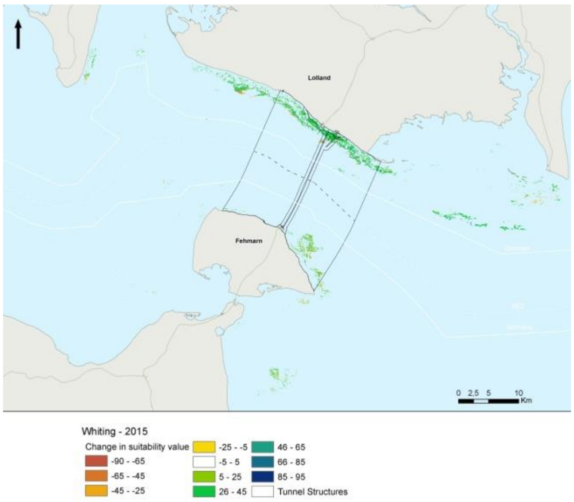


Figure 6.18: Changes in habitat suitability for juvenile whiting in Fehmarnbelt during the first year (2015) of construction of the E-ME tunnel.

Flatfish

The construction of the tunnel is not expected to have any indirect impact on the habitat suitability of juvenile flounder and dab in the near and local area. However, minor reduction of the suitability for flounder nursery is seen in Rødsand Lagoon, but these reductions seem to return to the baseline conditions during the construction period (Figure 6.19 and Figure 6.20).

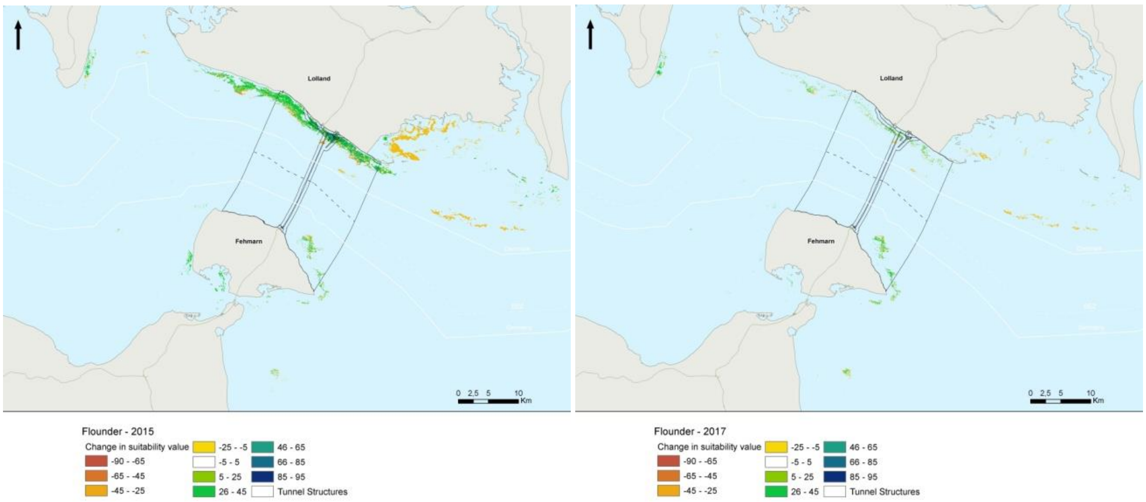


Figure 6.19: Changes in habitat suitability for flounder in the shallow water fish community in Fehmarnbelt during the construction year 2015 and 2017 of the E-ME tunnel.

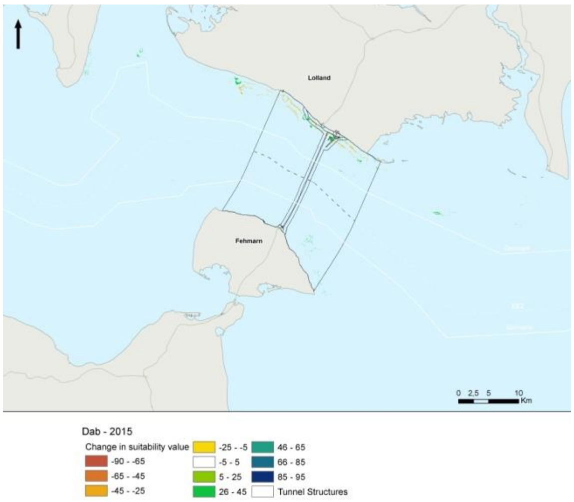


Figure 6.20: Changes in habitat suitability for dab in the shallow water fish community in Fehmarnbelt during the first year (2015) of construction of the E-ME tunnel.

Shallow water species
Shallow water species are resident fish which live their entire life in the shallow coastal areas.

Eelpout is a resident species which prefers structured vegetated habitats. During the baseline studies the vast majority of the eelpout were caught off the coast of Lolland. Minor reduction in the habitat suitability is expected during the construction. However, the impairment will decrease during the construction phase (Figure 6.21).

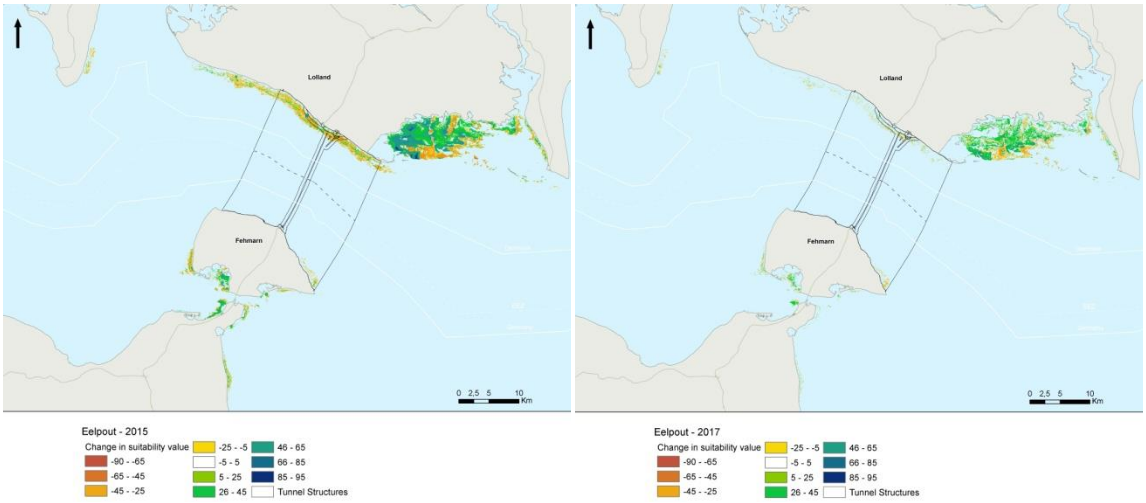


Figure 6.21: Changes in habitat suitability for eelpout in the shallow water fish community in Fehmarnbelt during the construction year 2015 and 2017 of the E-ME tunnel.

Goldsinny wrasse prefers highly structured habitats with stones and vegetation and is found along the coast off Lolland and Fehmarn. Minor reductions in the habitat suitability are expected primarily on the coast off Lolland. However, the reductions will decrease throughout the construction phase and return to baseline conditions (Figure 6.22).

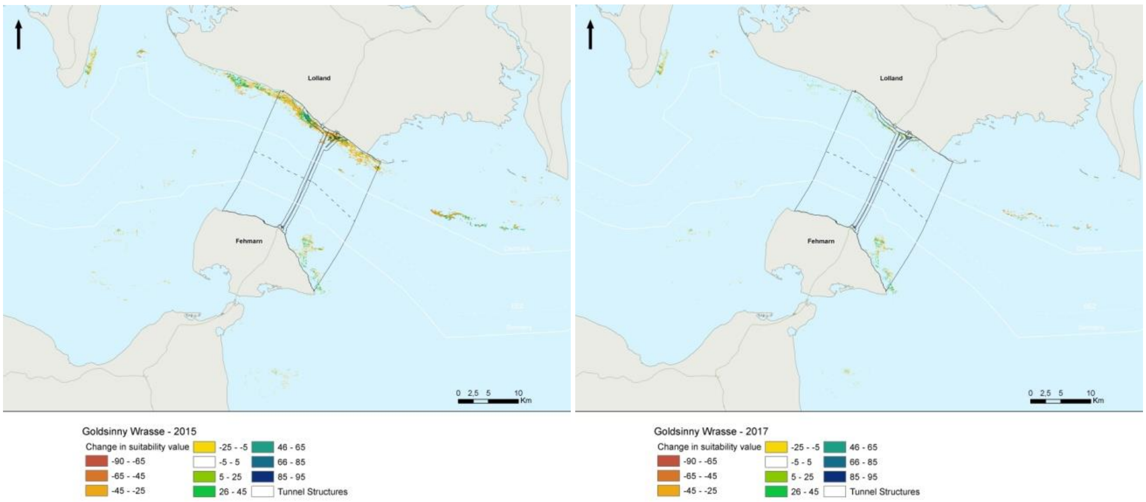


Figure 6.22: Changes in habitat suitability for goldsinny wrasse in the shallow water fish community in Fehmarnbelt during the construction year 2015 and 2017 of the E-ME tunnel.

Rødsand Lagoon is the most suitable area for black goby which prefers structured habitats with vegetation. The habitat suitability for black goby in Rødsand lagoon is not expected to be reduced. Only during the first year of construction of the tunnel minor reductions are expected. However, during the construction phase the suitability will return to the baseline situation (Figure 6.23).

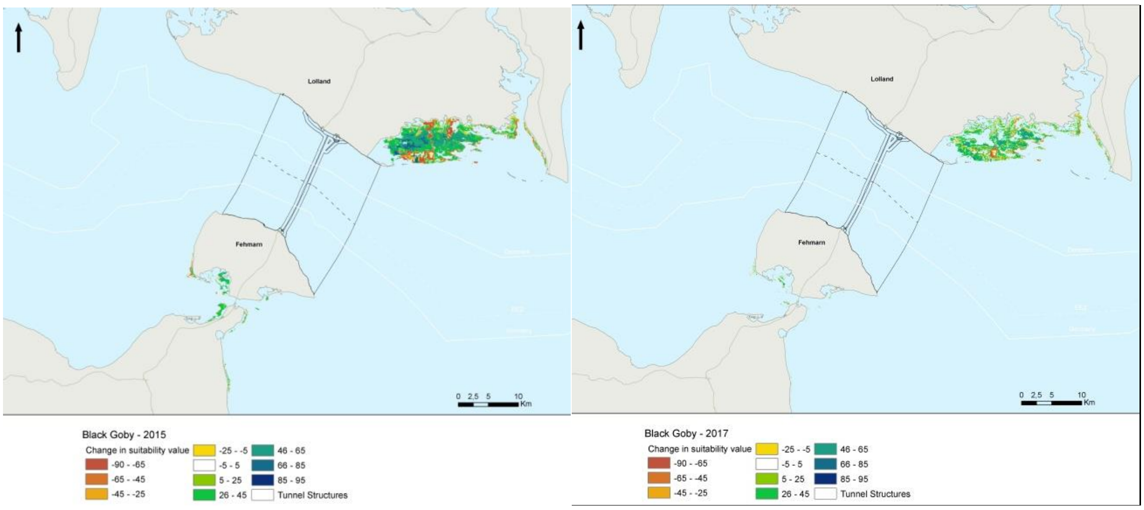


Figure 6.23: Changes in habitat suitability for black goby in the shallow water fish community in Fehmarnbelt during the construction year 2015 and 2017 of the E-ME tunnel.

The great sandeel prefers sandy habitats where it can hide in the bottom substrate. Thus, no impairment from indirect pressures is expected due to the construction of the tunnel (Figure 6.24).

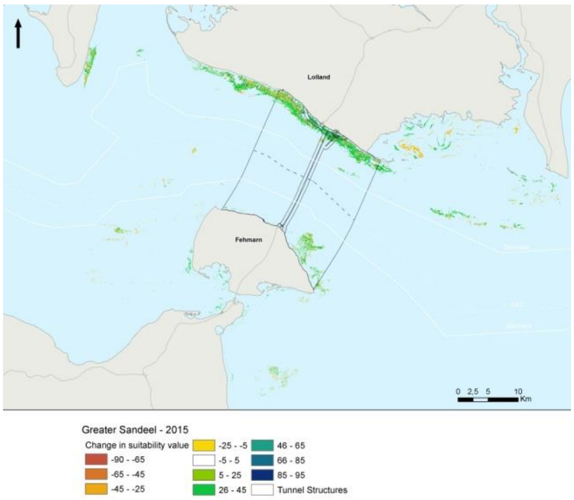


Figure 6.24: Changes in habitat suitability for great sandeel in the shallow water fish community in Fehmarnbelt during the first year (2015) of construction of the E-ME tunnel.

Sea stickleback

Rødsand Lagoon and the southern coast of Lolland are the most suitable habitats for sea stickleback in the area of Fehmarnbelt. Minor reductions of habitat suitability are expected during the construction phase. However, the habitat suitability seems to be very close to the baseline conditions in the last year (2019) of the construction of the tunnel (Figure 6.25).

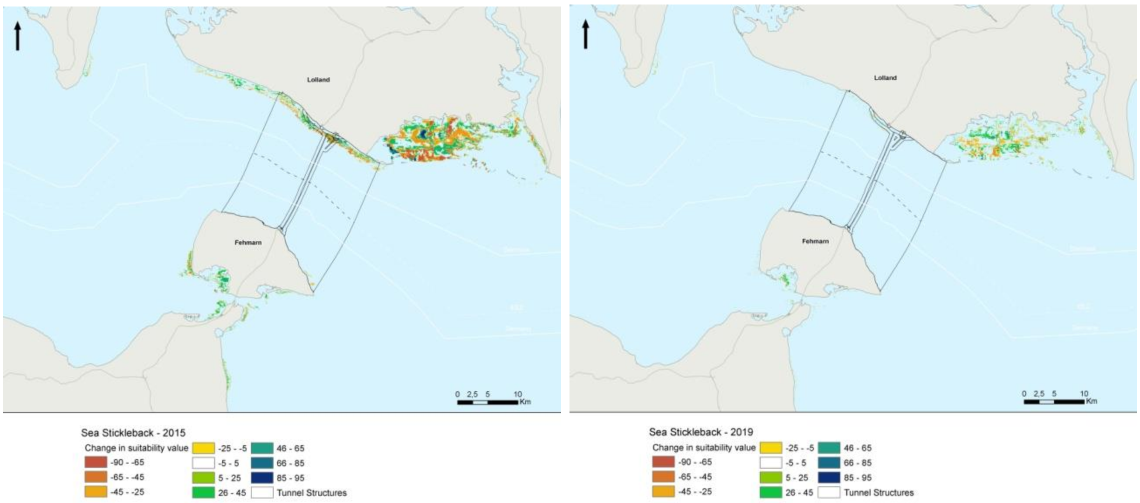


Figure 6.25: Changes in habitat suitability for sea stickleback in the shallow water fish community in Fehmarnbelt during the construction year 2015 and 2019 of the E-ME tunnel.

Overall, the indirect pressure of changes in the macroalgae and eelgrass does not seem to have a negative impact on the small shallow water species associated to the vegetation by reducing the suitability of the habitats. For shallow water species where minor reduction is expected the habitat conditions seem to return to baseline conditions throughout the construction phase. Thus, the impairment during the operation phase is considered as insignificant. Additionally, for juvenile cod only minor impairment of the nursery habitats is expected during the first years of construction and is insignificant at the last part of the construction phase. The habitat suitability for flatfish is also expected to return to the baseline conditions during the second part of the construction phase.

The habitat preferences differ between species and life stages and some species prefer sandy habitats whereas others prefer vegetated areas. However, fish does not seem to prefer habitats with 100 % cover of vegetation. The majority of the environmental components assessed are not affected by indirect pressures in relation to changes in benthic vegetation. Additionally, the habitat suitability for the majority of the shallow water fish community is not reduced. However, minor reductions in the habitat suitability of eelpout and goldsinny wrasse are expected during the construction. Thus, eelpout is chosen as environmental indicator of indirect pressures on the shallow water fish community in all areas (except Rødsand Lagoon) as it is considered as worst case scenario. The highest reduction (0.17 %) in Rødsand Lagoon is expected for the goldsinny wrasse and thus this species is chosen as indicator for shallow water species in Rødsand Lagoon.

The estimated reduction of environmental components for each area of investigation, except Rødsand Lagoon is presented in Table 6.28. The reduction of environmental components caused by indirect pressure is largest in Rødsand Lagoon and is thus presented in a separate table where the yearly changes during the construction phase (2015-2019) are illustrated (Table 6.29). The reduction of environmental components is estimated as the worst year during the construction phase (2015-2019).

Table 6.28: The reduction of environmental components caused by indirect pressures (% and ha) from the construction of the E-ME-tunnel solution in all areas of investigation except Rødsand Lagoon.

Reduction of environmental components % (ha) Tunnel Construction	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Nursery (<10 m)	0	0	0	0	0	0
Feeding (>5 m)	0	0	0	0	0	0
Whiting						
Nursery (>0 m)	0	0	0	0	0	0
Flatfish						
Nursery (<10 m)	0	0	0	0	0	0
Feeding (>0 m)	0	0	0	0	0	0
Shallow water species						
Spawning (<10 m)	0.16 (3.3)	0	1.00 (200.1)	0	0	3.10 (182.1)
Nursery (<10 m)	0.16 (3.3)	0	1.00 (200.1)	0	0	3.10 (182.1)
Feeding (<10 m)	0.16 (3.3)	0	1.00 (200.1)	0	0	3.10 (182.1)
Sea stickleback						
Spawning (habmap)	0.03 (0.1)	0	0.45 (40.2)	0	0	0.6 (7.5)
Nursery (")	0.03 (0.1)	0	0.45 (40.2)	0	0	0.6 (7.5)
Feeding (")	0.03 (0.1)	0	0.45 (40.2)	0	0	0.6 (7.5)

Table 6.29: The reduction of environmental components caused by indirect pressures (% and ha) from the construction (year 2015-2019) of the E-ME-tunnel solution in Rødsand Lagoon.

Reduction of environmental components % (ha) Tunnel Construction Rødsand Lagoon	**2015**	**2016**	**2017**	**2018**	**2019**
Cod					
Nursery (<10 m)	0.35 (35.9)	0.23 (16.1)	0.05 (0.6)	0.03 (0.2)	0.02 (0.1)
Feeding (>5 m)	-	-	-	-	-
Whiting					
Nursery (>0 m)	0	0	0	0	0
Flatfish					
Nursery (<10 m)	0.21 (12.5)	0.27 (22.2)	0.11 (3.8)	0.04 (0.5)	0.04 (0.6)
Feeding (>0 m)	0.21 (12.5)	0.27 (22.2)	0.11 (3.8)	0.04 (0.5)	0.04 (0.6)
Shallow water species					
Spawning (<10 m)	0.17 (8.8)	0.07 (1.4)	0.01 (0.0)	0.00 (0.0)	0.00 (0.0)
Nursery (<10 m)	0.17 (8.8)	0.07 (1.4)	0.01 (0.0)	0.00 (0.0)	0.00 (0.0)
Feeding (<10 m)	0.17 (8.8)	0.07 (1.4)	0.01 (0.0)	0.00 (0.0)	0.00 (0.0)
Sea stickleback					
Spawning (habmap)	2.41 (1708.4)	1.18 (410.4)	0.54 (84.5)	0.23 (14.9)	0.17 (8.2)

Nursery (”)	2.41 (1708.4)	1.18 (410.4)	0.54 (84.5)	0.23 (14.9)	0.17 (8.2)
Feeding (”)	2.41 (1708.4)	1.18 (410.4)	0.54 (84.5)	0.23 (14.9)	0.17 (8.2)

The degree of the impairment caused by indirect pressures from the construction of the tunnel in each area of investigation, except Rødsand Lagoon, on each indicator selected for the present assessment is presented in Table 6.30. The yearly degree of impairment in Rødsand Lagoon is presented in a separate table (Table 6.31). The impairment is minor for some environmental indicators and largest during the first year of construction. The habitat suitability of all environmental indicators is expected to return to baseline conditions at the end of the construction phase.

Table 6.30: The degree of impairment caused by indirect pressures from the construction of the E-ME-tunnel solution in all areas of investigation except Rødsand Lagoon.

Degree of impairment of indirect pressure % (ha) Tunnel Construction	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Nursery (<10 m)						
Feeding (>5 m)						
Whiting						
Nursery (>0 m)						
Flatfish						
Nursery (<10 m)						
Feeding (>0 m)						
Shallow water species						
Spawning (<10 m)	Minor		Minor			Minor
Nursery (<10 m)	Minor		Minor			Minor
Feeding (<10 m)	Minor		Minor			Minor
Sea stickleback						
Spawning (habmap)	Minor		Minor			Minor
Nursery (")	Minor		Minor			Minor
Feeding (")	Minor		Minor			Minor

Table 6.31: The degree of impairment caused by indirect pressures from the construction (year 2015-2019) of the E-ME-tunnel solution in Rødsand Lagoon.

Degree of impairment of indirect pressure % (ha) Tunnel Construction, Rødsand Lagoon	**2015**	**2016**	**2017**	**2018**	**2019**
Cod					
Nursery (<10 m)	Minor	Minor	Minor	Minor	Minor
Feeding (>5 m)	-	-	-	-	-
Whiting					
Nursery (>0 m)					
Flatfish					
Nursery (<10 m)	Minor	Minor	Minor	Minor	Minor
Feeding (>0 m)	Minor	Minor	Minor	Minor	Minor
Shallow water species					
Spawning (<10 m)	Minor	Minor	Insignif.	Insignif.	Insignif.
Nursery (<10 m)	Minor	Minor	Insignif.	Insignif.	Insignif.
Feeding (<10 m)	Minor	Minor	Insignif.	Insignif.	Insignif.
Sea stickleback					
Spawning (habmap)	Minor	Minor	Minor	Minor	Minor
Nursery (”)	Minor	Minor	Minor	Minor	Minor
Feeding (”)	Minor	Minor	Minor	Minor	Minor

6.5.3 Severity and significance

The severity of impairment of indirect pressure from the construction of the tunnel solution is assessed to be insignificant or minor on all indicators selected for the present assessment (Table 6.32 and Table 6.33). There are therefore no indications of significant consequences among fish and fish communities of indirect pressure from dredging activities related to the construction.

When an area is recovered in regard to the indirect pressures the fish species will return to the habitat within short time. Thus the recovery time for fish species in Fehmarnbelt in relation to indirect pressures is estimated to be less than three years after the construction phase of a tunnel is completed (Table 6.33).

Table 6.32: The severity of impairment caused by indirect pressures from the construction of the E-ME-tunnel solution in areas of investigation except Rødsand Lagoon.

Severity of impairment of indirect pressure % (ha) Tunnel Construction	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Nursery (<10 m)						
Feeding (>5 m)						
Whiting						
Nursery (>0 m)						
Flatfish						
Nursery (<10 m)						
Feeding (>0 m)						
Shallow water species						
Spawning (<10 m)	Minor		Minor			Minor
Nursery (<10 m)	Minor		Minor			Minor
Feeding (<10 m)	Minor		Minor			Minor
Sea stickleback						
Spawning (habmap)	Minor		Minor			Minor
Nursery (")	Minor		Minor			Minor
Feeding (")	Minor		Minor			Minor

Table 6.33: The severity of impairment caused by indirect pressures from the construction (2015-2019) of the E-ME-tunnel solution in Rødsand Lagoon.

Severity of impairment of indirect pressure % (ha), Tunnel Construction, Rødsand Lagoon	**2015**	**2016**	**2017**	**2018**	**2019**
Cod					
Nursery (<10 m)	Minor	Minor	Minor	Minor	Minor
Feeding (>5 m)	-	-	-	-	-
Whiting					
Nursery (>0 m)					
Flatfish					
Nursery (<10 m)	Minor	Minor	Minor	Minor	Minor
Feeding (>0 m)	Minor	Minor	Minor	Minor	Minor
Shallow water species					
Spawning (<10 m)	Minor	Minor			
Nursery (<10 m)	Minor	Minor			
Feeding (<10 m)	Minor	Minor			
Sea stickleback					
Spawning (habmap)	Minor	Minor	Minor	Minor	Minor
Nursery (”)	Minor	Minor	Minor	Minor	Minor
Feeding (”)	Minor	Minor	Minor	Minor	Minor

6.6 Cumulative and transboundary impacts

The existing projects and project plannings which, in summation, could cause significant impacts on fish are described in this chapter. According to Brandt et al. (2002), summation-effects occur if: “within a long period significant damage is caused collectively” and according to Planungsgruppe Ökologie und Umwelt (2004) if: “several projects are carried out in close spatial and temporal context” with respect to the environmental conditions. A project is relevant to consider if 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
- create new environmental impacts during the period from the environmental investigations were completed to the fixed link is in operation.

Summation-effects are particularly relevant to adjacent projects like offshore wind farms. Projects, which already are implemented or projects that are far in the planning, are important to consider in a cumulative analysis. The projects which are relevant in relation to the tunnel solution are listed in Table 6.34 and illustrated in Figure 6.26.

Table 6.34: Projects relevant for the cumulative analysis in relation to the tunnel solution.

Project	Placement	Phase	Possible interactions
Arkona-Becken Südost	North East of Rügen	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
EnBW Windpark Baltic 2	South East of Kriegers Flak	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
Wikinger	North East of Rügen	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
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, barrier effect

Rødsand II is specifically included as this is a project that went into operation, while Femern A/S conducted the environmental investigations, whereby a cumulative effect in principle cannot be excluded.

Generally, projects were deselected if the project already was in operation, while the environmental investigations were carried out. In this case the environmental impacts are included in the environmental investigations, and are therefore the benchmark for the environmental assessment. Thus all the cumulative impacts in the environmental assessment of the fixed link are included.

During the construction phase, the majority of the cumulative impacts are expected in relation to the sediment spill caused by dredging of the tunnel trench and noise extraction during pile driving at the work harbour. With respect to sediment spill a physical injury of individuals (affecting e.g. respiratory organs of pelagic fish) is not likely but possible. Based on their natural behaviour avoidance would be expected. Noise is known to provoke avoidance reactions. Thus both migrating fish passing a source and resident fish in the vicinity of a source of noise might be impacted. Overall, the duration of these impacts are short but may be of great extent.

A barrier effect caused by the overlapping of effect zones particular in relation to sediment spill might impact migratory fish e.g. anadromous species (Atlantic salmon and sea trout) as well as cod, herring and sprat. These migratory species will likely avoid areas with high intensities of noise or suspended sediment, and accordingly they might not reach areas of high importance for e.g. spawning. The modeled sedimentation rates for the tunnel outside of the alignment corridor are equal to the naturally occurring sedimentation (e.g. sediment spill in relation to storm, high current flow). Depending on weather and current conditions, it is not likely that the sedimentation of both projects (Fehmarnbelt fixed link and Rødsand II) will overlap extensively. Thus, it is possible for migrating fish species to use the “sedimentation-free” large areas as migration routes and therefore only minor barrier effects of migrating fish are expected during construction.

The impacts caused by the tunnel solution (tunnel trench and working harbours) could be enhanced by the planned offshore wind farm “GEOFReE” close to the area of the fixed link (Figure 6.26) if the impacts appear within the same areas and in the same period. The effect zones (sediment spill, noise) might be overlapping. In a worst-case-scenario large areas would be avoided by fish temporary because of this summation of impact factors. Foundation type and construction periods for this project are not known.

Cumulative impacts from noise emissions and sediment spill need to be assessed in case the construction periods of a tunnel and wind farm(s) are simultaneous. Cumulative impacts from “GEOFReE” will not occur, if the project not is built in the same period as the tunnel. The operation of the wind farms is not considered to affect the population of fish stocks.

So far, no cumulative impacts on fish distribution have been described. However, it is generally assumed that a cumulation will increase the impact on fish communities. For example, displacement of fishes might increase as well as the mortality of eggs and fish larvae.

Therefore, a coordination between projects (i.e. construction times) could reduce potential cumulative effects. Based on experience from similar projects, though it is estimated that the cumulative impacts from sediment spill and noise are not significant.

In summary, a spatial and temporal overlapping of sediment flags and noise emission, which will affect fish stocks and species, is possible in case the construction phases of projects close to the tunnel trench are carried out at the same time. Therefore, a simultaneous execution of different projects in the local area of Fehmarnbelt should be avoided.

Cumulative impacts from extraction of raw material and planned wind farms at Kriegers Flak and Rønne Banke are not likely, since there will be approximately 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 not likely that there will be an overlap in time between the projects.

No cumulative impacts are expected in relation to the operating offshore wind farms “Nysted”/“Rødsand II” and the planed wind farms “Arkona-Becken Südost “, “EnBW Windpark Baltic 2”, “Wikinger“ and “Kriegers Flak II” (distances are too large for cumulative effects).

No significantly negative environmental effects on fish stocks are expected during the operational phase.

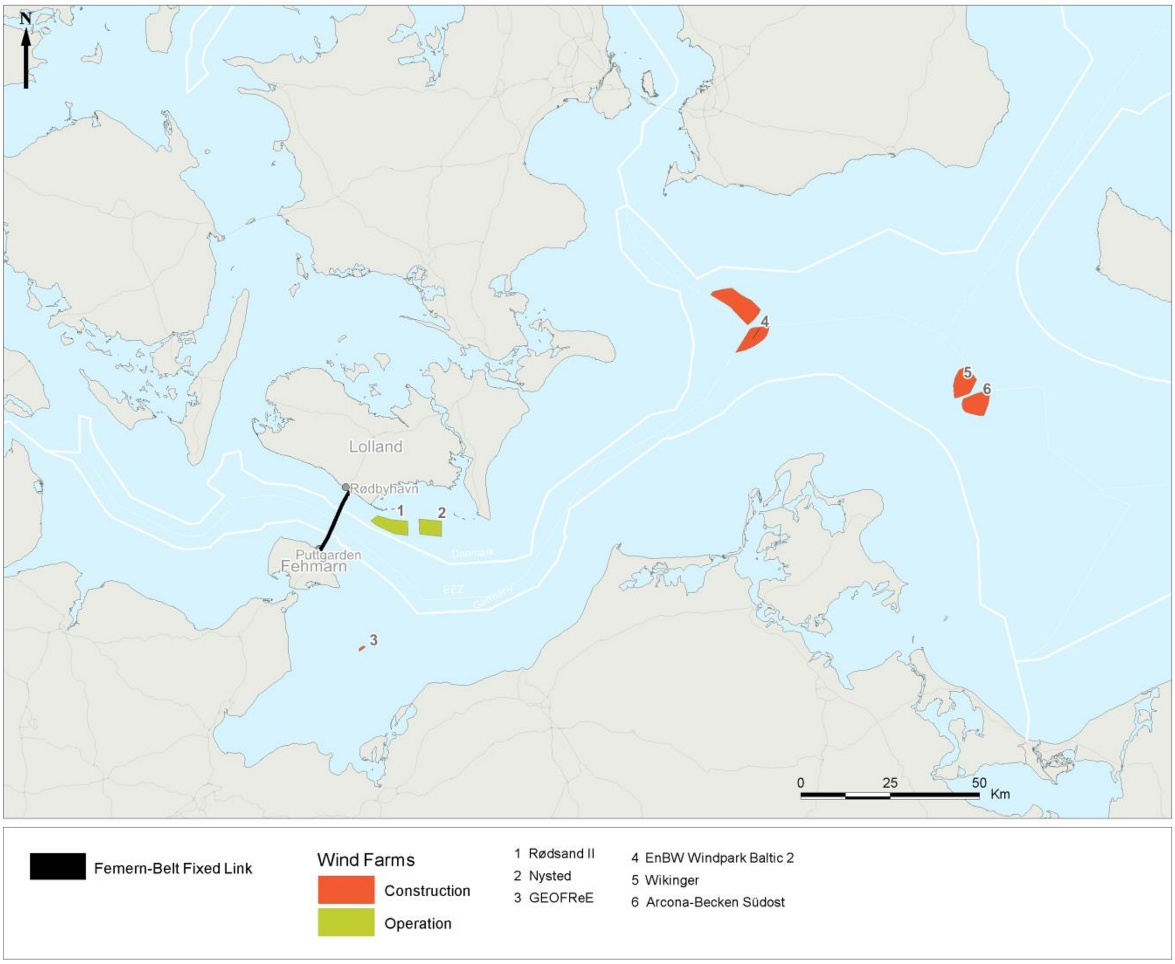


Figure 6.26: Overview of all projects in the Baltic Sea which can affect fish species and communities in the area of Fehmarnbelt by cumulative impacts.

Transboundary pressures:
This chapter includes a summary of potential impacts of the project which can be transboundary. In accordance with the requirements of the Espoo Convention there should be differentiated between each of the affected States.

Transboundary effects at the operational phase of the immersed tunnel are of minor importance (noise emission, sediment spill and barrier effect are insignificant) and thus primary construction-related effects are relevant.

Table 6.35 gives an overview of the minimum distance of the fixed link to the territorial waters of neighbouring states.

Table 6.35: Overview of the minimum distances of the fixed link to the territorial waters of neighboring states.

Fixed link	Distance to Poland	Distance to Sweden
Bridge	226 km	135 km
Tunnel	226 km	135 km

Furthermore, the increased presence of working vessels might cause an accident on sea. This might result in drift of water polluting substances over long distances due to currents and wind/waves. Thus, there is a risk of a small emission of oil and other polluting substances used in vehicles and machines. Therefore, transboundary effects caused by accidents at sea might be of minor importance for fish stocks in territorial waters of Poland or Sweden.

Direct impacts:
Transboundary environmental effects of the tunnel solution to adjacent waters comprise mainly visual and acoustic effects.

The possible transboundary effects are mainly caused by sediment plumes and re-suspension of material. According to FEHY (2013a) the central areas of the Mecklenburg and Arkona Bight will be affected by sediment spill (compare Figure 6.27). A medium level of sedimentation is carried out in these areas (maximum size of sediment deposition by 0.5 mm between 2015 and 2017). The territorial waters of Sweden will be affected by sedimentation in small quantities. The Mecklenburg and Arkona Bight is an important spawning area for flatfishes and particular for cod. A minor impairment of eggs and larvae can not be excluded.

On Kriegers Flak and Rönne Bank it is planned to use these areas for the extraction of sand. According to (FEHY, 2011a; FEHY, 2011b) the sediment plumes and sediment deposition are of low intensity and within a narrow range. These effects are located in the vicinity of the extraction areas. The territorial waters of Sweden and Poland will not be affected by dredging in the sand extraction areas.

Due to the low intensity of direct impacts by sedimentation the transboundary effects are classified as insignificant.

Indirect impacts:
During the construction phase a barrier effect caused by dredging of the tunnel trench and immersing the tunnel elements is expected for anadromous fish species and fish species with long term migrations (cod, herring and sprat). These species avoid areas with a high intensity of sediment plumes and noise. Thus, the migratory fish species might not reach areas of high importance (spawning areas) in neighbouring states. The impacts are of low intensity and extension, and therefore only minor transboundary effects are expected by indirect impacts.

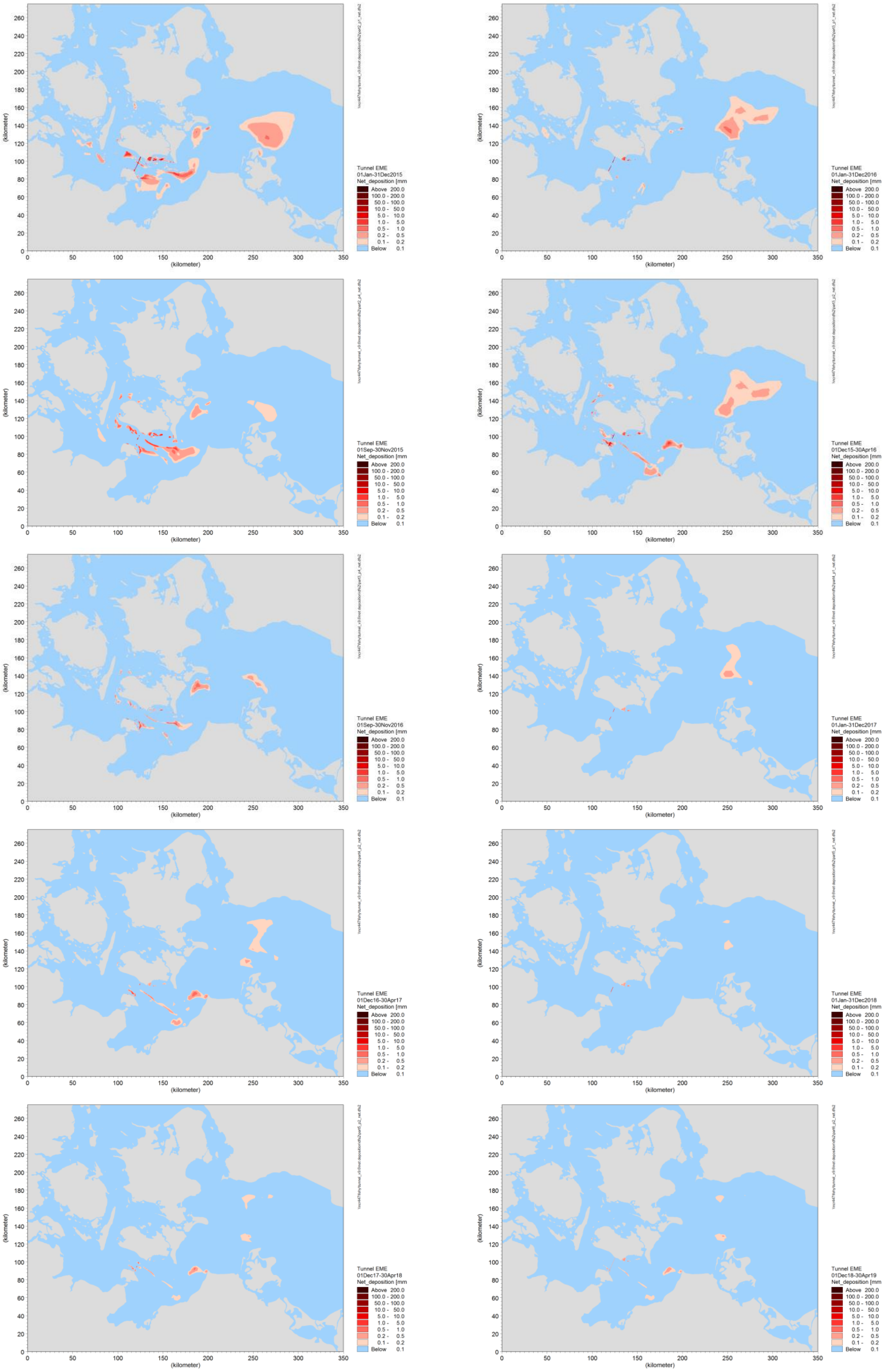


Figure 6.27: Temporal and spatial extent of sediment deposition of the immersed tunnel solution. Source: FEHY, 2013a).

6.7 Other pressures

Other pressures related to the tunnel scenario are mostly related to the construction phase.

- *Artificial light*
  The construction work at sea implies additional artificial light from operating vessels, and this work is expected 24 hours a day during the entire construction phase. During dark hours the working areas will be illuminated and the light will penetrate the sea surface. Artificial light is known to influence the behaviour of fish as some are phototaxic (herring, mackerel and sprat) and others are photophobic (eel and salmon smolt).

  Less than 30% of the Baltic silver eel use Fehmarnbelt as a spawning migration route. Eel swim near the surface in night time during the spawning migrations out of the Danish seas towards the Sargasso Sea from October to December. As they are photophobic the artificial light could act as a barrier for the eel migration through Fehmarnbelt during the construction phase. However, the construction will not take place along the entire alignment at one time and the light will thus not act as barrier across Fehmarnbelt. Thus, the eel migration is not expected to be impaired by these lights.

  Overall, the impact from artificial light during the tunnel construction is expected to be negligible.

- *Spill of hazardous materials*
  Accidental spill of hazardous materials from the operating vessels might occur, but this must be assumed only to occur in a small scale and it is not considered to have measurable impact on the fish fauna.

- *Electromagnetic fields* (EMF)
  In the operation of the tunnel the only potential pressure besides noise and vibration is electromagnetic fields (EMF) generated from the power supply cables for the electrified trains. The AC cables used for the electrified trains generate only a very weak EMF with a range of few meters. Taken into account, that the top of the tunnel is 3 m beneath the seabed the EMF would hardly be detectable on the seabed. Furthermore, the majority of migrating fish species has a pelagic migration (herring, sprat, whiting) or migrate near the surface well away from the potential EMF. Thus, EMF is not believed to have any impact.

6.8 Project impact

In the following sub-chapter, the results of project impacts analysis for all components and associated indicators are shown. These include the results of the impact analysis of all pressures existing during both, the “construction phase” and the “operation phase”. It has to be noted that the project impact analysis includes the results of severity-of-impairment analysis and the severity-of-loss analysis.

As no or minor impairment was determined for some species within the near zone and for all species in the local zone (see chapters below), the results of project impacts analysis for these species and for the local zone are not shown.

6.8.1 Cod

Construction phase

As shown in Table 6.36, only the pressure “temporary seabed reclamation” will lead to medium impairment of spawning, egg-larvae drift and feeding (only for DE near zone excl. EEZ) for cod. For all other indicator and pressures, no or minor impairment for cod is expected. Thus, the project impact during the construction phase is classified as overall medium.

Table 6.36: Project impact on cod related to the construction of an immersed tunnel.

Impairment DE-500 m (national and EEZ) Tunnel Construction	**Temporary seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Cod										
Spawning	🟧						Medium	High	Medium	
Egg-larvae drift	🟧						Medium	High	Medium	
Nursery							Minor	Medium	Minor	
Feeding	🟧						Medium	Medium	Medium	
Migration							Minor	High	Minor	
Project severity									Medium	

Impairment DK-500 m Tunnel Construction	**Temporary seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Cod										
Spawning	🟧						Medium	High	Medium	
Egg-larvae drift	🟧						Medium	High	Medium	
Nursery							Minor	Medium	Minor	
Feeding							Minor	Medium	Minor	
Migration							Minor	High	Minor	
Project severity									Medium	

Operation phase

During operation the physical structures in the DK near zone is expected to cause a medium impairment of cod feeding, and the project impact is classified as overall medium in this area. Due to seabed reclamation there is a small, but medium severe loss of cod nursery in the DE near zone and in the DK near zone.

Table 6.37: Project impact on cod related to the operation of an immersed tunnel.

Impairment DE-500 m (excl. EEZ) Tunnel Operation	**Permanent seabed reclamamtion**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Cod										
Spawning							Minor	High	Minor	
Egg-larvae drift							Minor	High	Minor	
Nursery							Minor	Medium	Minor	Medium
Feeding							Minor	Medium	Minor	
Migration							Minor	High	Minor	
Project severity									Minor	Medium

Impairment DK-500 m Tunnel Operation	**Permanent seabed reclamamtion**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Cod										
Spawning							Minor	High	Minor	
Egg-larvae drift							Minor	High	Minor	
Nursery							Minor	Medium	Minor	Medium
Feeding							Medium	Medium	Medium	
Migration							Minor	High	Minor	
Project severity									Medium	Medium

As project impact during the construction phase as well as the operation phase is assessed as medium or minor only, no significant impairments for cod are expected for the immersed tunnel.

6.8.2 Whiting

Construction phase

As shown in Table 6.38, only the pressure “temporary seabed reclamation” will lead to medium impairment of nursery for whiting. For all other indicator and pressures, no or minor impairment for whiting is expected. Thus, the project impact during the construction phase is classified as overall minor.

Table 6.38: Project impact on whiting related to the construction of an immersed tunnel.

Impairment DE-500 m (excl. EEZ) Tunnel Construction	**Temporary seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Whiting										
Spawning							Minor	not relevant	Insignif.	
Egg-larvae drift							Minor	not relevant	Insignif.	
Nursery							Medium	Minor	Minor	
Feeding							Minor	not relevant	Insignif.	
Migration							Minor	Medium	Minor	
Project severity									Minor	

Operation phase

As shown in Table 6.39, no or minor impairment for whiting from all existing pressures during the operation phase is expected. The very high project impairment on whiting nursery is only of minor importance, and the project impact during the operation phase is classified as overall minor.

Table 6.39: Project impact on whiting related to the operation of an immersed tunnel.

Impairment DK-500 m Tunnel Operation	**Permanent seabed reclamamtion**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Whiting										
Spawning							Minor	not relevant	Minor	
Egg-larvae drift							Minor	not relevant	Minor	
Nursery							Very high	Minor	Minor	
Feeding							Minor	not relevant	Minor	
Migration							Minor	Medium	Minor	
Project severity									Minor	

As project impact during the construction phase as well as the operation phase is assessed as minor or medium only, no significant impairments for whiting are expected for the immersed tunnel.

6.8.3 Herring

Construction phase

As shown in Table 6.40, only sediment spill in the Danish national territory will cause a medium impairment of egg-larvae drift. For all other indicators and pressures, no or minor impairment for herring is expected in both territories. Thus, the project impact during the construction phase is classified as overall minor.

Table 6.40: Project impact on herring related to the construction of an immersed tunnel.

Impairment DK-500 m Tunnel Construction	**Temporary seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Herring										
Spawning							Minor	Minor	Insignif.	
Egg-larvae drift		🟧					Medium	Minor	Minor	
Nursery							Minor	Minor	Insignif.	
Feeding							Minor	Minor	Insignif.	
Migration							Minor	High	Minor	
Project severity									Minor	

Operation phase

As shown in Table 6.41, no or minor impairment for herring from all existing pressures during the operation phase is expected. The very high project impairment on herring drift of eggs and larvae and nursery due to sebed reclamation is only of minor importance, and the project impact on herring during the operation phase is classified as overall minor.

Table 6.41: Project impact on herring related to the operation of an immersed tunnel.

Impairment DK-500 m Tunnel Operation	**Permanent seabed reclamamtion**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Herring										
Spawning							Minor	Minor	Minor	Minor
Egg-larvae drift	🟫						Very high	Minor	Minor	Minor
Nursery	🟫						Very high	Minor	Minor	
Feeding	🟧						Medium	Minor	Minor	
Migration							Minor	High	Minor	
Project severity									Minor	Minor

As project impact during the construction phase as well as the operation phase is assessed as minor or medium only, no significant impairments for herring are expected for the immersed tunnel.

6.8.4 Sprat

Construction phase

No pressure will lead to medium impairment of spawning, egg-larvae drift, nursery or feeding for sprat. Thus, the project impact for sprat during the construction phase is classified as overall minor.

Operation phase

As shown in Table 6.42, no or minor impairment for sprat from all existing pressures during the operation phase is expected. The very high project impairment on sprat nursery due to seabed reclamation is only of minor importance, and the project impact on sprat during the operation phase is classified as overall minor.

Table 6.42: Project impact related to the operation of an immersed tunnel.

Impairment DK-500 m Tunnel Operation	**Permanent seabed reclamamtion**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Sprat										
Spawning							Minor	Medium	Minor	
Egg-larvae drift							Minor	Medium	Minor	
Nursery							Very high	Minor	Minor	
Feeding							Medium	Minor	Minor	
Migration							Minor	Medium	Minor	
Project severity									Minor	

As project impact during the construction phase as well as the operation phase is assessed as medium or minor, no significant impairments for sprat are expected for the immersed tunnel.

6.8.5 **Flatfish**

Construction phase

As shown in Table 6.43, only the pressure “temporary seabed reclamation” will lead to medium impairment of spawning, egg-larvae drift and feeding (only for DE near zone) for flatfish. For all other indicator and pressures, no or minor impairment is expected. Thus, the project impact on flatfish during the construction phase is classified as overall medium.

Table 6.43: Project impact on flatfish related to the construction of an immersed tunnel.

Impairment DE-500 m (national and EEZ) Tunnel Construction	**Temporary seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Flatfish										
Spawning							Medium	Medium	Medium	
Egg-larvae drift							Medium	Medium	Medium	
Nursery							Minor	Medium	Minor	
Feeding							Medium	Medium	Medium	
Migration							Minor	Minor	Insignif.	
Project severity									Medium	
Impairment DK-500 m Tunnel Construction	**Temporary seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Flatfish										
Spawning							Medium	Medium	Medium	
Egg-larvae drift							Medium	Medium	Medium	
Nursery							Minor	Medium	Minor	
Feeding							Minor	Medium	Minor	
Migration							Minor	Minor	Insignif.	
Project severity									Medium	

As project impact during the construction phase is assessed as medium only, no significant impairments for flatfishes are expected for the immersed tunnel.

Operation phase:

No or minor impairment for flatfish from all existing pressures during the operation phase is expected. Thus, the project impact during the operation phase is classified as overall minor. Due to seabed reclamation there is a small, but medium severe loss of flatfish nursery and feeding in the DE near zone and in the DK near zone, where there is an additional small, but medium severe loss of spawning sites.

Table 6.44: Project impact on flatfish related to the operation of an immersed tunnel.

Impairment DE-500 m (excl. EEZ) Tunnel Operation	**Permanent seabed reclamamtion**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Flatfish										
Spawning							Minor	Medium	Minor	
Egg-larvae drift							Minor	Medium	Minor	
Nursery							Minor	Medium	Minor	Medium
Feeding							Minor	Medium	Minor	Medium
Migration							Minor	Minor	Insignif.	
Project severity									Minor	Medium

Impairment DK-500 m Tunnel Operation	**Permanent seabed reclamamtion**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Flatfish										
Spawning							Minor	Medium	Minor	Medium
Egg-larvae drift							Minor	Medium	Minor	
Nursery							Minor	Medium	Minor	Medium
Feeding							Minor	Medium	Minor	Medium
Migration							Minor	Minor	Insignif.	
Project severity									Minor	Medium

6.8.6 Shallow water species

Construction phase

As none of the considered pressures exceed a minor impairment during the construction phase, no significant impairments for shallow water species are expected for the immersed tunnel.

Operation phase:

No or minor impairment for shallow water species from all existing pressures during the operation phase is expected. Thus, the project impact during the operation phase is classified as overall minor. Due to seabed reclamation there is a medium severe loss of habitats in the DE near zone and in the DK near zone.

Table 6.45: Project impact on shallow water species related to the operation of an immersed tunnel.

Impairment DE-500 m (excl. EEZ) Tunnel Operation	**Permanent seabed reclamamtion**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Shallow water species										
Spawning							Minor	Medium	Minor	Medium
Egg-larvae drift							Minor	Minor	Insignif.	Minor
Nursery							Minor	Medium	Minor	Medium
Feeding							Minor	Medium	Minor	Medium
Migration							Minor	Not relevant	Insignif.	
Project severity									Minor	Medium

Impairment DK-500 m Tunnel Operation	**Permanent seabed reclamamtion**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Shallow water species										
Spawning							Minor	Medium	Minor	Medium
Egg-larvae drift							Minor	Minor	Insignif.	Minor
Nursery							Minor	Medium	Minor	Medium
Feeding							Minor	Medium	Minor	Medium
Migration							Minor	Not relevant	Insignif.	
Project severity									Minor	Medium

6.8.7 Eel

As none of the considered pressures exceed a minor impairment during the construction phase as well as the operation phase, no significant impairments for eel are expected for the immersed tunnel.

6.8.8 Sea stickleback

Construction phase

As none of the considered pressures exceed a minor impairment during the construction phase, no significant impairments for sea stickleback are expected for the immersed tunnel.

Operation phase:

Minor impairment for sea stickleback from all existing pressures during the operation phase is expected. Thus, the project impact during the operation phase is classified as overall minor. Due to seabed reclamation there is a highly severe loss of habitats in the DK near zone.

Table 6.46: Project impact on sea stickleback related to the operation of an immersed tunnel.

Impairment DK-500 m. Tunnel Operation	**Permanent seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Sea Stickleback										
Spawning							Minor	High	Medium	High
Egg-larvae drift							Minor	Hig	Medium	High
Nursery							Minor	High	Medium	High
Feeding							Minor	High	Medium	High
Migration							Minor	Not relevant	Insignif.	
Project severity									Medium	High

6.8.9 Snake blenny

Only the pressure “temporary seabed reclamation” will lead to medium impairment of spawning, egg-larvae drift, nursery and feeding for snake blenny (Table 6.47). For all other indicator and pressures, no or minor impairment is expected. The project impact for snake blenny during the construction phase is classified as overall medium.

Table 6.47: Project impact on snake blenny related to the construction of an immersed tunnel.

Impairment DE-500 m (national and EEZ) Tunnel Construction	**Temporary seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Snake blenny										
Spawning	🟧						Medium	High	Medium	
Egg-larvae drift	🟧						Medium	High	Medium	
Nursery	🟧						Medium	High	Medium	
Feeding	🟧						Medium	High	Medium	
Project severity									Medium	
Impairment DK-500 m Tunnel Construction	**Temporary seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Snake blenny										
Spawning	🟧						Medium	High	Medium	
Egg-larvae drift	🟧						Medium	High	Medium	
Nursery	🟧						Medium	High	Medium	
Feeding	🟧						Medium	High	Medium	
Project severity									Medium	

6.8.10 Legally protected species

As none of the considered pressures exceed a minor impairment during the construction phase as well as the operation phase, no significant impairments for all legally protected species are expected for the immersed tunnel.

7. Assessment of impacts of main bridge alternative

7.1 Hydrological changes

Primarily the underwater structure of a Fehmarnbelt fixed link will impact the hydrodynamics causing changes in the water flow. The bridge piers and pillars might thus cause changes in hydrographic parameters such as salinity and oxygen by influencing the vertical mixing of the stratified waters in the Baltic Sea. Furthermore, it could cause change in the current pattern and water exchange. These pressures will mainly be caused due to the structure of the bridge but the construction can result in local disturbance. The operation of the bridge is assumed not to influence the hydrological conditions.

Furthermore, hydrographical changes due to the construction and structure of a bridge in Fehmarnbelt can have an impact on the different life stages of fish. Especially, spawning, egg and larval drift and feeding (larvae) are sensitive to pressure from hydrological changes and are used as environmental indicators for these types of pressure.

The hydrography only has a minor impact on cod recruitment west of Fehmarnbelt and Mecklenburg Bight in the zero-scenario (Vitale, et al., 2008; Hüssy, 2011). Thus, a bridge in Fehmarnbelt will mainly affect cod spawning east of the fixed link especially the Arkona Basin and the deep basins of the central Baltic Sea and not have any impact on the spawning areas west of Fehmarnbelt and Mecklenburg Bight.

It is assumed that the limited changes in salinity caused by a bridge will have an insignificant large-scale impact on the eastern Baltic cod recruitment through reduced abundance of larval prey. Thus a bridge solution will not impact cod recruitment through decrease in larval abundance. Knowledge on the link between larval survival and prey availability in the western Baltic is lacking but it is expected that the salinity is less important for the copepod production in this area. Furthermore, the effect of climate change on zooplankton community is expected to be order of magnitude higher than the effects of a bridge in Fehmarnbelt.

7.1.1 **Magnitude of pressure**

The reduction of environmental components is determined on the basis of the duration and range of the hydrological pressure in addition to the background level exceeding the specific threshold value for the specific environmental indicators.

The local area corresponding to a zone covering 10 km on each side of the alignment has been assessed. However, if worst case scenario for hydrological pressures is identified in an adjacent area this area will be assessed as well.

Hydrodynamic and water quality modelling were performed by FEHY. Different scenarios were modelled:

- ”Ferry” (zero-alternative)
- ”Bridge + Ferry”
- ”Bridge”
- ”Tunnel + Bridge”
- ”Tunnel”

The results of the modelling of the “Bridge + Ferry” scenario are described below. This scenario is chosen as the impact is considered to be “worst case” scenario.

The structure of a bridge has an impact on the flow due to the extra resistance. The local effects to flow blocking are estimated to -0.42 to -0.50 %.

As an effect of the bridge the salinity is in general reduced by < 0.03 psu and up to 0.08 psu in the Arkona Basin. Furthermore, a maximum local decrease in oxygen concentration is estimated to be 0.09 mg/l. However, increase in oxygen content in the bottom water layer also occurs due to increased turbulence near the bridge piers.

The local effect on the bottom salinity is primarily restricted to east of the bridge where a maximum decrease of 0.2 psu is estimated and is an effect of the increased mixing at the piers and pylons.

However, the changes in hydrological parameters, caused by a bridge, are in general limited compared to the temporal variability in the 0-scenario (Baseline situation).

The local model of the bottom oxygen effect showed a minor increase in the concentration as a result of the increased mixing due to the structures. Isolated this is a positive effect on the conditions in Fehmarnbelt.

The minor salinity and temperature changes will affect the water density and the vertical stratification. However, the impact of the density and stratification in the Baltic Sea was less than 0.01 kg/m^3 and 0.02 kg/m^3 (Figure 7.1). The stratification in the Baltic Sea is in general 4 kg/m^3.

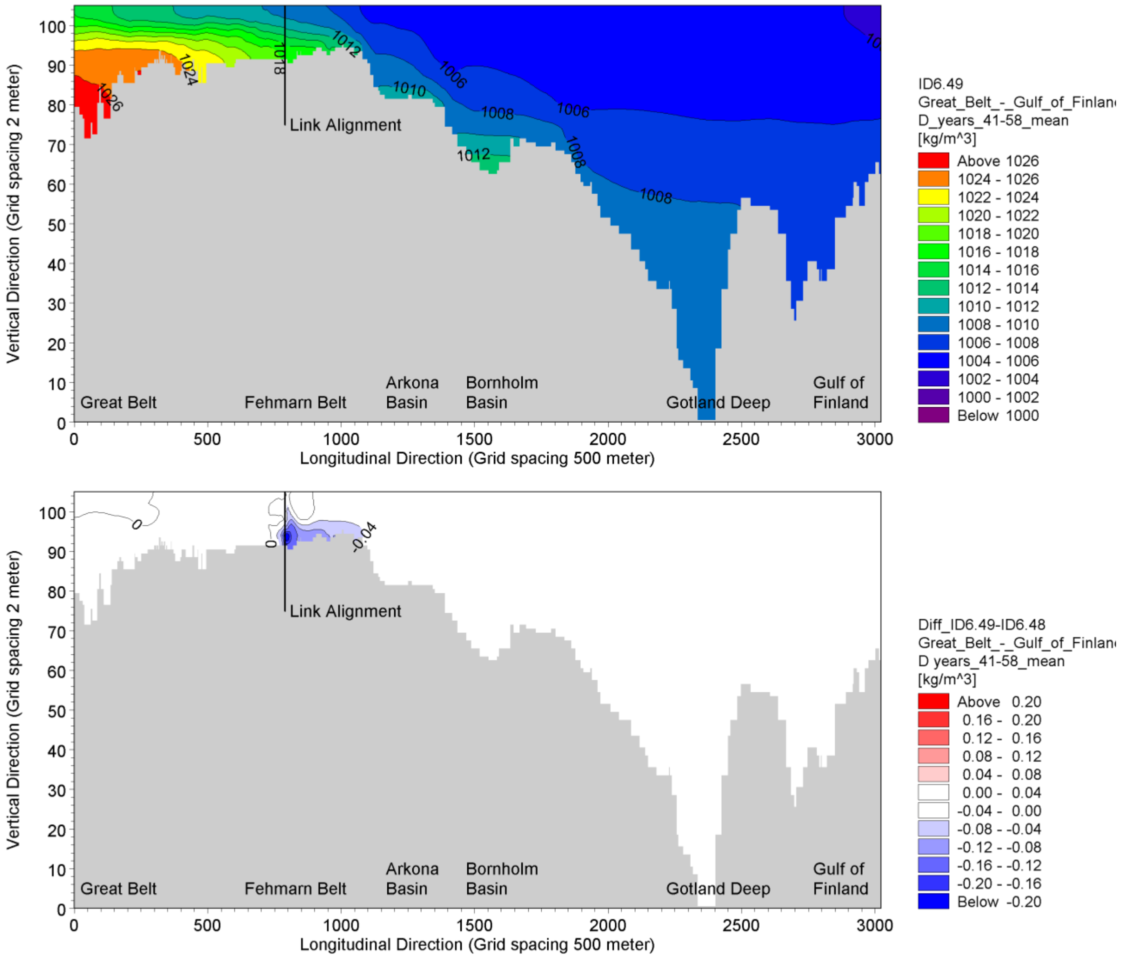


Figure 7.1: Long-term mean density along longitudinal transect from Great Belt to Gulf of Finland: "Bridge + Ferry" scenario result and difference from the reference case. Data from FEHY – MIKE regional model. Source: FEHY (2011c).

Cod

Köster, et al., 2011 simulated changes in the reproductive volume for the period 1990-2001. This period included both stagnation years (early and late 1990's), inflow (1993), post-inflow (1994) and severe winter situations (1996). A hydrodynamic model (MIKE setup) was conducted by FEHY and two scenarios were simulated: with and without a Fehmarnbelt bridge. Similar scenario simulations were performed with a hydrodynamic model of the Institute for Baltic Sea Research in Warnemünde. In general, simulations from this model indicated smaller impact by a bridge compared to the MIKE setup. Thus, results from the hydrodynamic simulations from FEHY are considered to represent worst case scenarios for bridge impact and these results are presented in the following.

Bornholm Basin

The spawning of cod in the Baltic is delayed towards the east and ends in July-August in the eastern Baltic. The reproductive volume in the Bornholm Basin was simulated in the period 1990-2001 on monthly basis. The scenario without bridge indicated that during spring the reproductive volume fluctuated between 5-17% of the total water volume and 2-11% in summer (Table 7.1). The reproductive volumes were always lower during the bridge scenario. In general the bridge scenario was 2.5% lower during spring except in 2001 where the difference was 4.5%. Differences in summer were slightly higher but mostly below 3% except 1991 where it reached 3.8% and 2001 reaching 5%.

No differences in reproductive volume was found when comparing stagnation years (1990) and inflow years. The maximum fraction was 15% in March/April with a reducing reproductive volume throughout the year. Comparing the two scenarios with and without bridge showed almost similar differences in reproductive volume in both years (Table 7.1). In December/January the reproductive volume was approximately 2.5-3% smaller in the bridge scenario while it was reduced with 0.5-1.5% during the rest of the year. During the spawning season the differences between the two scenarios were less than 1%. However, the largest difference in the reproductive volume was 10% simulated during the spawning period August 2001.

Table 7.1: The reproductive volume in percentage of the water mass in the scenario without a bridge and the percentage difference between in the bridge scenario. In general the RV is reduced in the bridge scenarios. BB = Bornholm Basin, AK = Arkona Basin, WB = western Baltic, EB = eastern Baltic

	Without bridge	With bridge (% reduction in RV)
BB in spring	5-17%	-2.5%
BB in summer	2-11%	< -3%
BB stagnation (1990)	<16%	-0.5-1.5% -2.5-3% Dec/Jan
BB inflow (1993)	<15%	-0.5-1.5% -2.5-3% Dec/Jan
AK February (WB cod)	0-40%	≤ 3% 5% 1999 and 2001
AK March (WB cod)	0-16%	≤ -3%
AK June (EB cod)	0-20%	-1-5%
AK July (EB cod)	0-25%	-0.5-5%

The horisontal distribution of the reproductive volume follows the depth contour of the Bornholm Basin. The maximum water masses suitable for egg survival are found in the center of the basin (Figure 7.2).

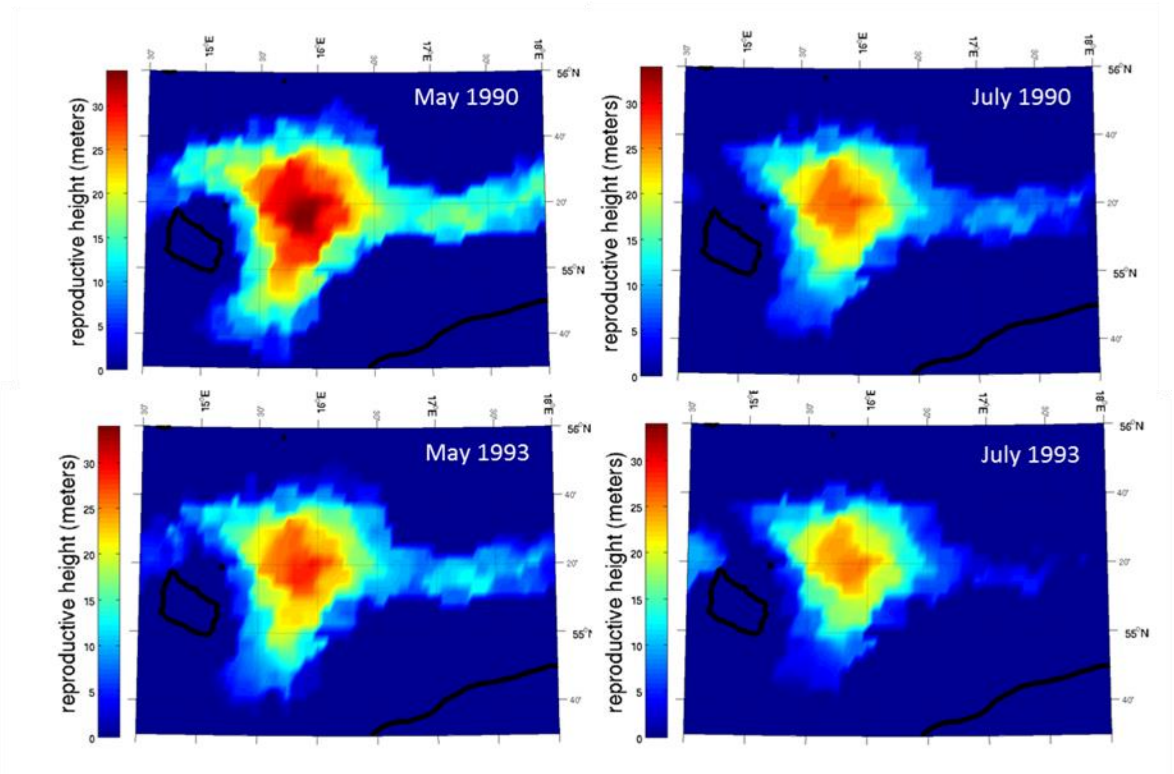


Figure 7.2: Heigh of water volume (m) suitable for egg survival of the eastern Baltic cod stock as a measure of the reproductive volume for the scenario without bridge in the Bornholm Basin in May and July 1990 and 1993. Source: Köster, et al. (2011).

Arkona Basin

The hydrographic conditions in the Arkona Basin impact the survival of cod eggs from both the eastern and western Baltic cod stock as they spawn in this area. The egg survival and recruitment of both stocks might thus be impacted by a bridge in Fehmarnbelt. The magnitude of pressure will mainly depend on the amount of salt and oxygen introduced into the bottom waters of the Arkona Basin and the Bornholm Basin. The temperature effects are less clear and most likely minor.

Spawning in the Arkona Basin has been observed in February-March (western Baltic cod) and from June onwards (eastern Baltic cod). Thus, especially data on reproductive volume from February-March and June-July from the hydrodynamic model have been analysed.

The reproductive volume for western Baltic cod in the Arkona Basin is highly variable fluctuating between 0-40% in February and 0-16% in March. Low temperatures of inflowing water masses (cooled surface water from the western Baltic) filling the part of the Arkona Basin in March can explain the on average smaller reproductive volume in March. The reproductive volume is mostly but not always lower in the bridge scenario. The differences between the two scenarios with and without bridge are 3% or below except for February 1999 and 2001 with maximum deviations of 5% (Table 7.1).

The reproductive volume of the eastern Baltic cod in the Arkona Basin varies between 0-20% in June and 0-25% in July. The bridge scenario is characterized by lower reproductive volume and the differences to the scenario without bridge fluctuated between 0.5-5 %.

Figure 7.3 illustrates the horizontal distribution of the reproductive volume in subdivision 24 in 1990. It confirms the overall good hydrographic conditions for the reproduction in the western Baltic. However, observations could not confirm the high reproductive volume in the Arkona

Basin in February based on model observations. During June and July unfavourable conditions for eastern Baltic cod was seen in the model which corresponds well with observations.

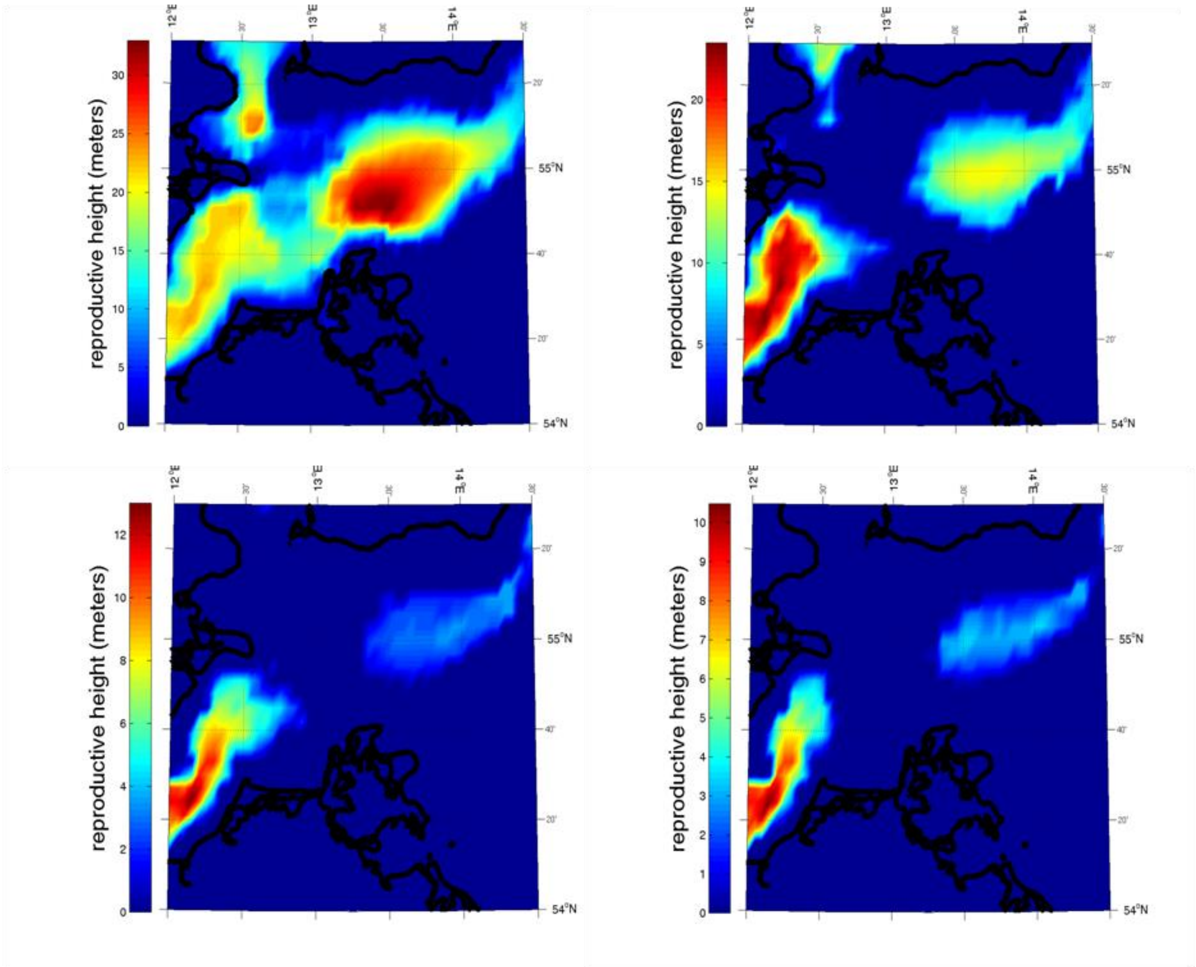


Figure 7.3: Hight of water volume suitable for egg survival of the western and eastern Baltic cod as a measure of the reproductive volume for the scenario without bridge in subdivision 24 in 1990. Top row shows western Baltic cod reproductive volume in February (left) and March (right). Bottom row shows eastern Baltic cod reprodutive volume in June (left) and July (right). Source: Köster, et al. (2011).

However, favourable spawning condtions was seen in the Arkona Basin in 1993 for the western Baltic cod in February and the eastern Baltic cod in July (Figure 7.4). There is limited indication of inflow in June.

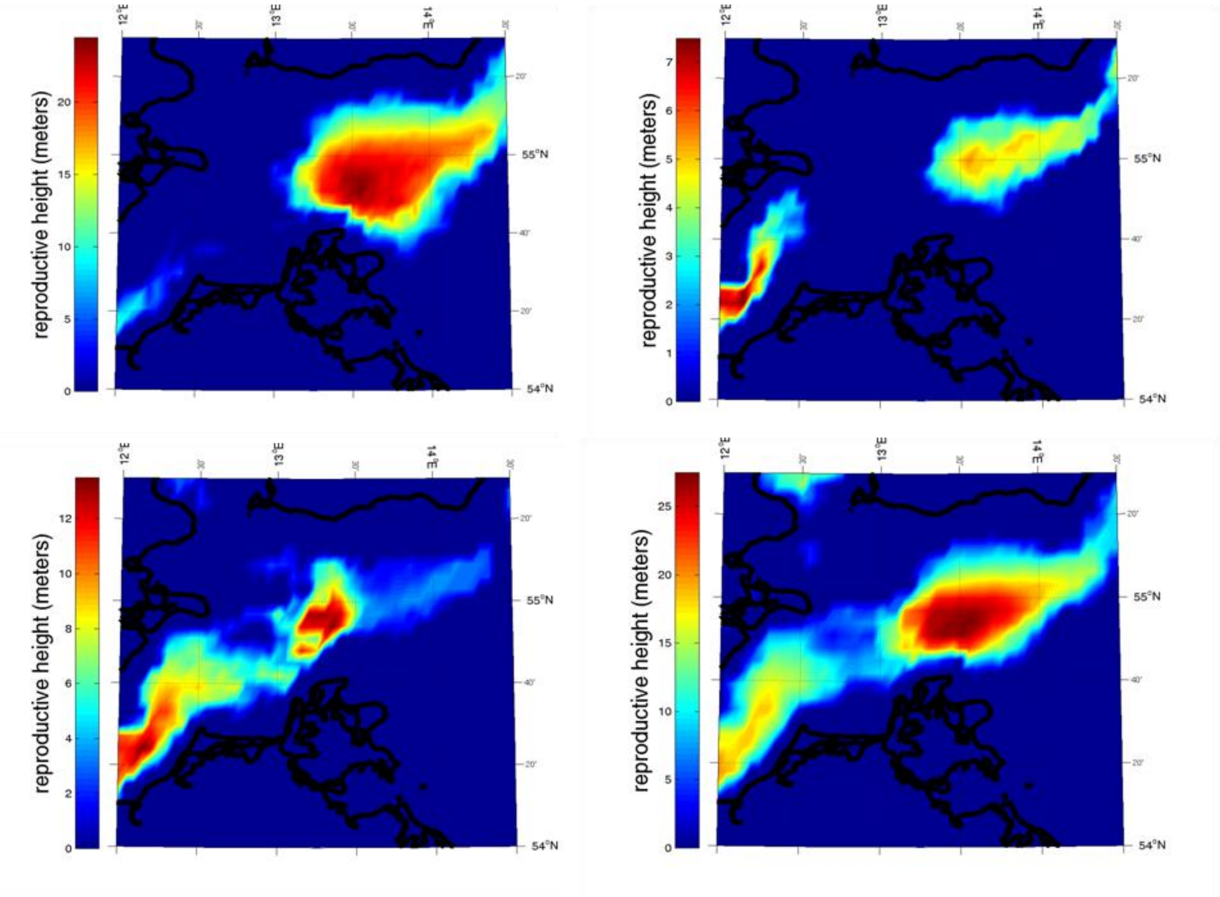


Figure 7.4: Hight of water volume suitable for egg survival of the western and eastern Baltic cod as a measure of the reproductive volume for the scenario without bridge in subdivision 24 in 1993. Top row shows western Baltic cod reproductive volume in February (left) and March (right). Bottom row shows eastern Baltic cod reprodutive volume in June (left) and July (right). Source: Köster, et al. (2011).

Studies have shown that, despite the lack of major inflow into the central Baltic since 2003, a low spawning stock biomass have produced relatively high recruitment since 2005. Thus, it is suggested that other processes than hydrographic conditions favouring egg survival contributes to the increase in reproductive success.

Studies have indicated severe starvation and food limitation in larval Baltic cod especially in the early larval stages found in the deep parts of the Bornholm Basin (Köster, et al., 2011). Thus it is concluded that both the temporal and spatial differences in prey and the associated mortality of larvae due to starvation is highly responsible for the great variation in recruitment of eastern Baltic cod.

It is assumed that the limited changes in salinity caused by a bridge will have an insignificant large-scale impact on the eastern Baltic cod recruitment through reduced abundance of larval prey. Knowledge on the link between larval survival and prey availability in the western Baltic is lacking but it is expected that the salinity is less important for the copepod production in this area. Furthermore, the effect of climate change on zooplankton community is expected to be order of magnitude higher than the effects of a bridge in Fehmarnbelt.

The hydrography only has a minor impact on cod recruitment west of Fehmarnbelt and Mecklenburg Bight (Vitale, et al., 2008; Hüssy, 2011). Thus, a bridge in Fehmarnbelt will mainly affect cod spawning east of the fixed link especially the Arkona Basin and the deep basins of the central Baltic Sea and not have any impact on the spawning areas west of Fehmarnbelt and Mecklenburg Bight.

Egg and larvae drift
The basis of the recruitment potential for a fish stock is production of viable eggs. The natural cod egg mortality is extremely high and in general > 95%. This high mortality is observed in the laboratory and estimated on basis of abundance of egg development stages (von Westernhagen, 1970; Bleil, 1995; von Westernhagen, et al., 1988; Köster, et al., 2005).

The threshold of salinity for successful survival of eastern Baltic cod eggs is lower compared western Baltic cod stock. It is suggested, that eastern Baltic cod may spawn successful and eggs may hatch in the western Baltic Sea but western Baltic cod is not able to reproduce successful in the eastern Baltic Sea. Salinity limits the eastward distribution of cod eggs due to the salinity requirements as they will sink to the bottom and die. Thus, stock mixing is possible in the areas in the western Baltic Sea where the salinity is sufficient for both stocks.

During this assessment it is assumed that pelagic eggs will die if they are in contact with the bottom substrate.

The hydrodynamic conditions in the Baltic Sea are highly variable especially, in the narrow belts where all water is passing in and out of the Baltic Sea. Due to the limited water depths the western Baltic Sea and the Arkona Basin are also very dynamic. Cod eggs drift in the water column and is thus affected by the currents and the prevailing wind and current conditions determines the destination of nursery area. Hydrodynamic models are an essential tool to evaluate these dynamics.

Hinrichsen et al. (2001) is the only study of the general drift patterns in the western Baltic. The main aim of this hydrodynamic modelling was to study the potential impact of different wind-driven circulation patterns on the transport of cod early life stages between the western and eastern Baltic Sea. Eggs spawned in four different spawning areas (I. Great Belt, II. Little Belt, Kiel Bay, Langeland Belt and Fehmarnbelt, III. Mecklenburg Bay, IV. Øresund) were studied. The drift of early life stages of cod are almost exclusively towards east regardless spawning area. However, there were large variability in egg and larvae transport both within and between years. These differences were primarily due to great variation in wind forcing. The drift of early life stages from the western Baltic cod stock into the Arkona Basin and the Bornholm Basin are mainly caused by strong westerly winds. Only during periods of strong westerly winds early life stages of cod are transported from Øresund and the Great Belt, but significant easterwards drift from Kiel Bay and Mecklenburg was also found during periods with minor westerly wind (Hinrichsen, et al., 2001).

However, (Köster, et al., 2011) studied the importance of transport through Fehmarnbelt for cod egg and yolk-sac larval survival. The drift of cod eggs and yolk-sac larvae from five different spawning areas in the western Baltic Sea during the period 1979-2005 was modelled (Figure 7.5). Sub-area Kiel Bight includes the western part of Fehmarnbelt whereas sub-area Mecklenburg Bight includes the eastern part of Fehmarnbelt. The mean end positions of the drifters were calculated for four categories: 1) drifters that died due to bottom contact as eggs, 2) drifters that died due to bottom contact as yolk-sac larvae, 3) drifters that died due to lethal temperatures (both eggs and yolk-sac larvae combined) and 4) drifters that survived to the end of the yolk-sac phase.

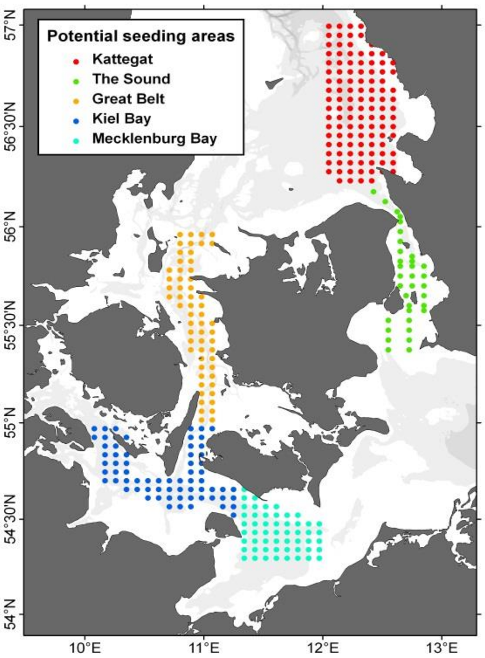


Figure 7.5: Spawning areas of cod as used in drift modelling of egg and larvae in the western Baltic. Eggs were seeded on each grid point if salinity was above 18 PSU. Source: Köster, et al. (2011).

The drift model shows that surviving yolk-sac larvae from eggs spawned in the deeper water layers of Kiel Bight either stay in the spawning area or are transported northwards (Figure 7.6). A large proportion of the larvae die due to bottom contact which indicated that the transport through Fehmarnbelt does not enhance the survival probability. Contrary, the egg mortality and temperature related mortality is highest west of Fehmarnbelt (Köster, et al., 2011).

No drift of eggs and yolk-sac larvae towards the Arkona Basin and Bornholm Basin was found. These results indicate that no recruitment of eggs spawned in Fehmarnbelt to the eastern Baltic cod occured. However, the results are based on mean values from a 26 years period and thus the resolution is low. This indicate that recruitment from west to east only occur during major inflow events transporting eggs and larvae through Darss Sill or that the transport towards east occur after the yolk-sac larval stage. Mean values of drift are presented on Figure 7.6 and it is thus not possible to see if there is a transport of eggs and larvae during major inflow events.

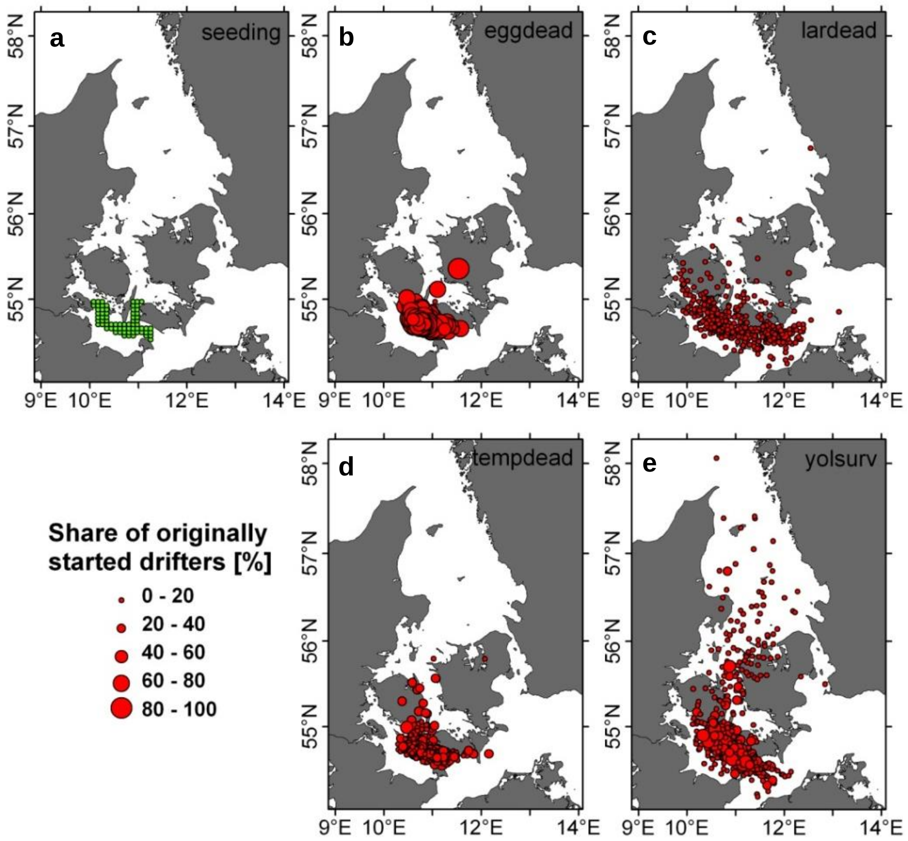


Figure 7.6: Seed positions in deeper water layers of Kiel Bight (a), shares of cod eggs (b) and larvae (c) dying due to bottom contact, eggs and larvae dying due to low temperature (d) and surviving to the end of the yolk-sac stage (e) with their respective average positions; due to the averaging procedure of the end position of all drifters released from one position, positions are partly located on land. Source: Köster, et al. (2011).

Furthermore, eggs spawned in the eastern part of Fehmarnbelt also had a tendency to either stay within the spawning area or transported towards northwest (Figure 7.7).

The results from this drift model contradict previous findings of Hinrichsen et al. (2001) suggesting that strong westerly winds allow transport of eggs and early larval stage towards east into the Bornholm Basin. However, this model was lacking data on vertical distribution of eggs. Furthermore it did not consider that the early life stages inhabit and maintain certain density levels which can change during the ontogenetic development. However, the hydrodynamic model by Köster et al. (2011) took this into account and thus it was found that almost no cod eggs and early larvae survived transport towards east.

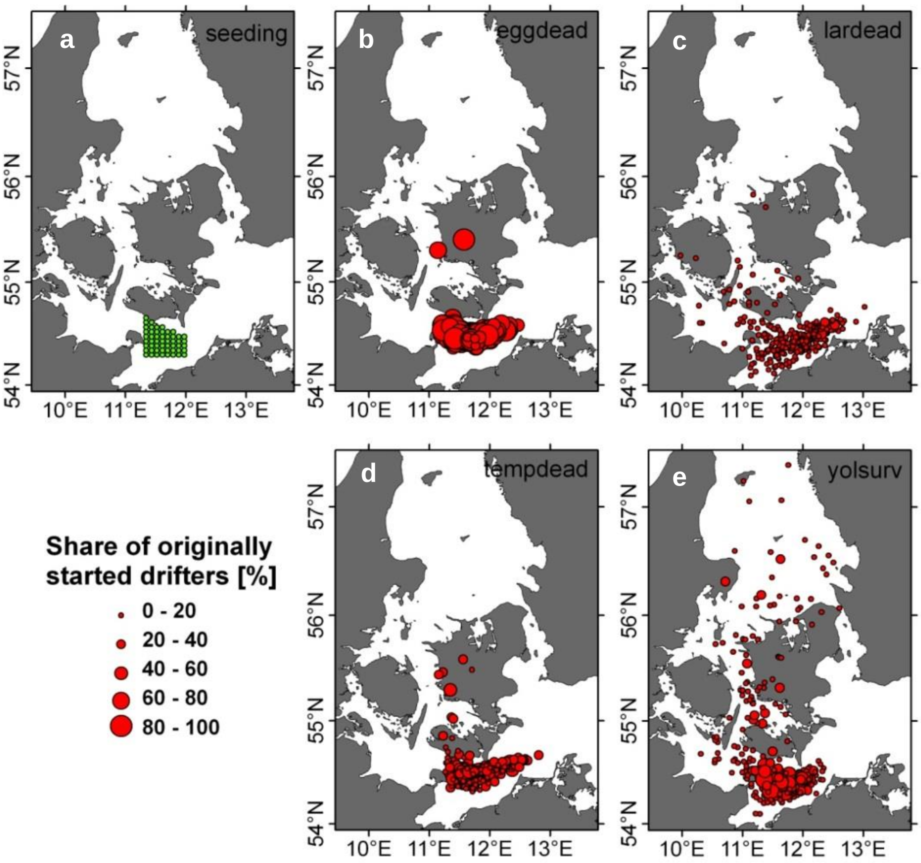


Figure 7.7: Seed positions in deeper water layers of the Mecklenburg Bight (a), shares of cod eggs (b) and larvae (c) dying due to bottom contact, eggs and larvae dying due to low temperature (d) and surviving to the end of the yolk-sac stage (e) with their respective average positions; due to the averaging procedure of the end position of all drifters released from one position, positions are partly located on land. Source: Köster, et al. (2011).

When comparing all five sub-areas (Figure 7.5) there is a clear trend of decrease in survival of eggs and yolk-sac larvae from north to south and from west to east. Transport through Fehmarnbelt from spawning areas west of the Belt will reduce survival probabilities. Thus, a bridge will not decrease the survival for the western Baltic cod if the bridge causes a reduction of transport through Fehmarnbelt. Conversely, the survival of eggs spawned in Mecklenburg Bight might decrease if the transport towards west is reduced. However, a reduced transport of eggs spawned in Mecklenburg Bight transported towards the Arkona Basin and Bornholm Basin might counteract this decrease in survival probability. This indicates, that a decreased west-east transport not even have a negative impact on the eastern side of the bridge.

7.1.2 **Degree of impairment**

Changes in the hydrology may impact the fish communites and the impairments of the important fish species will be assessed separately.

Results from FEHY indicate only small changes in temperature, salinity and oxygen. No significant changes are expected on fish communities.

The assessment considers the magnitude of pressure relative to the background hydrological conditions.

The impact of hydrological changes on fish communities is difficult to assess due to the large natural fluctuations both between years and within a year. However, the changes in the hydrodynamics are small and limited. Thus, the impact on fish communities is assessed to be limited as well. The degree of impairment to spawning, eggs and larvae are only minor.

The degree of the impairment caused by hydrological changes due to a bridge in each area of investigation on each indicator selected for the present assessment is presented in Table 7.2.

Table 7.2: The degree of impairment caused by hydrological changes of the bridge solution Fehmarnbelt.

Degree of impairment of Hydrological regime, Bridge scenario	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**	**Rødsand Lagoon**
Cod							
Spawning (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Herring							
Spawning (mod)	Insignif.		Insignif.		Insignif.	Insignif.	Insignif.
Sprat							
Spawning (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Flatfish							
Spawning (>15 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-

7.1.3 Severity and significance

Tables of severity/loss of hydrological regime in relation to construction and operation of a bridge are not included as it is only the structure that has an impact on the hydrological regime.

Table 7.3: The severity of impairment caused by hydrological changes of the bridge solution Fehmarnbelt.

Severity of impairment/loss of Hydrological regime, bridge, structure	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**	**Rødsand Lagoon**
Cod							
Spawning (>15 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Herring							
Spawning (mod)	Insignif.		Insignif.		Insignif.	Insignif.	Insignif.
Sprat							
Spawning (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Flatfish							
Spawning (>15 m)	Minor	Minor	Minor	Minor	Minor	Minor	-
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	-

7.2 Seabed reclamation

The permanent and temporary establishment of constructions in marine environments ("seabed reclamation") is always associated with a permanent or temporary loss of natural habitat. Therefore, also the construction of the cable-stayed bridge in the Fehmarnbelt region will be associated with a permanent or temporary loss of natural habitat. A temporary loss of marine habitat is expected to occur in regard to the expansion and construction of the project associated infrastructure. In Rødbyhavn and Puttgarden, construction harbours will be built. After completion of the bridge the construction based infrastructure will be scaled back. In contrast to the tunnel alternative, a permanent loss of marine habitat will occur within the whole alignment corridor by building bridge pillars. The sea bottom in the alignment corridor is dominated by unstructured, sandy habitats. By inserting artificial substrate to the sea for the bridge pillars, a kind of artificial reefs will be created. These artificial reefs generate an attraction effect on different fish species (e.g. cod, whiting, plaice, and flounder) (Keller, et al., 2006; Schulz, et al., 2007). Fish communities in the area of artificial reefs are similar to those at natural reefs (Keller, et al., 2006). Therefore, the bridge alternative affects and changes the fish communities in the area of Fehmarnbelt permanently.

In relation to migration behaviour of fishes (e.g. cod, herring, eel or salmon) it is assumed that the physical structures by the cable-stayed bridge do not create avoidance reactions like suspended sediment, noise or light. Physical structures like pylons or piers do not impair fish by themselves and fish are not negatively sensitive to any physical structures. This relationship is confirmed by the results from the accompanying operational monitoring of the "Øresund Bridge". The results did not show any negative impacts on the migratory behavior of the spring spawning herring (Appelberg, et al., 2005). According to the authors the fluctuations of the spring spawning stock of herring were based on natural variations (by hydrology and climate-weather conditions) and an impact of the bridge could not be detected. Actually, physical structures tend to attract fish. Barrier effects in relation to physical structures only exist if they in any way impair fish migration. This is true in situations where the physical structure gives rise to entrapment in dead ends or openings are so narrow that the passage is hampered by crowding or by high water currents or turbulence.

A physical structure, like the cable-stayed bridge, comprising bridge pylons and piers does not give rise to neither dead ends nor any specific narrowing. In fact, as already described, the impairment from a cable-stayed bridge on the flow regime is as low as 0.05 %.

Since fish are not sensitive to physical structures and the physical structures are not creating any pressures in relation to migration (no blockage) the degree of impairment is minor.

7.2.1 Magnitude of pressure

The magnitude of pressure in terms of seabed reclamation is defined by the spatial size of footprint or by the direct loss of area due to the physical structures. Permanent changes will occur by building the bridge foundations. Also the ramp areas at the coasts of Fehmarn and Lolland will cause a permanent change of the original seabed (Figure 7.8). Temporary changes will be caused by the temporary work harbours. These harbours will be scaled back after finishing the construction. In total, an area of 79.5 ha will be directly lost by the construction of the cable-stayed bridge within the Fehmarnbelt region. This includes the loss of marine habitats by the installation of "permanent" as well as "temporary long-term" bridge construction components (Table 7.4).

Table 7.4: Footprint area for the different bridge structures and footprint categories.

Footprint category	Bridge structures	Area loss (ha)	
1 ("permanent"; ≥8 years)	Reclamation peninsulas bridge pylons and piers	Danish waters	23.6
		German waters	32.3
		German EEZ	8.6
		German national	23.7
		Overall	55.9
2 ("temporary long-term", 3 – 8 years)	Working harbours	Danish waters	14.7
		German waters	8.9
		German EEZ	-
		German national	8.9
		Overall	23.6
3 ("temporary short-term", ≤3 years))	None	Danish waters	0.0
		German waters	0.0
		German EEZ	0.0
		German national	0.0
		Overall	0.0
		Total	79.5

As shown in Table 7.4, the permanent physical bridge structures will cause the largest loss of marine habitats within the Fehmarnbelt region. A total area of 55.9 ha will be lost by the construction of the permanent physical bridge structures: the bridge pylons along the projected fixed link route, the reclamation areas and bridge piers on the Fehmarn and Lolland coast. This corresponds to 70.3 % of the total footprint area.

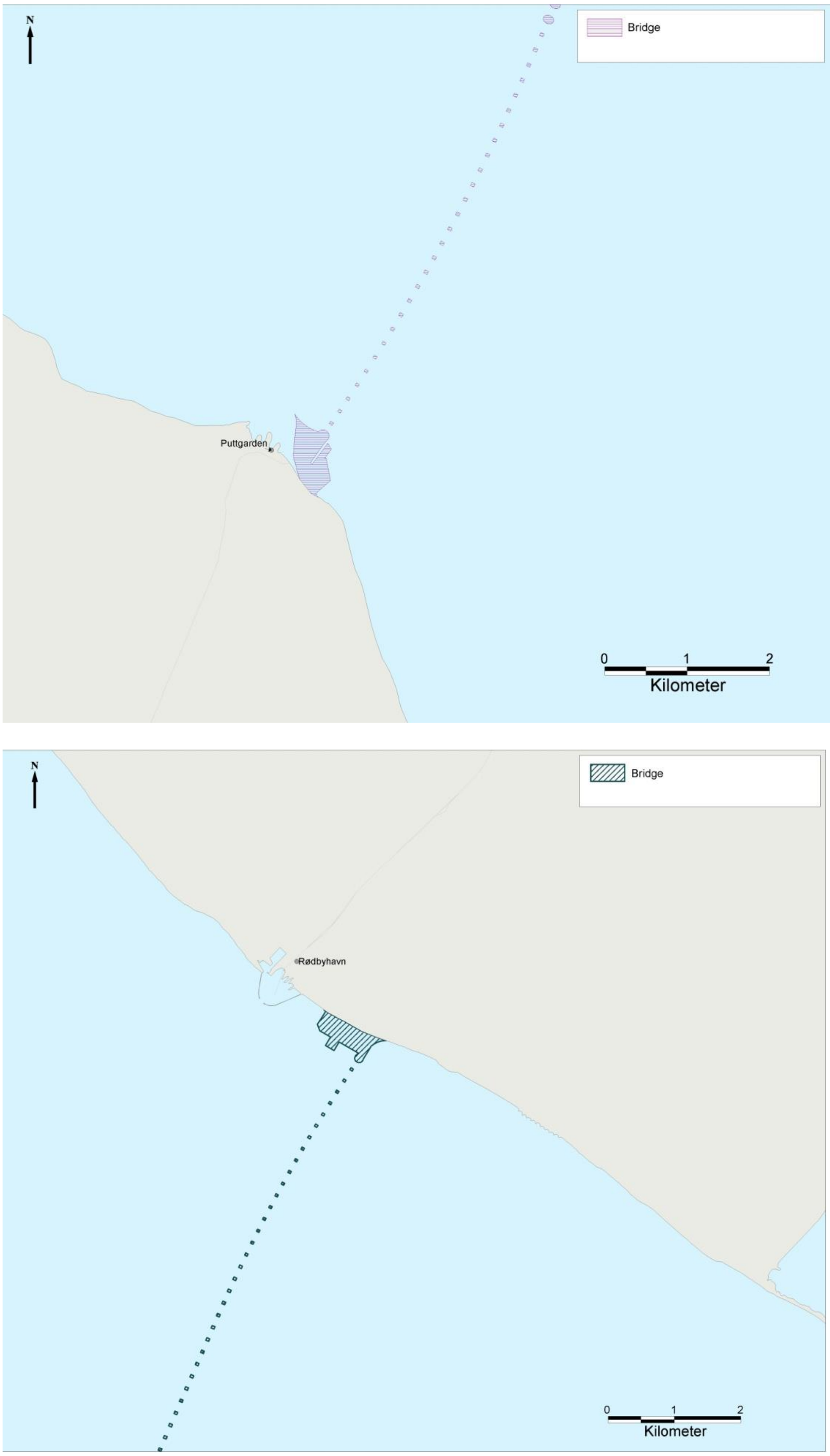


Figure 7.8: Overview of the various footprints of the bridge approach in the coastal waters of Fehmarn (above) and Lolland (below).

According to the general assessment methodology, severity of loss and severity of impairment is used to describe the impact of permanent and temporary seabed reclamation on the respective environmental components and associated indicators. Both severities were determined by the ecology of the respective species and the resulting consequences of seabed reclamation on their population dynamic. For species which depends directly on the availability of “seabed” habitats, the “severity of loss” was used to assess if the permanent physical structures leads to a habitat loss. For all other species, the severity of impairment was used.

For the impact assessment of temporary construction components, only the severity of impairment was used assuming that temporary habitat losses lead to temporary impairment only.

The degree of impairment for the respective construction components (category 1-3) was derived from estimated habitat loss (% of the total important area within in the near zone).

7.2.2 **Degree of impairment**

Footprint assessment for the physical bridge structures (category 1-2) was done by comparing the bridge footprints and the importance maps compiled for the respective components (species) and associated five indicators (spawning, egg-larvae drift, nursery, feeding and migration). The results of the analyses of the reduction of environmental components and the degree of impairment are presented separately for the two physical bridge structures (category 1-2).

Habitat loss caused by seabed reclamation is only expected in the near zone (DE 500 m zone, DE 500 m EEZ zone and DK 500 m zone) as all structures are found within the near zone.

Permanent physical bridge structures:
The permanent physical bridge structures (category 1) will cause a permanent habitat loss for all components and associated indicators (Table 7.5). The level of habitat loss is expected relatively high for all shallow water species (including sea stickleback) as well as for species which use shallow waters as nursery area (e.g. cod). In contrast, for all other species the level of habitat loss is relatively low.

As described in chapter 5.2.2 (sensitivity to pressure) a low degree of impairment (0.05 %) is expected in relation to the migratory species cod, herring, eel and salmon (protected species).

Table 7.5: Estimated area loss for the respective component and associated indicator resulting from the installation of permanent bridge construction components in the Fehmarnbelt region (in % (ha) of the total importance area within the near zone).

Reduction of environmental components by seabed reclamation permanent, bridge	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.7)	0.5 (2.5)	0.2 (1.1)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.7)	0.5 (2.5)	0.2 (1.1)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.3 (19.9)	0.0 (0.0)	6.1 (17.6)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.7 (8.7)	0.5 (2.5)	0.2 (1.5)
Migration (> 5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.05 (0.0)	0.05 (0.0)	0.05 (0.0)
Whiting						
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.6 (20.2)	0.5 (2.5)	1.8 (17.4)
Migration (>5m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.05 (0.0)	0.05 (0.0)	0.05 (0.0)
Herring						
Spawning (mod)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.0 (19.9)	0.0 (0.0)	0.0 (0.0)
Egg drift (>2 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.8 (8.6)	3.4 (18.3)	1.7 (16.0)
Larvae drift (>2 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (15.5)	0.5 (2.5)	1.0 (9.9)
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.6 (20.2)	0.5 (2.5)	1.8 (17.4)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.7 (8.7)	0.5 (2.5)	0.2 (1.5)
Migration (>5m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.05 (0.0)	0.05 (0.0)	0.05 (0.0)
Sprat						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.7)	0.5 (2.5)	0.2 (1.1)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.7)	0.5 (2.5)	0.2 (1.1)
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.6 (20.2)	0.5 (2.5)	1.8 (17.4)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.7 (8.7)	0.5 (2.5)	0.2 (1.5)
Migration (>5m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.05 (0.0)	0.05 (0.0)	0.05 (0.0)
Flatfish						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.8 (3.5)	1.8 (8.6)	0.8 (6.0)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.7)	0.5 (2.5)	0.2 (1.1)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.3 (19.9)	0.0 (0.0)	6.1 (17.6)
Feeding (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	4.2 (23.5)	1.8 (8.6)	2.4 (23.6)
Migration (>5m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.05 (0.0)	0.05 (0.0)	0.05 (0.0)
Shallow water species						
Spawning (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.3 (19.9)	0.0 (0.0)	6.1 (17.6)
Egg-larvae drift (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.3 (19.9)	0.0 (0.0)	6.1 (17.6)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.3 (19.9)	0.0 (0.0)	6.1 (17.6)
Feeding (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.3 (19.9)	0.0 (0.0)	6.1 (17.6)
Eel						
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.3 (19.9)	0.0 (0.0)	6.1 (17.6)
Feeding (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.3 (19.9)	0.0 (0.0)	6.1 (17.6)
Migration (>2m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.05 (0.0)	0.05 (0.0)	0.05 (0.0)
Sea stickleback						
Spawning	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.4 (15.2)
Egg-larvae drift	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.4 (15.2)
Nursery	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.4 (15.2)
Feeding	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.4 (15.2)
Snake blenny						
Spawning (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (2.2)	1.8 (8.6)	0.9 (1.9)
Egg-larvae drift (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (2.2)	1.8 (8.6)	0.9 (1.9)
Nursery (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (2.2)	1.8 (8.6)	0.9 (1.9)
Feeding (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (2.2)	1.8 (8.6)	0.9 (1.9)
Protected species						
Migration (>5m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.05 (0.0)	0.05 (0.0)	0.05 (0.0)

Temporary long-term physical bridge structures:
The temporary long-term physical bridge structures (category 2) will cause a temporary habitat loss for all components and associated indicators, except snake blenny (Table 7.6). The level of habitat loss is relatively high for all shallow water species (including sea stickleback) as well as for species which use shallow waters as nursery ground. For all other species, contrastingly, the level of habitat loss is relatively low.

Table 7.6: Estimated area loss for the respective component and associated indicator resulting from the installation of temporary long-term bridge construction components in the Fehmarnbelt region (in % (ha) of the total importance area within the near zone

Reduction of environmental components by seabed reclamation temporary long-term. bridge	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.3 (8.9)	0.0 (0.0)	5.1 (14.7)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.1 (6.1)	0.0 (0.0)	0.0 (0.0)
Migration (> 5 m)	-	-	-	-	-	-
Whiting						
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.6 (8.9)	0.0 (0.0)	1.5 (14.7)
Migration (>5m)	-	-	-	-	-	-
Herring						
Spawning (mod)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.2 (8.9)	0.0 (0.0)	0.0 (0.0)
Egg-larvae drift (>2 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.6 (8.8)	0.0 (0.0)	1.4 (13.8)
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.6 (8.9)	0.0 (0.0)	1.5 (14.7)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.1 (6.1)	0.0 (0.0)	0.0 (0.0)
Migration (>5m)	-	-	-	-	-	-
Sprat						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Nursery (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.6 (8.9)	0.0 (0.0)	1.5 (14.7)
Feeding (>5 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.1 (6.1)	0.0 (0.0)	0.0 (0.0)
Migration (>5m)	-	-	-	-	-	-
Flatfish						
Spawning (> 10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Egg-larvae drift (>10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.3 (8.9)	0.0 (0.0)	5.1 (14.7)
Feeding (>0 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.6 (8.9)	0.0 (0.0)	1.5 (14.7)
Migration (>5m)	-	-	-	-	-	-
Shallow water species						
Spawning (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.3 (8.9)	0.0 (0.0)	5.1 (14.7)
Egg-larvae drift (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.3 (8.9)	0.0 (0.0)	5.1 (14.7)
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.3 (8.9)	0.0 (0.0)	5.1 (14.7)
Feeding (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.3 (8.9)	0.0 (0.0)	5.1 (14.7)
Eel						
Nursery (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.3 (8.9)	0.0 (0.0)	5.1 (14.7)
Feeding (<10 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.3 (8.9)	0.0 (0.0)	5.1 (14.7)
Migration (>2m)	-	-	-	-	-	-
Sea stickleback						
Spawning	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.1 (14.7)
Egg-larvae drift	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.1 (14.7)
Nursery	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.1 (14.7)
Feeding	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.1 (14.7)
Snake blenny						
Spawning (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Egg-larvae drift (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Nursery (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Feeding (>20 m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Protected species						
Migration (>5m)	-	-	-	-	-	-

According to general assessment methodology, the degree of impairment is determined for all bridge construction components. This included the permanent as well as the temporary long-term bridge construction components. The “severity of loss” is only determined for species which depend on the availability of “seabed” habitats.

Permanent physical structures:

The permanent physical structures will only have minor impact on the sub-components and associated indicators (except for sea stickleback) (Table 7.7). For the sea stickleback the permanent physical structures will have a medium impact.

Table 7.7: The degree of impairment (permanent) for each environmental component based on the pressure indicators and the loss of seabed (%) for the near (500 m on both sides of the middle of the alignment corridor) and the local zone (10 km on both sides of the middle of the alignment corridor).

Degree of impairment by seabed reclamation permanent, bridge	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Spawning (> 10 m)	-	-	-	Minor	Minor	Minor
Egg-larvae drift (>10 m)	-	-	-	Minor	Minor	Minor
Feeding (>5 m)	-	-	-	Minor	Minor	Minor
Migration (> 5 m)	-	-	-	Minor	Minor	Minor
Whiting						
Nursery (>0 m)	-	-	-	Minor	Minor	Minor
Migration (>5m)	-	-	-	Minor	Minor	Minor
Herring						
Larvae drift (>2 m)	-	-	-	Minor	Minor	Minor
Nursery (>0 m)	-	-	-	Minor	Minor	Minor
Feeding (>5 m)	-	-	-	Minor	Minor	Minor
Migration (>5m)	-	-	-	Minor	Minor	Minor
Sprat						
Spawning (> 10 m)	-	-	-	Minor	Minor	Minor
Egg-larvae drift (>10 m)	-	-	-	Minor	Minor	Minor
Nursery (>0 m)	-	-	-	Minor	Minor	Minor
Feeding (>5 m)	-	-	-	Minor	Minor	Minor
Migration (>5m)	-	-	-	Minor	Minor	Minor
Flatfish						
Egg-larvae drift (>10 m)	-	-	-	Minor	Minor	Minor
Migration (>5m)	-	-	-	Minor	Minor	Minor
Eel						
Migration (>2m)	-	-	-	Minor	Minor	Minor
Sea stickleback						
Spawning	-	-	-	-	-	Medium
Egg-larvae drift	-	-	-	-	-	Medium
Nursery	-	-	-	-	-	Medium
Feeding	-	-	-	-	-	Medium
Snake blenny						
Spawning (>20 m)	-	-	-	Minor	Minor	Minor
Egg-larvae drift (>20 m)	-	-	-	Minor	Minor	Minor
Nursery (>20 m)	-	-	-	Minor	Minor	Minor
Feeding (>20 m)	-	-	-	Minor	Minor	Minor
Protected species						
Migration (>5m)	-	-	-	Minor	Minor	Minor

Temporary long-term construction components:

The construction of working harbours and access channel on the Lolland and Fehmarn coast and associated temporary habitat loss will have only a minor impact on most species (Table 7.8), a medium impact was assessed only for the sea stickleback.

Table 7.8: The degree of impairment (temporary long-term) for each environmental component based on the pressure indicators and the loss of seabed (%) for the near (500 m on both sides of the middle of the alignment corridor) and the local zone (10 km on both sides of the middle of the alignment corridor).

Degree of impairment by seabed reclamation temporary long-term, bridge	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Spawning (> 10 m)	-	-	-	-	-	-
Egg-larvae drift (>10 m)	-	-	-	-	-	-
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (>5 m)	-	-	-	Minor	-	-
Migration (> 5 m)	-	-	-	-	-	-
Whiting						
Nursery (>0 m)	-	-	-	Minor	-	Minor
Migration (>5m)	-	-	-	-	-	-
Herring						
Spawning (mod)	-	-	-	Minor	-	-
Egg-larvae drift (>2 m)	-	-	-	Minor	-	Minor
Nursery (>0 m)	-	-	-	Minor	-	Minor
Feeding (>5 m)	-	-	-	Minor	-	-
Migration (>5m)	-	-	-	-	-	-
Sprat						
Spawning (> 10 m)	-	-	-	-	-	-
Egg-larvae drift (>10 m)	-	-	-	-	-	-
Nursery (>0 m)	-	-	-	Minor	-	Minor
Feeding (>5 m)	-	-	-	Minor	-	-
Migration (>5m)	-	-	-	-	-	-
Flatfish						
Spawning (> 10 m)	-	-	-	-	-	-
Egg-larvae drift (>10 m)	-	-	-	-	-	-
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (>0 m)	-	-	-	Minor	-	Minor
Migration (>5m)	-	-	-	-	-	-
Shallow water species						
Spawning (<10 m)	-	-	-	Minor	-	Minor
Egg-larvae drift (<10 m)	-	-	-	Minor	-	Minor
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (<10 m)	-	-	-	Minor	-	Minor
Eel						
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (<10 m)	-	-	-	Minor	-	Minor
Migration (>2m)	-	-	-	-	-	-
Sea stickleback						
Spawning	-	-	-	-	-	Medium
Egg-larvae drift	-	-	-	-	-	Medium
Nursery	-	-	-	-	-	Medium
Feeding	-	-	-	-	-	Medium
Snake blenny						
Spawning (>20 m)	-	-	-	-	-	-
Egg-larvae drift (>20 m)	-	-	-	-	-	-
Nursery (>20 m)	-	-	-	-	-	-
Feeding (>20 m)	-	-	-	-	-	-
Protected species						
Migration (>5m)	-	-	-	-	-	-

7.2.3 Severity and significance

In the following chapter, the severity of loss caused by the permanent physical bridge structures and the severity of impairment caused by the long-term physical bridge structures are presented. The “severity of loss” was only determined for species which depend on the availability of “seabed” habitats.

Permanent physical bridge structures (severity of loss):
The severity of loss caused by the permanent physical bridge structures (Category 1) will be high for all life stages of sea stickleback and snake blenny (spawning, egg-larvae drift, nursery and feeding) within the near zone (table 5.9). For all other species and indicators, the severity of loss is assessed minor or medium.

Although the severity of loss was determined as high for sea stickleback, it has to be considered that the level of severity was directly derived from the importance status of the respective component (species) and associated indicators independently from the level of habitat loss (area size). Considering the relatively small size of the area lost due to the permanent physical bridge structures (see Table 7.9-Table 7.11) and the small size of the “near zone”-area, no strong impact on these species is expected.

Therefore, no significant loss of function is expected of the population dynamics of all species by the permanent bridge structures.

Table 7.9: Severity of loss (permanent) for each environmental component based on the pressure indicators and the loss of seabed (%) for the near (500 m on both sides of the middle of the alignment corridor) and the local zone (10 km on both sides of the middle of the alignment corridor).

Severity of loss by seabed reclamation permanent, bridge	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Nursery (<10 m)	-	-	-	Medium	-	Medium
Herring						
Spawning (mod)	-	-	-	Minor	-	-
Egg drift (>2 m)	-	-	-	Minor	Minor	Minor
Flatfish						
Spawning (> 10 m)	-	-	-	Medium	Medium	Medium
Nursery (<10 m)	-	-	-	Medium	-	Medium
Feeding (>0 m)	-	-	-	Medium	Medium	Medium
Shallow water species						
Spawning (<10 m)	-	-	-	Medium	-	Medium
Egg-larvae drift (<10 m)	-	-	-	Minor	-	Minor
Nursery (<10 m)	-	-	-	Medium	-	Medium
Feeding (<10 m)	-	-	-	Medium	-	Medium
Eel						
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (<10 m)	-	-	-	Minor	-	Minor
Sea stickleback						
Spawning	-	-	-	-	-	High
Egg-larvae drift	-	-	-	-	-	High
Nursery	-	-	-	-	-	High
Feeding	-	-	-	-	-	High
Snake blenny						
Spawning (>20 m)	-	-	-	High	High	High
Egg-larvae drift (>20 m)	-	-	-	High	High	High
Nursery (>20 m)	-	-	-	High	High	High
Feeding (>20 m)	-	-	-	High	High	High

Permanent bridge construction components (severity of impairment):
The permanent physical structures will only have insignificant or minor impairments on all components and associated indicators (Table 7.10).

Therefore, no significant impairment is expected for all species (i.e. components) and associated indicators (i.e. spawning, egg-larvae-drift, nursery and feeding).

Table 7.10: Severity of impairment (permanent) for each environmental component based on the pressure indicators and the loss of seabed (%) for the near (500 m on both sides of the middle of the alignment corridor) and the local zone (10 km on both sides of the middle of the alignment corridor).

Severity of impairment/loss by seabed reclamation permanent, bridge	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Spawning (> 10 m)	-	-	-	Minor	Minor	Minor
Egg-larvae drift (>10 m)	-	-	-	Minor	Minor	Minor
Feeding (>5 m)	-	-	-	Minor	Minor	Minor
Migration (> 5 m)	-	-	-	Minor	Minor	Minor
Whiting						
Nursery (>0 m)	-	-	-	Insignif.	Insignif.	Insignif.
Migration (>5m)	-	-	-	Minor	Minor	Minor
Herring						
Larvae drift (>2 m)	-	-	-	Insignif.	Insignif.	Insignif.
Nursery (>0 m)	-	-	-	Insignif.	Insignif.	Insignif.
Feeding (>5 m)	-	-	-	Insignif.	Insignif.	Insignif.
Migration (>5m)	-	-	-	Minor	Minor	Minor
Sprat						
Spawning (> 10 m)	-	-	-	Minor	Minor	Minor
Egg-larvae drift (>10 m)	-	-	-	Minor	Minor	Minor
Nursery (>0 m)	-	-	-	Insignif.	Insignif.	Insignif.
Feeding (>5 m)	-	-	-	Insignif.	Insignif.	Insignif.
Migration (>5m)	-	-	-	Minor	Minor	Minor
Flatfish						
Egg-larvae drift (>10 m)	-	-	-	Minor	Minor	Minor
Migration (>5m)	-	-	-	Insignif.	Insignif.	Insignif.
Eel						
Migration (>2m)	-	-	-	Minor	Minor	Minor
Protected species						
Migration (>5m)	-	-	-	Minor	Minor	Minor

Temporary long-term physical bridge structures (severity of impairment):
The temporary long-term physical bridge structures will only cause insignificant or minor impairment on the different species (Table 7.11). Only for sea stickleback, a medium impairment was assessed. Therefore no significant impairment by the installation of temporary long-term construction components for all species is expected.

Table 7.11: Severity of impairment (temporary long term) for each environmental component based on the pressure indicators and the loss of seabed (%) for the near (500 m on both sides of the middle of the alignment corridor) and the local zone (10 km on both sides of the middle of the alignement corridor).

Severity of impairment/loss by seabed reclamation temporary long-term, bridge	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Spawning (> 10 m)	-	-	-	-	-	-
Egg-larvae drift (>10 m)	-	-	-	-	-	-
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (>5 m)	-	-	-	Minor	-	-
Migration (> 5 m)	-	-	-	-	-	-
Whiting						
Nursery (>0 m)	-	-	-	Insignif.	-	Insignif.
Migration (>5m)	-	-	-	-	-	-
Herring						
Spawning (mod)	-	-	-	Insignif.	-	-
Egg-larvae drift (>2 m)	-	-	-	Insignif.	-	Insignif.
Nursery (>0 m)	-	-	-	Insignif.	-	Insignif.
Feeding (>5 m)	-	-	-	Insignif.	-	-
Migration (>5m)	-	-	-	-	-	-
Sprat						
Spawning (> 10 m)	-	-	-	-	-	-
Egg-larvae drift (>10 m)	-	-	-	-	-	-
Nursery (>0 m)	-	-	-	Insignif.	-	Insignif.
Feeding (>5 m)	-	-	-	Insignif.	-	-
Migration (>5m)	-	-	-	-	-	-
Flatfish						
Spawning (> 10 m)	-	-	-	-	-	-
Egg-larvae drift (>10 m)	-	-	-	-	-	-
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (>0 m)	-	-	-	Minor	-	Minor
Migration (>5m)	-	-	-	-	-	-
Shallow water species						
Spawning (<10 m)	-	-	-	Minor	-	Minor
Egg-larvae drift (<10 m)	-	-	-	Insignif.	-	Insignif.
Nursery (<10 m)	-	-	-	Minor	-	Minor
Feeding (<10 m)	-	-	-	Minor	-	Minor
Eel						
Nursery (<10 m)	-	-	-	Insignif.	-	Insignif.
Feeding (<10 m)	-	-	-	Insignif.	-	Insignif.
Migration (>2m)	-	-	-	-	-	-
Sea stickleback						
Spawning	-	-	-	-	-	Medium
Egg-larvae drift	-	-	-	-	-	Medium
Nursery	-	-	-	-	-	Medium
Feeding	-	-	-	-	-	Medium
Snake blenny						
Spawning (>20 m)	-	-	-	-	-	-
Egg-larvae drift (>20 m)	-	-	-	-	-	-
Nursery (>20 m)	-	-	-	-	-	-
Feeding (>20 m)	-	-	-	-	-	-
Protected species						
Migration (>5m)	-	-	-	-	-	-

7.3 Sediment spill

The bridge solution implicates several dredging activities involving the construction of a working harbour at Rødby and dredging and backfilling of piers and access channels. The total amount of handled sediment is approximated to be 3.2 mill m^3 whereof 0.11 mill m^3 is estimated to be spilled.

The spilled sediment will consist of everything which is present in the dredged soil. Boulders and coarser sand fractions will settle close to the dredging site while finer sediment may be carried away. As for natural sediment transport and deposition of spilled sediment during dredging are determined by the hydrodynamic conditions. In periods with rough weather and currents the sediment will be kept in suspension and transported with the flow whereas in periods with calm weather the sediment will settle out on the seabed. Normally the weather is shifting with the irregular weather patterns and therefore the sediment transport happens in a series of events. The sediment will continue being resuspended and re-deposited until it reaches a final deposition area where the hydrodynamic forces, waves and currents are so weak that the sediment cannot be resuspended.

In addition to the background level the excess concentrations of suspended sediment and sedimentation may impact fish in various ways as described in detail in chapter 4.3.2. This may be either directly affecting the fish in one or the other way or indirectly by impairing the habitats of fish including their food resources.

Apart from excess concentrations the duration of the dredging activites is descisive for the magnitude of the pressure. The dredging is planned to last three years but hereafter there will be no sediment spill associated with the bridge. The impact assessment regarding sediment spill is therefore only related to the construction phase.

7.3.1 Magnitude of pressure

The pressure towards fish caused by sediment spill from the construction of the bridge solution is assessed upon spill scenarios established by FEHY. The simulations used in the present assessment are the sediment spill budget for the cable-stayed bridge alignment BEE. The simulations are based on the average hydrographic year 2005, which is considered to represent average conditions, and assume that the timing and construction will follow the plan presented in the design project description (FEHY, 2013c).

In general the simulations show that the concentration of suspended sediment will vary during the construction period depending on the location of the dredging operations and the current and wave conditions. In the coastal waters waves will prevent the spilled material from settling and resuspend material from the seabed. Excess concentrations from the construction will therefore be higher in the shallow waters and sediment will be transported along the coastline before settling. However, the excess concentrations are generally much smaller for the bridge than the tunnel solutions. Figure 7.9 shows two simulations from May to August 2015 of net deposition and suspended sediment exceeding 5 mg/l which represents a period with high spillage.

At the end of the construction period deposition will be present over large areas but in very thin layers, which for all practical reason are considered insignificant (FEHY, 2013c).

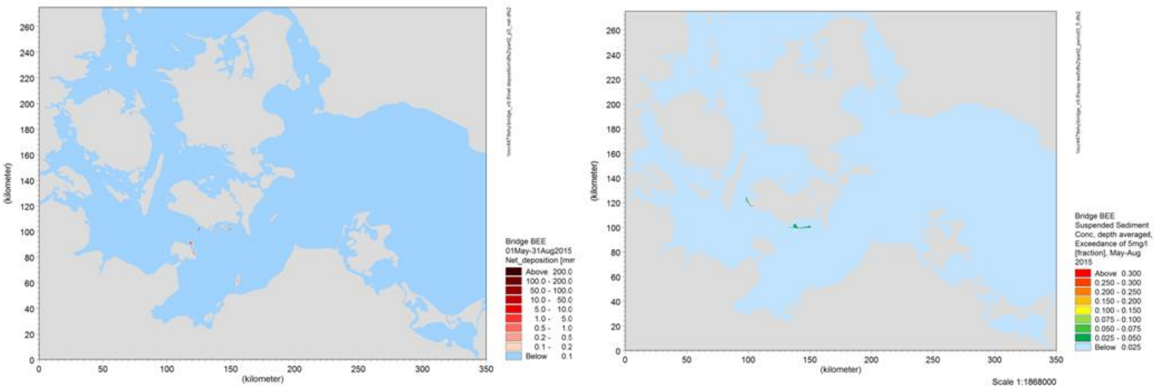


Figure 7.9 Sediment spill scenarios of net deposition and frequency of exceeding of 5 mg/l in the period May-August 2005 from the bridge solution (modelled for FeBEC by FEHY 2011c).

Since spawning and migration among fish are highly seasonal the timing of the dredging activities is included in the assessment considering relevant periods for each environmental indicator. It should be noted that changes from the schedule of the dredging may affect the magnitude of the pressure and consequently the impairment.

Table 7.12 gives an overview over the sediment spill scenarious used in the assessment of each environmental indicator and Figure 7.10 shows examples of two scenarious of respective suspended sediment and sedimentation.

Table 7.12: Sediment spill scenarios used for the assessment of each sub-components in relevant periods.

Sub-components	Species	Pressure	Threshold	Period	Years
Spawning	herring	net sedimentation	0.1 mm/d	Mar-May	2014-2016
	shallow water species, sea stickleback, snake blenny	"	0.1 mm/d	Jan-Dec	2014-2016
Egg-larvae drift	cod, flatfish (plaice), snake blenny	SS, frequency of exceedance	2 mg/l	Dec-Apr	2014-2016
	sprat, flounder, dab	"	2 mg/l	Mar-May	2014-2016
	turbot	"	2 mg/l	May-Aug	2014-2016
Nursery ground	cod, whiting, herring, sprat	"	10 mg/l	Jan-Dec	2014-2016
	shallow water species, eel, sea stickleback, snake blenny	"	50 mg/l	Jan-Dec	2014-2016
Feeding ground	cod, whiting, herring, sprat	"	10 mg/l	Jan-Dec	2014-2016
	shallow water species, eel, sea stickleback, snake blenny	"	50 mg/l	Jan-Dec	2014-2016
Migration	cod, sprat, whiting	"	10 mg/l	Dec-Apr	2014-2016
	herring	"	10 mg/l	Mar-May	2014-2016
	silver eel	"	50 mg/l	Oct-Dec	2014-2016

From simulations of net deposition and excess concentrations as shown in Figure 7.9 and the perspective exceeding threshold values given in Table 7.12 the reduction of each environmental component has been quantified. Thus, the area of occurrence of the specific indicator overlapping the area, where the specific threshold is exceeded, is considered the reduction of the environmental components. With respect to suspended sediment each overlap is weighted according to the frequency of exceedance and the fractions represents either percentages of time or area. With respect to deposition the fractions represents only areas.

For each of the considered areas of investigation the year with the maximal reduction of the respective environmental components as well as the maximal average of three successive years are used for the classification of the degree of impairment. Figure 7.10 shows the calculated percentages exceeding concentrations of suspended sediment of 2 mg/l used for impact assessment of egg and larvae drift among cod and flatfish.

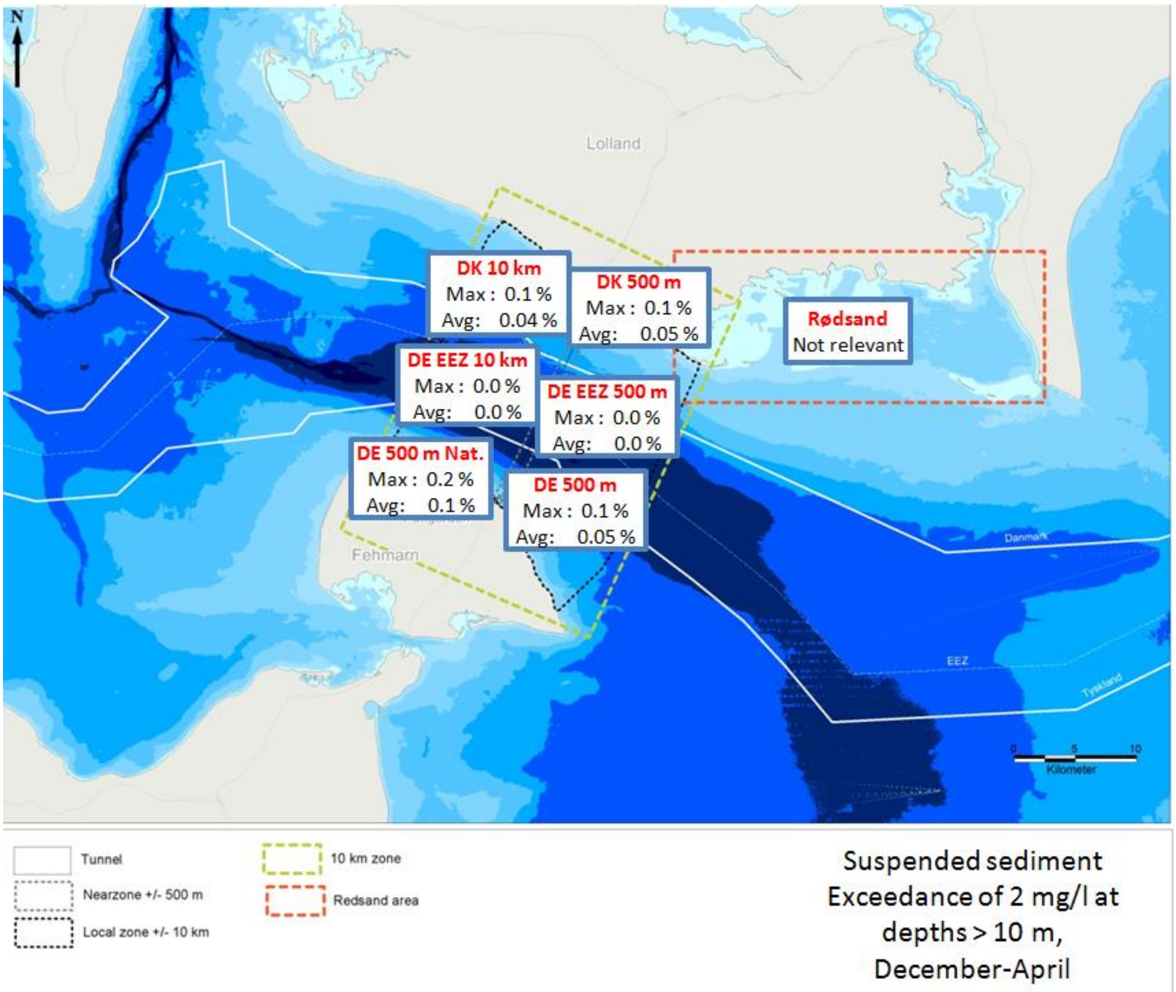


Figure 7.10: Weighted fractions exceeding concentrations of 2 mg/l at depths > 10 m in the period December-April for the year with maximal concentrations of suspended sediment and the maximal three successive years during the construction of the bridge solution from 2014-2016. The fractions are used to assess impacts caused by sediment spill towards egg- and larvae drift among cod and flatfish in Fehmarnbelt.

Due to smaller amount of spilled sediment the deposition and situations with higher excess concentrations are much less than for the tunnel solution and more than tenfold less than the normal background concentration. Table 7.13 shows fractiles and exceedance times for excess concentrations simulated for 2014-2016 at the same stations used for the baseline study (FEHY, 2013c). These years represent the period where most of the excess concentrations are found, and here the maximum exceedance time is only 5 %.

Table 7.13: Fractiles and exceedance times for the excess concentrations modelled for the bridge solution 201-2016. In FEHY, 2013c.

Stations	f_{50} (mg/l)	F_{75} (mg/l)	F_{95} (mg/l)	E_2 (%)	E_{10} (%)	E_{20} (%)
NS01	0.0	0.0	0.1	0.1	0.0	0.0
NS02	0.0	0.0	0.0	0.2	0.0	0.0
NS03	0.0	0.0	0.1	0.3	0.0	0.0
NS04	0.0	0.1	0.5	3.8	0.4	0.0
NS05	0.0	0.0	0.1	0.1	0.0	0.0
NS06	0.0	0.0	0.0	0.0	0.0	0.0
NS07	0.0	0.0	0.0	0.0	0.0	0.0
NS08	0.0	0.0	0.0	0.0	0.0	0.0
NS09	0.0	0.0	0.0	0.0	0.0	0.0
NS10	0.0	0.0	0.0	0.0	0.0	0.0
MS01	0.0	0.0	0.0	0.0	0.0	0.0
MS02	0.0	0.0	0.0	0.0	0.0	0.0

Since resuspension of natural fines and spillage will occur at the same time the real increase in exceedance times will be much smaller. In fact the excess concentrations are so small that exceedance of 2 mg/l caused alone by spillage must be considered so rare that impacts from the construction of the bridge most likely are negligable. Thus the criteria for impacts going from minor to of medium Table 7.14 of the most vulnerable environmental inidicator is set to 8 %, which is far beyond the 3.8 % which is the maximal simulated exceedance time only occurring in the Rødsand Lagoon at station NS04.

7.3.2 **Degree of impairment**

The estimated magnitude of pressure of each area of investigation for each environmental indicator is presented in Table 7.14. The values represent the percentage reduction/ loss of function in the year with the maximal spillage. In addition the corresponding areas or, regarding migration, the length of the corridor are presented in brackets. The magnitude of pressure from each construction year is not presented here, but is included in the overall project impact assessment.

In general the magnitude of pressure towards most indicators is far less than 1 %. Compared to the natural levels of suspended sediment the magnitude of pressure caused by the construction of the bridge is expected to be insignificant.

Table 7.14: The reduction of environmental components caused by sediment spil from the construction of the main bridge solution in Fehmarnbelt.

Reduction of environmental components Sediment spill. % (ha or m) Bridge Construction	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m	Rødsand Lagoon
Cod							
Egg-larvae drift (>10 m)	0.2 (16)	0.0 (0)	0.1 (13)	0.2 (1)	0.0 (0)	0.1 (1)	-
Nursery (<10 m)	0.5 (17)	-	0.3 (15)	0.9 (1)	-	0.3 (1)	0.1 (43)
Feeding (>5 m)	0.0 (3)	0.0 (0)	0.0 (4)	0.2 (1)	0.0 (0)	0.1 (1)	0.3 (3)
Migration (>5m)	-	-	-	0.2 (11m)	0.0 (0m)	0.1 (8m)	-
Whiting							
Nursery (>0 m)	0.1 (18)	0.0 (0)	0.1 (15)	0.2 (1)	0.0 (0)	0.1 (1)	0.1 (43)
Migration (>5m)	-	-	-	0.2 (11m)	0.0 (0m)	0.1 (8m)	-
Herring							
Spawning (mod)	0.0 (0)	-	0.0 (0)	0.0 (0)	-	0.0 (0)	0.0 (0)
Egg-larvae drift (>2 m)	0.6 (73)	0.0 (0)	0.0 (9)	0.9 (5)	0.0 (0)	0.1 (1)	0.3 (58)
Nursery (>0 m)	0.1 (18)	0.0 (0)	0.1 (15)	0.2 (1)	0.0 (0)	0.1 (1)	0.1 (43)
Feeding (>5 m)	0.0 (3)	0.0 (0)	0.0 (4)	0.2 (1)	0.0 (0)	0.1 (1)	0.3 (3)
Migration (>5m)	-	-	-	0.1 (3m)	0.0 (0m)	0.0 (2m)	-
Sprat							
Egg-larvae drift (>10 m)	0.1 (9)	0.0 (0)	0.0 (1)	0.4 (2)	0.0 (0)	0.1 (0)	-
Nursery (>0 m)	0.1 (18)	0.0 (0)	0.1 (15)	0.2 (1)	0.0 (0)	0.1 (1)	0.1 (43)
Feeding (>5 m)	0.0 (3)	0.0 (0)	0.0 (4)	0.2 (1)	0.0 (0)	0.1 (1)	0.3 (3)
Migration (>5m)	-	-	-	0.2 (8m)	0.0 (2m)	0.1 (8m)	-
Flatfish							
Egg-larvae drift (>10 m)	0.1 (9)	0.0 (0)	0.0 (1)	0.4 (2)	0.0 (0)	0.1 (0)	
Nursery (<10 m)	0.0 (2)	-	0.0 (0)	0.1 (0)	-	0.1 (0)	0.0 (2)
Feeding (>0 m)	0.0 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (2)
Migration (>5m)	-	-	-	0.0 (1m)	0.0 (0m)	0.0 (2m)	-
Shallow water species							
Spawning (<10 m)	0.1 (4)	-	0.2 (11)	14.1 (20)	-	4.1 (12)	0.0 (0)
Nursery (<10 m)	0.0 (2)	-	0.0 (0)	0.1 (0)	-	0.1 (0)	0.0 (2)
Feeding (<10 m)	0.0 (2)	-	0.0 (0)	0.1 (0)	-	0.1 (0)	0.0 (2)
Eel							
Nursery (<10 m)	0.0 (2)	-	0.0 (0)	0.1 (0)	-	0.1 (0)	0.0 (2)
Feeding (<10 m)	0.0 (2)	-	0.0 (0)	0.1 (0)	-	0.1 (0)	0.0 (2)
Migration (>2m)	-	-	-	0.0 (1m)	0.0 (0m)	0.0 (4m)	-
Sea stickleback							
Spawning (habmap)	0.0 (0)	-	0.0 (0)	0.0 (0)	-	0.0 (0)	0.0 (0)
Nursery (")	0.1 (0)	-	0.0 (0)	0.0 (0)	-	0.1 (0)	0.0 (1)
Feeding (")	0.1 (0)	-	0.1 (3)	0.1 (0)	-	0.1 (0)	0.1 (20)
Snake blenny							
Spawning (>20 m)	0.0 (0)	0.0 (0)	0.1 (8)	0.0 (0)	0.0 (0)	0.0 (0)	-
Egg-larvae drift (>20 m)	0.0 (2)	0.0 (0)	0.0 (1)	0.0 (0)	0.0 (0)	0.0 (0)	-
Nursery (>20 m)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	
Feeding (>20 m)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	
Protected species							
Migration (>5m)	-	-	-	0.2 (11m)	0.0 (0m)	0.1 (8m)	-

The degree of impairment caused by sediment spill is consequently classified minor to all indicators selected for the present assessment of the bridge solution in all areas of investigation (Table 7.15). The impairment of the spill is thus far less compared to the impairment caused by natural levels of suspended material in the area.

Table 7.15: The degree of impariment caused by sediment spill from the construction of the main bridge solution in Fehmarnbelt.

Degree of impairment Sediment spill Bridge Construction	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m	Rødsand Lagoon
Cod							
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (>5 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor	
Whiting							
Nursery (>0 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor	
Herring							
Spawning (mod)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Egg-larvae drift (>2 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Nursery (>0 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Feeding (>5 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor	
Sprat							
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (>0 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Feeding (>5 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor	
Flatfish							
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (>0 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor	
Shallow water species							
Spawning (<10 m)	Minor		Minor	Minor		Minor	Minor
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (<10 m)	Minor		Minor	Minor		Minor	Minor
Eel							
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (<10 m)	Minor		Minor	Minor		Minor	Minor
Migration (>2m)				Minor	Minor	Minor	
Sea stickleback							
Spawning (habmap)	Minor		Minor	Minor		Minor	Minor
Nursery (")	Minor		Minor	Minor		Minor	Minor
Feeding (")	Minor		Minor	Minor		Minor	Minor
Snake blenny							
Spawning (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Egg-larvae drift (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Feeding (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Protected species							
Migration (>5m)				Minor	Minor	Minor	

7.3.3 Severity and significance

The severity of impairment of sediment spill from the bridge is assessed minor on all indicators selected for the present assessment (Table 7.16). Therefore, no impacts among fish and fish communities of the dredging activities related to the construction of the main bridge solution are expected.

Table 7.16: The severity of impariment caused by sediment spill from the construction of the main bridge solution in Fehmarnbelt.

Severity of impairment Sediment spill Bridge Construction	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**	**Rødsand Lagoon**
Cod							
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (>5 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor	
Whiting							
Nursery (>0 m)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Migration (>5m)				Minor	Minor	Minor	
Herring							
Spawning (mod)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Egg-larvae drift (>2 m)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Nursery (>0 m)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Feeding (>5 m)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Migration (>5m)				Minor	Minor	Minor	
Sprat							
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (>0 m)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Feeding (>5 m)	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.	Insignif.
Migration (>5m)				Minor	Minor	Minor	
Flatfish							
Egg-larvae drift (>10 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (>0 m)	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Migration (>5m)				Insignif.	Insignif.	Insignif.	
Shallow water species							
Spawning (<10 m)	Minor		Minor	Minor		Minor	Minor
Nursery (<10 m)	Minor		Minor	Minor		Minor	Minor
Feeding (<10 m)	Minor		Minor	Minor		Minor	Minor
Eel							
Nursery (<10 m)	Insignif.		Insignif.	Insignif.		Insignif.	Insignif.
Feeding (<10 m)	Insignif.		Insignif.	Insignif.		Insignif.	Insignif.
Migration (>2m)				Minor	Minor	Minor	
Sea stickleback							
Spawning (habmap)	Minor		Minor	Minor		Minor	Minor
Nursery (")	Minor		Minor	Minor		Minor	Minor
Feeding (")	Minor		Minor	Minor		Minor	Minor
Snake blenny							
Spawning (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Egg-larvae drift (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Nursery (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Feeding (>20 m)	Minor	Minor	Minor	Minor	Minor	Minor	
Protected species							
Migration (>5m)				Minor	Minor	Minor	

7.4 Noise and vibration

The noise scenarios related to the construction and operation of a bridge are primarily caused by dredging, drilling and backfilling in relation to the construction and placement of the pilons and piers and to the traffic associated with work at sea. During the operation of the bridge low frequent noise (vibrations) from passing trains and heavy traffic would be a potential source of impact. Following issues will be assessed:

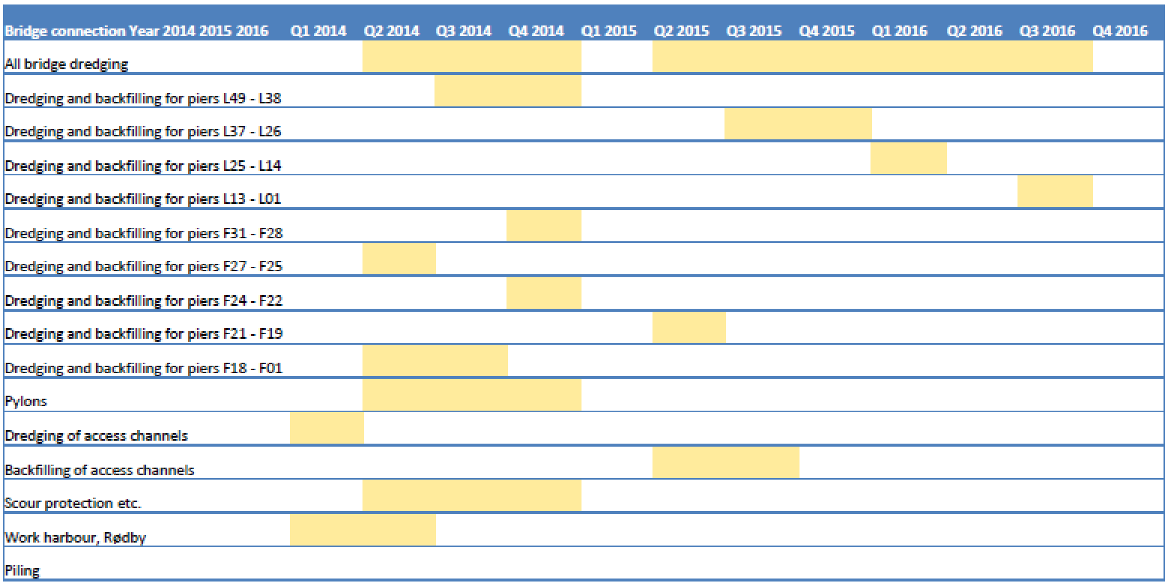
- Dredging – foundations, harbour & approaches
- Drilling (bored piles)
- Construction (sheet piling)
- Construction vessels
- Ship traffic (including changes to ferry service)
- Bridge traffic

7.4.1 Magnitude of pressure

Construction

In general, no detailed information is available on the noise scenarios associated with the construction of the bridge. The timing and location of dredging and driling for the bridge is taken from the client literature (Annex 1), but no information on dredger type or numbers has been provided. For this assesment we have therefore used the dredger specification and numbers from the tunnel option as a proxy for the bridge.

Although limited information for the piling works at the harbours for the bridge option is available the more detailed descriptions for the tunnel have also been used as a proxy. Thus for this assessment it is assumed, that the noise during the construction of the bridge equalize the noise emitted in the tunnel scenario both during construction in the alignment and in the harbour areas. The time schedule is shown in Figure 7.11.



Bridge connection Year 2014 2015 2016	Q1 2014	Q2 2014	Q3 2014	Q4 2014	Q1 2015	Q2 2015	Q3 2015	Q4 2015	Q1 2016	Q2 2016	Q3 2016	Q4 2016
All bridge dredging		🟨	🟨	🟨		🟨	🟨	🟨	🟨	🟨	🟨	
Dredging and backfilling for piers L49 - L38			🟨	🟨								
Dredging and backfilling for piers L37 - L26							🟨	🟨				
Dredging and backfilling for piers L25 - L14									🟨			
Dredging and backfilling for piers L13 - L01											🟨	
Dredging and backfilling for piers F31 - F28				🟨								
Dredging and backfilling for piers F27 - F25		🟨										
Dredging and backfilling for piers F24 - F22				🟨								
Dredging and backfilling for piers F21 - F19						🟨						
Dredging and backfilling for piers F18 - F01		🟨	🟨									
Pylons		🟨	🟨	🟨								
Dredging of access channels	🟨											
Backfilling of access channels						🟨	🟨					
Scour protection etc.		🟨	🟨	🟨								
Work harbour, Rødby	🟨	🟨										
Piling												

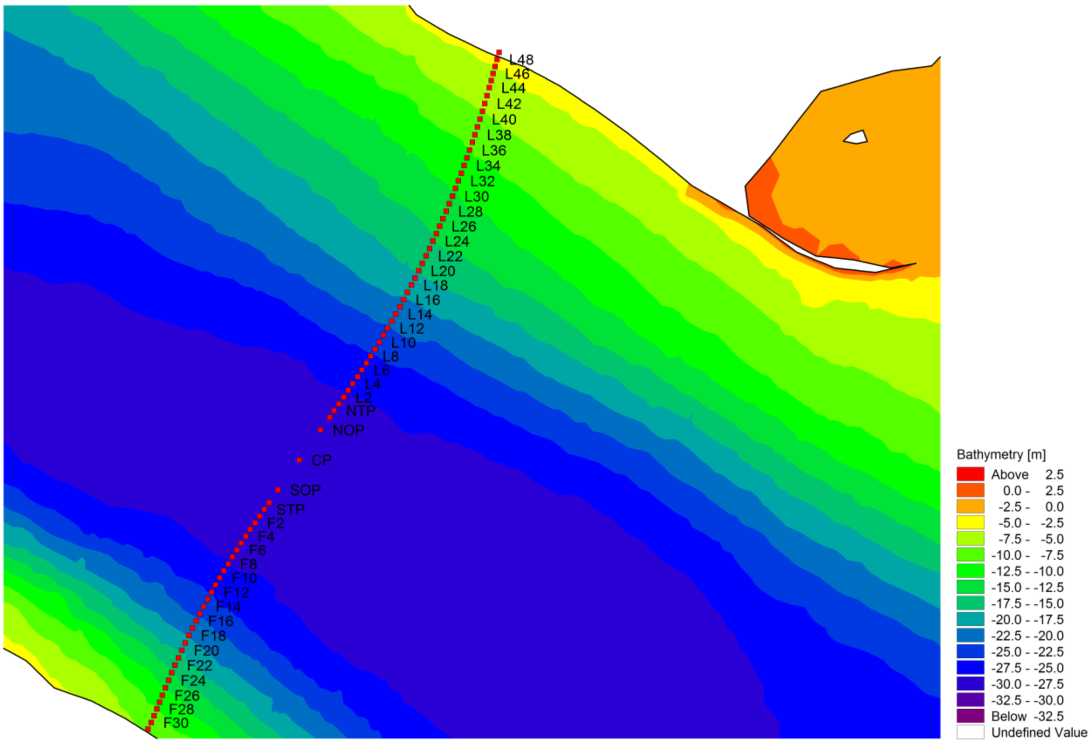


Figure 7.11: Construction activities for bridge.

Operation

Heavy vehicles and freight trains might produce significant low frequency noise or vibrations during the passage and the noise will be conducted to the water by the piers and pylons. Measurements from the Øresund Bridge revealed a source sound level during train passages of 120 dB at a distance of 50 m from the bridge piers in the frequency band 10-16 Hz (Appelberg, et al., 2005). This equalizes a source level of 137 dB 1 m from the piers. A source level of 132 dB in the frequency 8-30 Hz was measured at truck passages. This equals the level of 134 dB measured at the Great Belt Bridge (FEMM 2011b).

Although these levels are in the hearing range of fish, they are below the level of any avoidance behaviour. The measurements at Øresund did not imply particle acceleration, which is a major component of vibrations. Westerberg (1996) measured the particle acceleration from vibrations at the Storstrøm Bridge and the acceleration reached a maximum level between 3-10 m/s^2 during the passage of trains. The threshold for avoidance behavoir (0.01 m/s^2) according to Sand et al. (2000) was thus exceeded within 10 m from the bridge piers (Appelberg et al., 2005).

With 74 piers and three pilons each producing vibrations exceeding the threshold level with a reach of 10 m in every direction during train passage and with train passages 4 % of the time, the average worst case resulting impact would be 0.4 % of the alignment excluded for fish passage. Accordingly 12 ha would be impacted with vibrations causing avoidance behaviour in 4 % of the time equalizing a 0.03 % reduction of grounds.

7.4.2 Degree of impairment

5.5 % of the migration of gadoids and clupeids are estimated to be lost due to noise in the near zone, while 1.1 % of the migration of other species is lost (Table 7.17). Only small areas of spawning, feeding and nursery grounds will be lost due to noise. Most area are lost close to the construction harbours (12 ha for gadoids and clupeids near Rødby and 3 ha near Puttgarden). The loss of ground for other species is small.

Table 7.17: Estimated reduction of environmental components caused by noise and vibrations during construction of the bridge in % and ha (m for migration).

Reduction of environmental components of noise and vibrations (%-ha/m) Construction. Bridge	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Nursery (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	2.07 (3.0)	0.00 (0.0)	4.29 (12.5)
Feeding (>5 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.45 (2.0)	0.40 (1.9)	0.43 (3.4)
Migration (>5m)				5.49 (255)	5.49 (245)	5.49 (445)
Whiting						
Nursery (>0 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.35 (2.0)	0.40 (1.9)	0.39 (3.9)
Migration (>5 m)				5.49 (255)	5.49 (245)	5.49 (445)
Herring						
Spawning (mod)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	2.07 (0.0)	0.00 (0.0)	4.29 (0.0)
Nursery (>0 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.35 (2.0)	0.40 (1.9)	0.39 (3.9)
Feeding (>5 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.45 (2.0)	0.40 (1.9)	0.43 (3.4)
Migration (>5 m)				5.49 (255)	5.49 (245)	5.49 (445)
Sprat						
Nursery (>0 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.35 (2.0)	0.40 (1.9)	0.39 (3.9)
Feeding (>5 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.45 (2.0)	0.40 (1.9)	0.43 (3.4)
Migration (>5 m)				5.49 (255)	5.49 (245)	5.49 (445)
Flatfish						
Nursery (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.51 (0.7)	0.00 (0.0)	1.02 (2.9)
Feeding (>0 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.02 (0.1)	0.02 (0.1)	0.02 (0.2)
Migration (>5 m)				1.14 (53)	1.14 (51)	1.14 (93)
Shallow water species						
Spawning (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.51 (0.7)	0.00 (0.0)	1.02 (2.9)
Nursery (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.51 (0.7)	0.00 (0.0)	1.02 (2.9)
Feeding (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.51 (0.7)	0.00 (0.0)	1.02 (2.9)
Eel						
Nursery (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.51 (0.7)	0.00 (0.0)	1.02 (2.9)
Feeding (<10 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.51 (0.7)	0.00 (0.0)	1.02 (2.9)
Migration (>2 m)				1.14 (53)	1.14 (51)	1.14 (98)
Sea stickleback						
Spawning (habmap)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.51 (0.7)	0.00 (0.0)	1.02 (2.9)
Nursery (")	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.51 (0.7)	0.00 (0.0)	1.02 (2.9)
Feeding (")	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.51 (0.7)	0.00 (0.0)	1.02 (2.9)
Snake blenny						
Nursery (>20 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.04 (0.0)	0.04 (0.0)	0.04 (0.0)
Feeding (>20 m)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.04 (0.0)	0.04 (0.0)	0.04 (0.0)
Protected species						
Migration (>5 m)				1.14 (53)	1.14 (51)	1.14 (93)

Table 7.18: Estimated reduction of environmental components caused by noise and vibrations during operation of the bridge in % and ha (m for migration).

Reduction of environmental components of noise and vibrations (%-ha/m) operation. Bridge	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Nursery (<10 m)				0.03 (0.1)		0.03 (0.3)
Feeding (>5 m)				0.03 (0.1)	0.02 (0.1)	0.03 (0.3)
Migration (>5m)				0.40 (17)	0.27 (11)	0.40 (34)
Whiting						
Nursery (>0 m)				0.03 (0.1)	0.02 (0.1)	0.03 (0.3)
Migration (>5 m)				0.40 (17)	0.27 (11)	0.40 (34)
Herring*						
Nursery (>0 m)				0.03 (0.1)	0.02 (0.1)	0.03 (0.3)
Feeding (>5 m)				0.03 (0.1)	0.02 (0.1)	0.03 (0.3)
Migration (>5 m)				0.40 (17)	0.27 (11)	0.40 (34)
Sprat						
Nursery (>0 m)				0.03 (0.1)	0.02 (0.1)	0.03 (0.3)
Feeding (>5 m)				0.03 (0.1)	0.02 (0.1)	0.03 (0.3)
Migration (>5 m)				0.40 (17)	0.27 (11)	0.40 (34)
Flatfish						
Nursery (<10 m)				0.03 (0.1)		0.03 (0.3)
Feeding (>0 m)				0.03 (0.1)	0.02 (0.1)	0.03 (0.3)
Migration (>5 m)				0.40 (17)	0.27 (11)	0.40 (34)
Shallow water species						
Spawning (<10 m)						
Nursery (<10 m)				0.03 (0.1)		0.03 (0.3)
Feeding (<10 m)				0.03 (0.1)	0.02 (0.1)	0.03 (0.3)
Eel						
Nursery (<10 m)				0.03 (0.1)		0.03 (0.3)
Feeding (<10 m)				0.03 (0.1)	0.02 (0.1)	0.03 (0.3)
Migration (>2 m)				0.40 (17)	0.27 (11)	0.40 (34)
Sea stickleback **						
Spawning (habmap)				0.03 (0.1)		0.03 (0.3)
Nursery (")				0.03 (0.1)	0.02 (0.1)	0.03 (0.3)
Feeding (")				0.03 (0.1)	0.02 (0.1)	0.03 (0.3)
Snake blenny						
Nursery (>20 m)				0.04 (0.0)	0.04 (0.0)	0.04 (0.0)
Feeding (>20 m)				0.04 (0.0)	0.04 (0.0)	0.04 (0.0)
Protected species*						
Migration (>5 m)				0.40 (17)	0.27 (11)	0.40 (34)

The classification of impact from noise and vibration according to the assessment criteria is given in Table 7.19 and Table 7.20. No degree of impairment exceeding minor was found.

Table 7.19: Classification of impact from noise and vibrations during construction of the bridge.

Degree of impairment of Noise and vibration, Bridge, Construction	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Nursery (<10 m)				Minor		Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor
Whiting						
Nursery (>0 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Herring						
Spawning (mod)				Minor		Minor
Nursery (>0 m)				Minor	Minor	Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Sprat						
Nursery (>0 m)				Minor	Minor	Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Flatfish						
Nursery (<10 m)				Minor		Minor
Feeding (>0 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Shallow water species						
Spawning (<10 m)						
Nursery (<10 m)				Minor		Minor
Feeding (<10 m)				Minor		Minor
Eel						
Nursery (<10 m)				Minor		Minor
Feeding (<10 m)				Minor		Minor
Migration (>2 m)				Minor	Minor	Minor
Sea stickleback						
Spawning (habmap)				Minor		Minor
Nursery (")				Minor		Minor
Feeding (")				Minor		Minor
Snake blenny						
Nursery (>20 m)				Minor	Minor	Minor
Feeding (>20 m)				Minor	Minor	Minor
Protected species						
Migration (>5 m)				Minor	Minor	Minor

Table 7.20: Classification of impact from noise and vibrations during operation of the bridge.

Degree of impairment of Noise and vibration, Bridge, Operation	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Nursery (<10 m)				Minor		Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor
Whiting						
Nursery (>0 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Herring*						
Spawning (mod)				Minor		Minor
Nursery (>0 m)				Minor	Minor	Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Sprat						
Nursery (>0 m)				Minor	Minor	Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Flatfish						
Nursery (<10 m)				Minor		Minor
Feeding (>0 m)				Minor	Minor	Minor
Migration (>5 m)				Minor	Minor	Minor
Shallow water species						
Spawning (<10 m)						
Nursery (<10 m)				Minor		Minor
Feeding (<10 m)				Minor		Minor
Eel						
Nursery (<10 m)				Minor		Minor
Feeding (<10 m)				Minor		Minor
Migration (>2 m)				Minor	Minor	Minor
Sea stickleback **						
Spawning (habmap)				Minor		Minor
Nursery (")				Minor		Minor
Feeding (")				Minor		Minor
Snake blenny						
Nursery (>20 m)				Minor	Minor	Minor
Feeding (>20 m)				Minor	Minor	Minor
Protected species*						
Migration (>5 m)				Minor	Minor	Minor

7.4.3 Severity and significance

The classification of the severity of impairment from noise and vibration is given in Table 7.21 and Table 7.22. No degree of severity exceeding minor was found.

Table 7.21: Severity of impairment due to noise and vibrations during construction of the bridge.

Severity of impairment/loss of noise and vibration, Bridge, construction	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Nursery (<10 m)				Minor		Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor
Whiting						
Nursery (>0 m)				Insignif.	Insignif.	Insignif.
Migration (>5 m)				Minor	Minor	Minor
Herring						
Spawning (mod)				Insignif.		Insignif.
Nursery (>0 m)				Insignif.	Insignif.	Insignif.
Feeding (>5 m)				Insignif.	Insignif.	Insignif.
Migration (>5 m)				Minor	Minor	Minor
Sprat						
Nursery (>0 m)				Insignif.	Insignif.	Insignif.
Feeding (>5 m)				Insignif.	Insignif.	Insignif.
Migration (>5 m)				Minor	Minor	Minor
Flatfish						
Nursery (<10 m)				Minor		Minor
Feeding (>0 m)				Minor	Minor	Minor
Migration (>5 m)				Insignif.	Insignif.	Insignif.
Shallow water species						
Spawning (<10 m)						
Nursery (<10 m)				Minor		Minor
Feeding (<10 m)				Minor		Minor
Eel						
Nursery (<10 m)				Insignif.		Insignif.
Feeding (<10 m)				Insignif.		Insignif.
Migration (>2 m)				Minor	Minor	Minor
Sea stickleback						
Spawning (habmap)				Minor		Minor
Nursery (")				Minor		Minor
Feeding (")				Minor		Minor
Snake blenny						
Nursery (>20 m)				Minor	Minor	Minor
Feeding (>20 m)				Minor	Minor	Minor
Protected species				-		
Migration (>5 m)				Minor	Minor	Minor

Table 7.22: Severity of impairment due to noise and vibrations during operation of the bridge.

Severity of impairment/loss of noise and vibration, Bridge, operation	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Nursery (<10 m)				Minor		Minor
Feeding (>5 m)				Minor	Minor	Minor
Migration (>5m)				Minor	Minor	Minor
Whiting						
Nursery (>0 m)				Insignif.	Insignif.	Insignif.
Migration (>5 m)				Minor	Minor	Minor
Herring						
Nursery (>0 m)				Insignif.	Insignif.	Insignif.
Feeding (>5 m)				Insignif.	Insignif.	Insignif.
Migration (>5 m)				Minor	Minor	Minor
Sprat						
Nursery (>0 m)				Insignif.	Insignif.	Insignif.
Feeding (>5 m)				Insignif.	Insignif.	Insignif.
Migration (>5 m)				Minor	Minor	Minor
Flatfish						
Nursery (<10 m)				Minor		Minor
Feeding (>0 m)				Minor	Minor	Minor
Migration (>5 m)				Insignif.	Insignif.	Insignif.
Shallow water species						
Nursery (<10 m)				Minor		Minor
Feeding (<10 m)				Minor		Minor
Eel						
Nursery (<10 m)				Insignif.		Insignif.
Feeding (<10 m)				Insignif.		Insignif.
Migration (>2 m)				Minor	Minor	Minor
Sea stickleback						
Spawning (habmap)				Minor		Minor
Nursery (")				Minor		Minor
Feeding (")				Minor		Minor
Snake blenny						
Nursery (>20 m)				Minor	Minor	Minor
Feeding (>20 m)				Minor	Minor	Minor
Protected species						
Migration (>5 m)				Minor	Minor	Minor

The impact of underwater noise and vibrations on fish in the bridge scenario is overall insignificant and limited to the near zone during the construction. Underwater noise and vibrations from the traffic during the operation is rather insignificant, and the impact from the bridge is less than the impact from the existing heavy traffic of ferries. The establishment of a bridge would presumably reduce the noise level in Fehmarnbelt if the ferry service stops.

7.5 Indirect pressures

The construction of a bridge across Fehmarnbelt can affect the substrate, vegetation and macrofauna and thus the habitat suitability of the different fish species. These types of pressure are described as indirect pressures.

The vegetation in an area as Fehmarnbelt reduces the water currents and can act as a sediment trap. Thus sediment spill from the construction of a bridge can affect the macroalgae and seagrass communities.

The habitat choice of an organism depends on a compination of factors such as habitat structure and availability, food supply, predation and inter- and intraspecific competition. Specific requirements for feeding, shelter or spawning often determine the dependence on a habitat. Additionally, for some fish species habitat choice vary between season and life stages.

Especially the shallow water fish communities depend on the occurrence of vegetation. However, vegetation is important for specific life stages of other fish species such as benthic herring eggs which are attached to the vegetation. Other species use these protected, shallow and vegetated areas as nursery grounds. The macrofauna associated with the coastal habitats constitutes a major food source for the fish communities presented in these areas.

Few of the German redlisted species prefers vegetated habitats and is thus vulnerable to indirect pressure from changes in the vegetation which will cause changes in the habitat suitability.

Furthermore, changes prey availability due to e.g. change in hydrological conditions will cause an indirect pressure to the predatory fish species. Especially fish larvae are vulnerable to changes in the occurrence of their main food items copepods. However, changes in prey abundance due to the construction of a bridge are not considered to impact the fish communities in Fehmarnbelt.

The habitat suitability of fish in Fehmarnbelt were analysed and mapped during the present assessment. The analysis compares the distribution of fish species with environmental variables. Data from the catches in the shallow waters of Fehmarnbelt (<20 m) together with information of the habitat (coverage of macroalgae and eelgrass) the fish were caught in were used for the analsis of suitability. Furthermore, changes in habitat suitability during the construction phase, based on data from FEMA modelling the changes in the cover of eelgrass and macroalgae, were analysed.

7.5.1 Magnitude of pressure

Different pressures such as sedimentation, increased concentration of suspended matter, sealing/footprint and additional solid substrates are expected to affect the benthic vegetation in relation to the construction of a bridge in Fehmarnbelt. The most considerable impacts on the vegetation and thus the fish communities are expected to be the increase in suspended material and sealing/footprint.

Sand erosion and deposition are natural occurring processes in the shallow water exposed ecosystem and the benthic flora is accustomed to these conditions. However, increase in these processes e.g. in relation to the construction of a bridge will affect the flora. Macroalgae are more sensitive to sedimentation compared to angiosperms.

The expected impacts on the benthic flora in relation to a bridge are:

- In general very small compared to impacts from a tunnel.
- Very small area with benthic vegetation is lost due to sedimentation.

- No impacts from suspended sediments.
- Very small areas are impacted by footprints.

The benthic fauna is an important food resource for some fish species and changes in this fauna is considered as indirect pressure on fish. However, the impact on benthic fauna is minor, temporary and very local and the impairment on fish species is considered insignificant. Furthermore, changes in zooplankton composition and abundance caused by the bridge will affect pelagic planktivorous species such as herring and sprat. Additionally, copepods are important food items for e.g. cod larvae. The plankton community in Fehmarnbelt is, however, only expected to be minor affected by the bridge and thus the indirect pressure from changes in zooplankton is considered insignificant.

Suitability mapping:
The reduction of environmental components caused by indirect pressure is estimated as the changes (reductions) in the suitability of habitat for the specific environmental indicator.

Habitat modelling has been done for a number of fish species in the coastal zone on the basis of two benthic fishing methods. The passive fishing methods gill nets and fyke nets are believed to provide valid data, proportional with the actual abundance of a number of species. Due to the nature of the selected fishing gear, which can never provide valid absence data, the modelling was carried out using a presence-only method.

The method, Ecological-Niche Factor Analysis (ENFA), is detailed described in (Hirzel, et al., 2002; Hirzel, et al., 2006), but is a presence-only multifactorial analysis, comparing the distribution of the species in question with the distribution of a number of Eco-Geographical Variables (EGVs) believed to describe the habitat available for the species (Table 7.23). The EGVs are transformed into a smaller set of uncorrelated factorial axes, of which the first represents Marginality (how much a species' habitat differs from the mean available environmental conditions) and the rest contributes to Specialization (width of the ecological niche).

The coefficients of the EGV's on the factors give the importance of EGV's in describing each factorial axes. A Habitat Suitability (HS) index was calculated on the basis of the marginality factor and the first 2-4 specialization factors by comparison with a broken-stick distribution. All grid cells in the study area were allocated values by the habitat suitability algorithm proportional to the distance between the grid value and the value for the species optimum in factorial space. The geometric mean algorithm was used for computing the habitat suitability because of the algorithms improved estimation in situations with non-unimodal distributions (Hirzel, et al., 2003). Habitat Suitability Index (HSI) values ranging from 0 to 100 were calculated based on the habitat suitability values; cells near the geometric mean of an axis scoring the most.

In order to compare the habitat suitability in the baseline year with each of the following years, the HSI computations mentioned above was done by pairing information for each year with information from the baseline year in one “pseudo map”. Changes in habitat suitability was calculated by subtracting the baseline years HSI value in a given grid cell from the HSI value in the given year.

The only EGV's that change from the baseline year and the following years are coverage of eelgrass and coverage of macroalgae. Both of the variables are modelled on the basis of changing spill scenarios.

ENFA analyses were carried out using Biomapper 4.0 (Hirzel, et al., 2007) and IDRISI (Clarks University).

Table 7.23: The Eco-Geographical-Variables (EGV's) used for the habitat modelling.

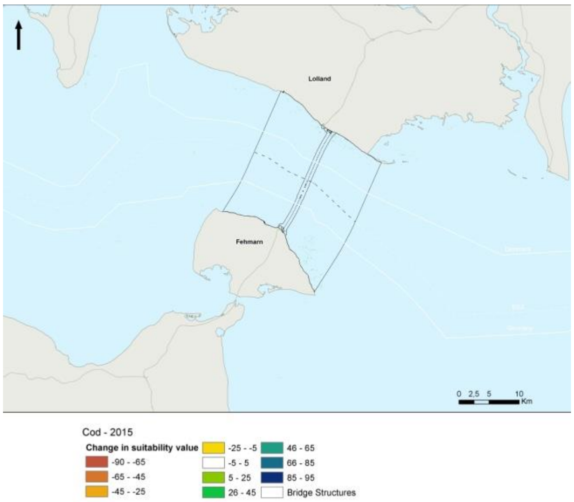
EGV
Distance to Danish coastline (constant above 5000 m)
Distance to German coastline (constant above 500 m)
Distance to nearest mussel area (constant above 2000 m)
Current speed (yearly mean, direction into the Baltic, m/s)
Depth (negative numbers, m)
Coverage of eelgrass 0-100%
Coverage of macroalgae 0 – 100%
Distance to nearest coarse, mixed substrate (constant above 2000 m)
Distance to nearest mud, sandy mud or thin sandy mud substrate (constant above 2000 m)
Distance to nearest muddy sand or sand substrate (constant above 2000 m)
Density (yearly mean, current direction into the Baltic, g/cm^3)
Pycnocline strength (yearly mean, current direction into the Baltic, g/cm^3/m)

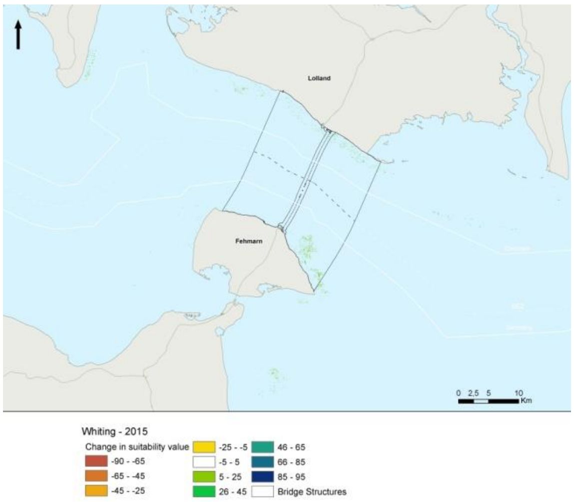
7.5.2 Degree of impairment

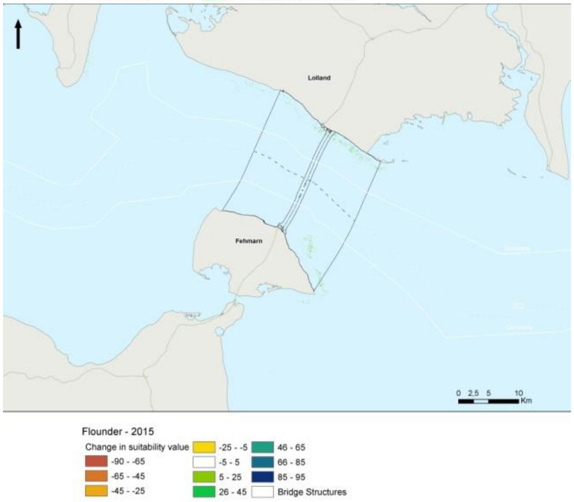
The degree of impairment is estimated as changes in habitat suitability due to changes in the coverage of macroalgae and eelgrass caused by e.g. sediment spill during the construction phase of the bridge.

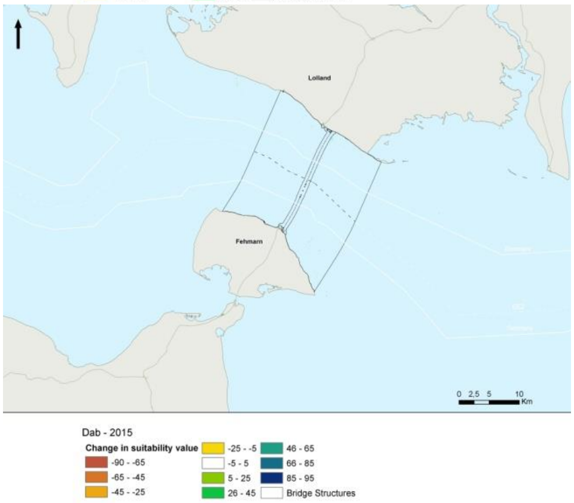
Figure 7.12 illustrates the changes in habitat suitability between the baseline situation and a specific year during the construction for juvenile cod, juvenile whiting, juvenile flatfish and shallow water species including sea stickleback. These are the environmental indicators of the shallow water fish community which are affected by the indirect pressure from changes in the benthic vegetation.

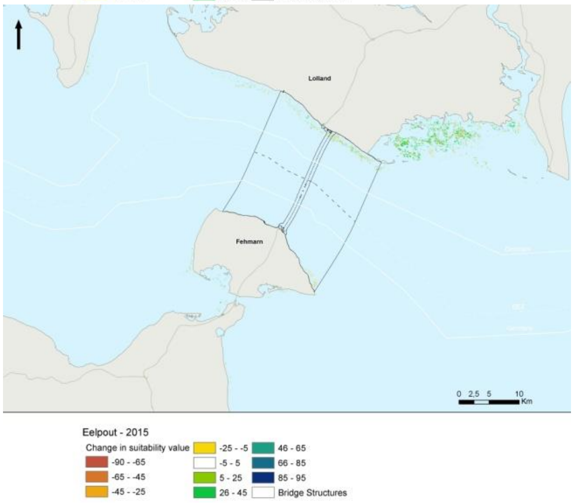
Only small reductions in habitat suitability of shallow water species, flatfish and sea stickleback are expected. These reductions are very small and the impairment of the construction of the bridge is considered to be insignificant. Furthermore, no effect of indirect pressures is expected during the operation phase.

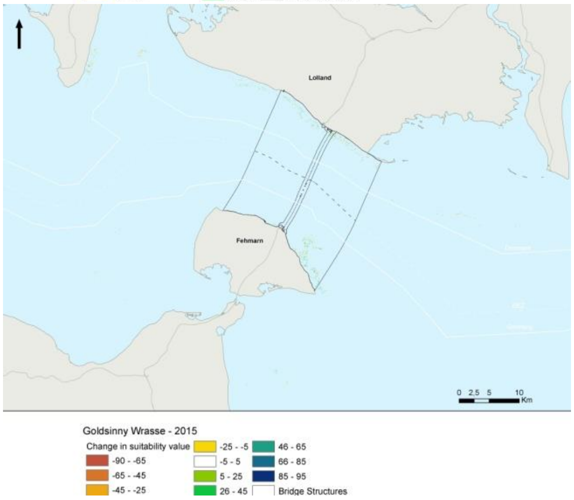

Cod - 2015


Whiting - 2015


Flounder - 2015


Dab - 2015


Eelpout - 2015


Goldsinny Wrasse - 2015

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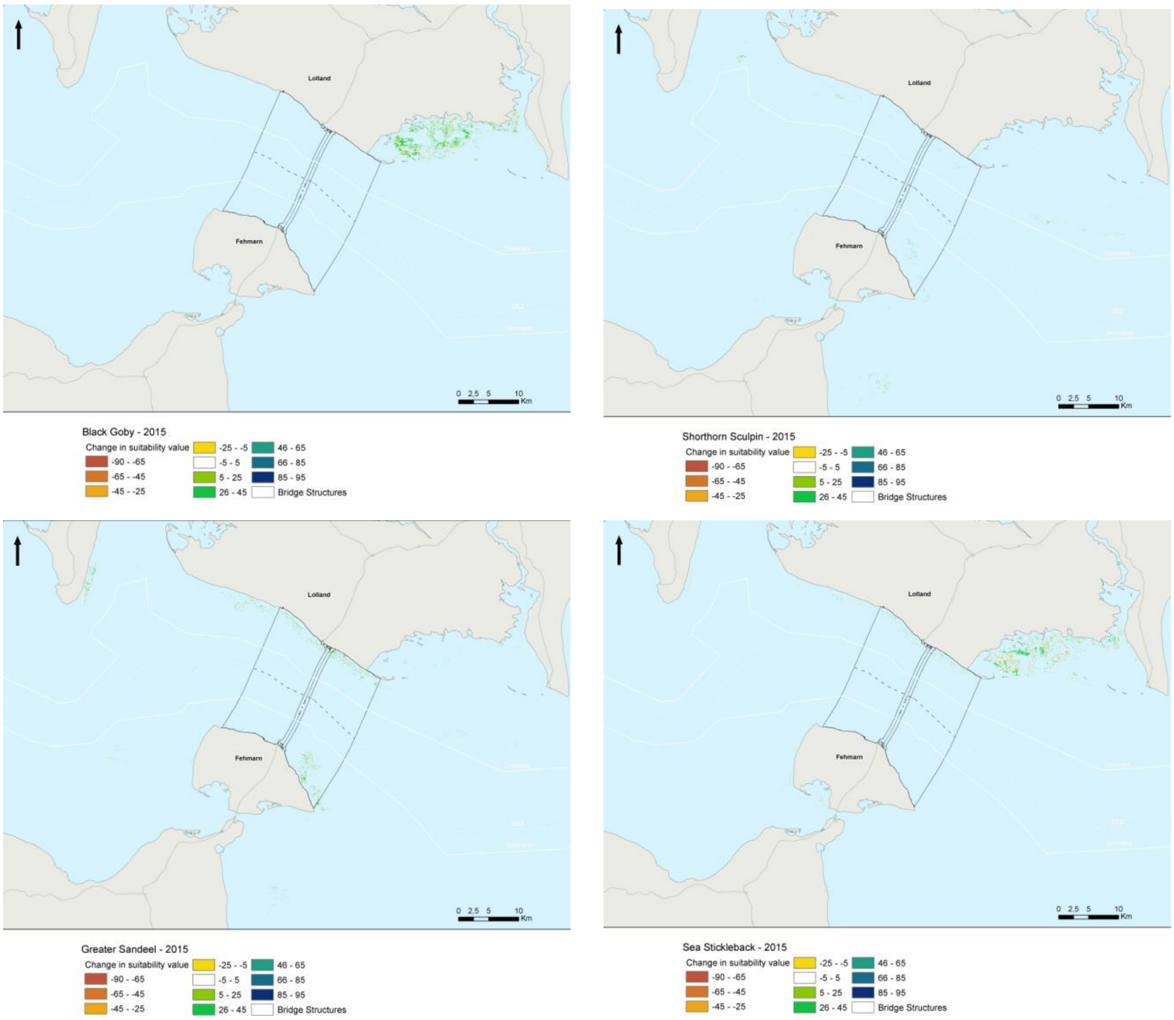

Figure 7.12: Changes in habitat suitability for cod (from left upper panel), whiting, flounder, dab, eelpout, goldsinny wrasse, black goby, shorthorn sculpin, great sandeel and sea stickleback in the shallow water fish community in Fehmarnbelt during the first year (2015) of construction of the bridge.

The habitat preferences differ between species and life stages and some species prefer sandy habitats whereas others prefer vegetated areas. However, fish does not seem to prefer habitats with 100 % cover of vegetation. The majority of the environmental components assessed are not affected by indirect pressures in relation to changes in benthic vegetation. Additionally, the habitat suitability for the majority of the shallow water fish community is not reduced. Minor reductions in the habitat suitability of eelpout are expected. Thus, this species is chosen as environmental indicator for the shallow water fish community in the assessment of indirect pressures as it is considered as worst case scenario.

The reduction of environmental components is estimated as the worst year during the construction phase (2015-2017) (Table 7.24-Table 7.25).

Table 7.24: The reduction of environmental components caused by indirect pressures (% and ha) from the construction of the main bridge solution in all areas investigation except Rødsand Lagoon.

Reduction of environmental components % (ha) Bridge Construction	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Nursery (<10 m)	0	0	0	0	0	0
Feeding (>5 m)	0	0	0	0	0	0
Whiting						
Nursery (>0 m)	0	0	0	0	0	0
Flatfish						
Nursery (<10 m)	0	0	0	0	0	0
Feeding (>0 m)	0	0	0	0	0	0
Shallow water species						
Spawning (<10 m)	0.05 (0.3)	0	0.11 (2.4)	0	0	0.32 (1.0)
Nursery (<10 m)	0.05 (0.3)	0	0.11 (2.4)	0	0	0.32 (1.0)
Feeding (<10 m)	0.05 (0.3)	0	0.11 (2.4)	0	0	0.32 (1.0)
Sea stickleback						
Spawning (habmap)	0	0	0.03 (0.2)	0	0	0
Nursery (")	0	0	0.03 (0.2)	0	0	0
Feeding (")	0	0	0.03 (0.2)	0	0	0

Table 7.25: The reduction of environmental components caused by indirect pressures (% and ha) from the construction (year 2015-2017) of the main bridge solution in Rødsand Lagoon.

Reduction of environmental components % (ha), Bridge Construction, Rødsand Lagoon	**2015**	**2016**	**2017**
Cod			
Nursery (<10 m)	0	0	0
Feeding (>5 m)	-	-	-
Whiting			
Nursery (>0 m)			
Flatfish			
Nursery (<10 m)	0.00 (0.0)	0.02 (0.1)	0.02 (0.1)
Feeding (>0 m)	0.00 (0.0)	0.02 (0.1)	0.02 (0.1)
Shallow water species			
Spawning (<10 m)	0	0	0
Nursery (<10 m)	0	0	0
Feeding (<10 m)	0	0	0
Sea stickleback			
Spawning (habmap)	0	0	0
Nursery (”)	0	0	0
Feeding (”)	0	0	0

The degree of the impairment caused by indirect pressures from the construction of the bridge in each area of investigation, except Rødsand Lagoon, on each indicator selected for the present assessment is presented in Table 7.26. The yearly degree of impairment in Rødsand Lagoon is presented in a separate table (Table 7.27). Overall the construction of a bridge has minor and almost insignificant impairment on environmental indicators relevant for indirect pressure.

Table 7.26: The degree of impairment caused by indirect pressures from the construction of the main bridge solution in all areas investigation except Rødsand Lagoon.

Degree of impairment of indirect pressure % (ha) Bridge Construction	DE 10 km Nat.	DE 10 km EEZ	DK 10 km	DE 500 m Nat.	DE 500 m EEZ	DK 500 m
Cod						
Nursery (<10 m)						
Feeding (>5 m)						
Whiting						
Nursery (>0 m)						
Flatfish						
Nursery (<10 m)						
Feeding (>0 m)						
Shallow water species						
Spawning (<10 m)	Minor		Minor			Minor
Nursery (<10 m)	Minor		Minor			Minor
Feeding (<10 m)	Minor		Minor			Minor
Sea stickleback						
Spawning (habmap)			Minor			
Nursery (")			Minor			
Feeding (")			Minor			

Table 7.27: The degree of impairment caused by indirect pressures from the construction (year 2015-2017) of the main bridge solution in Rødsand Lagoon.

Degree of impairment of indirect pressure, Bridge (%-ha), Rødsand Lagoon	2015	2016	2017
Cod			
Nursery (<10 m)			
Feeding (>5 m)	-	-	-
Whiting			
Nursery (>0 m)			
Flatfish			
Nursery (<10 m)	Minor	Minor	Minor
Feeding (>0 m)	Minor	Minor	Minor
Shallow water species			
Spawning (<10 m)			
Nursery (<10 m)			
Feeding (<10 m)			
Sea stickleback			
Spawning (habmap)			
Nursery (”)			
Feeding (”)			

7.5.3 Severity and significance

The severity of impairment of indirect pressure from the construction of the cable-stayed bridge solution is assessed to be very limited, insignificant and only minor for a few indicators selected for the present assessment (Table 7.28 and Table 7.29). There are therefore no indications of significant consequences among fish and fish communities of the dredging activities related to the construction.

When an area is recovered in regard to the indirect pressures the fish species will return to the habitat within short time. Thus the recovery time for fish species in Fehmarnbelt in relation to indirect pressures is estimated to be less than three years after the construction phase of a bridge is completed (Table 7.29).

Table 7.28: The severity of impairment caused by indirect pressures from the construction of the main bridge solution in all areas of investigation except Rødsand Lagoon.

Severity of impairment of indirect pressure % (ha) Bridge Construction	**DE 10 km Nat.**	**DE 10 km EEZ**	**DK 10 km**	**DE 500 m Nat.**	**DE 500 m EEZ**	**DK 500 m**
Cod						
Nursery (<10 m)						
Feeding (>5 m)						
Whiting						
Nursery (>0 m)						
Flatfish						
Nursery (<10 m)						
Feeding (>0 m)						
Shallow water species						
Spawning (<10 m)	Minor		Minor			Minor
Nursery (<10 m)	Minor		Minor			Minor
Feeding (<10 m)	Minor		Minor			Minor
Sea stickleback						
Spawning (habmap)			Minor			
Nursery (")			Minor			
Feeding (")			Minor			

Table 7.29: The severity of impairment caused by indirect pressures from the construction (year 2015-2017) of the main bridge solution in Rødsand Lagoon.

Severity of impairment of indirect pressure % (ha) Bridge Construction, Rødsand Lagoon	**2015**	**2016**	**2017**
Cod			
Nursery (<10 m)			
Feeding (>5 m)	-	-	-
Whiting			
Nursery (>0 m)			
Flatfish			
Nursery (<10 m)	Minor	Minor	Minor
Feeding (>0 m)	Minor	Minor	Minor
Shallow water species			
Spawning (<10 m)			
Nursery (<10 m)			
Feeding (<10 m)			
Sea stickleback			
Spawning (habmap)			
Nursery (”)			
Feeding (”)			

7.6 Cumulative and transboundary impacts

Cumulative pressures:

The existing projects and project plannings which, in summation, could cause significant impacts on fish are described in this chapter. According to Brandt et al. (2002), summation-effects occur if: "within a long period significant damage is caused collectively" and according to Planungsgruppe Ökologie und Umwelt (2004) if: "several projects are carried out in close spatial and temporal context" with respect to the environmental conditions. A project is relevant to consider if 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
- create new environmental impacts during the period from the environmental investigations were completed to the fixed link is in operation

Summation-effects are particularly relevant to adjacent projects like offshore wind farms. Projects, which already are implemented or projects that are far in the planning, are important to consider in a cumulative analysis. The projects which are relevant in relation to the bridge solution are listed in Table 7.30 and illustrated in Figure 7.13.

Table 7.30: Projects need to be considered for a cumulative analysis at this time.

Project	Placement	Phase	Possible interactions
Arkona-Becken Südost	North East of Rügen	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
EnBW Windpark Baltic 2	South East of Kriegers Flak	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
Wikinger	North East of Rügen	Construction	Sediment spill, habitat displacement, collision risk, barrier effect
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, barrier effect

Rødsand II is specifically included as this is a project that went into operation, while Femern A/S conducted the environmental investigations, whereby a cumulative effect in principle cannot be excluded.

Generally, projects are deselected if the project already was in operation, while the environmental investigations were carried out. In this case the environmental impacts are included in the environmental investigations, and are therefore the benchmark for the environmental assessment. Thus all the cumulative impacts in the environmental assessment of the fixed link are included.

During construction phase the majority of the cumulative impacts are expected to occur in relation to sediment flags and noise by ramming while working at the bridge pillars and working harbours. A physical injury of fish tissue by sedimentation is possible. Particularly the respiratory organs of pelagic fishes (gills) could be affected. However, the fish species are expected to demonstrate avoidance behaviour. Overall, the duration of these impacts are short but of great extent. According to FEHY (2013a) the degree of the sediment spillage is in small concentrations.

The current discussion on the assessment of the impact of ramming noise is based on the cumulative effects of many “ramming’s” that are required for each foundation of each bridge pillar. The breaks between every “ramming-hit” are very short and thus the degree of injury of the fish tissue is related to the number of noise events in a short period. Thomsen et al. (2006) assumed that “ramming” within short distances could lead to physical harm or injury of tissue of cod and herring. The natural behaviour of harmed fish is an escape reaction. The duration of this impact factor is short but may be of great extent. According to chapter 7.4 (noise and vibration) a minor impairment by noise is expected.

A barrier effect based upon the described impacts, sediment spill and noise extraction, is not expected.

The impacts caused by the bridge solution could be enhanced by the planned offshore wind farm “GEOFReE” close to the area of the fixed link (Figure 7.13) if the impacts appear within the same areas and the same period. In a worst-case-scenario large areas would be avoided by fish temporary because of the summation of impact factors. Foundation type and construction periods for these projects are not known.

Cumulative impact from noise emissions need to be assessed in case the construction periods of a bridge and wind farm are simultaneous. Cumulative impacts from “GEOFReE” will not occur, if the project not is built in the same period as the bridge. The operation of the wind farm is not considered to affect the population of fish stocks.

Cumulative impacts from extraction of raw material and planned wind farms at Kriegers Flak and Rønne Banke are not likely, since there will be approximately 15 km distance between the raw material extraction and windmills, 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 not likely that there will be an overlap in time between the projects.

During the operational phase, cumulative effects on fish are expected to occur in relation to the offshore wind farm “Rødsand II” (see Figure 7.13). The environmental assessment indicates that there is a possibility 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 southern 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.

No cumulative impacts are expected in relation to the operating offshore wind farms “Nysted”/“Rødsand II” and the planed wind farms “Arkona-Becken Südost “, “EnBW Windpark Baltic 2”, “Wikinger“ and “Kriegers Flak II” (distances are too large for cumulative effects).

In summary, with respect to the one wind farm project close to the alignment corridor of the cable-stayed bridge and with the assumption that all provisions are fulfilled during the construction and operation phase, no significant cumulative effects are expected to harm the fish communites in Fehmarnbelt.

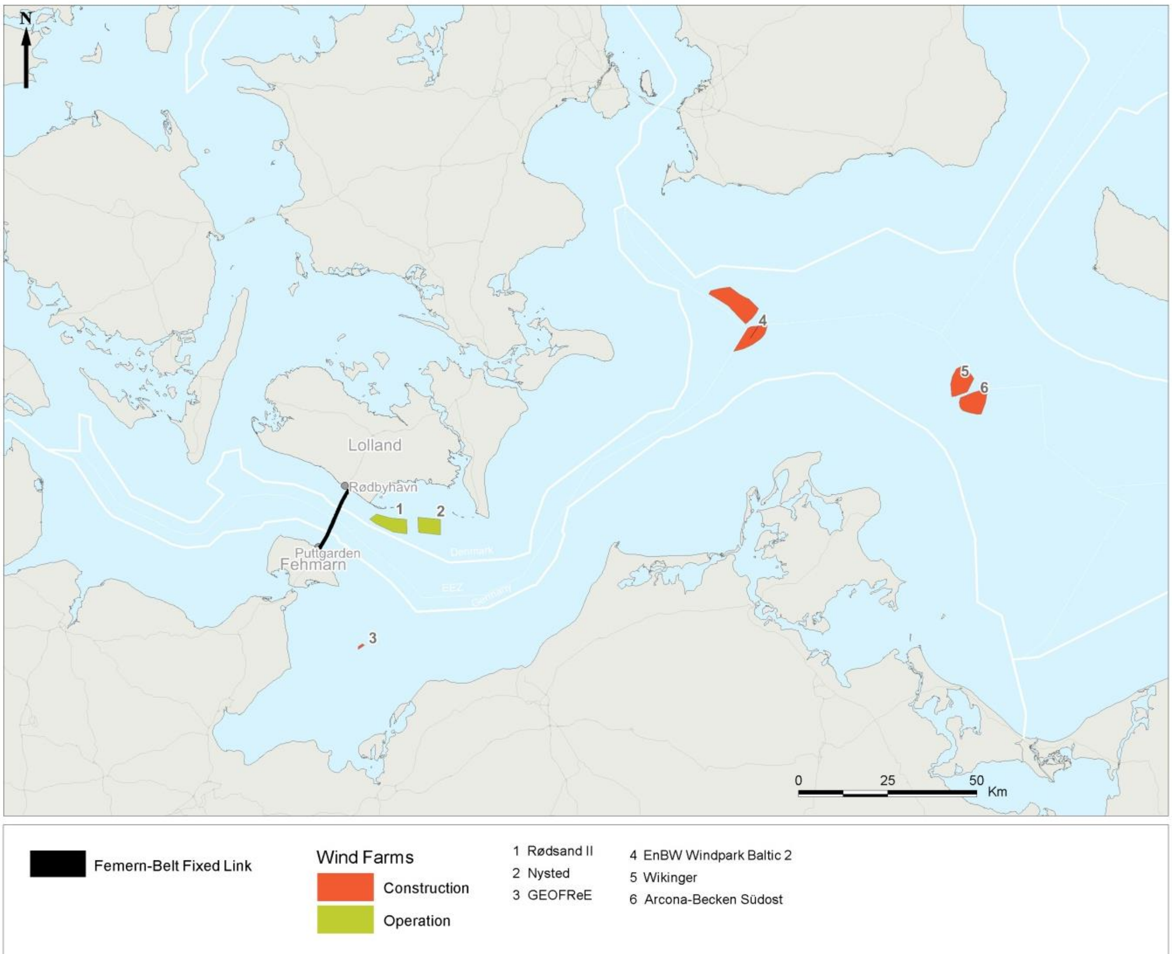

Figure 7.13: Overview of all projects in the Baltic Sea which can affect fish species and communities in the area of Fehmarnbelt by cumulative effects.

Transboundary pressure:
This chapter includes a summary of potential impacts of the project which can be transboundary. In accordance with the requirements of the Espoo Convention there should be differentiated between each of the affected States.

Transboundary effects at the operational phase of the cable-stayed bridge are of minor importance (noise emission, sediment spill and barrier effect are insignificant) and thus primary construction-related effects are relevant.

Table 7.31 gives an overview of the minimum distances of the fixed link project to the territorial waters of neighboring states.

Table 7.31: Overview of the minimum distances of the fixed link to the territorial waters of neighboring states.

Fixed link	Distance to Poland	Distance to Sweden
Bridge	226 km	135 km
Tunnel	226 km	135 km

Furthermore, the increased presence of working vessels might cause an accident on sea. This might result in drift of water polluting substances over long distances due to currents and wind/waves. Thus, there is a risk of a small emission of oil and other polluting substances used in vehicles and machines. Therefore, transboundary effects caused by accidents at sea might be of minor importance for fish stocks in the territorial waters of Poland or Sweden.

Direct impacts:
Direct transboundary environmental effects of the cable-stayed bridge to adjacent waters comprise mainly visual and acoustic effects during operation. Due to the large distance to neighboring states direct transboundary effects on fish in relation to noise are not expected. According to FEHY (2013a) the sediment spillage is of low intensity and duration and it is limited to short ranges during construction.

On Kriegers Flak and Rönne Bank it is planned to use these areas extraction of sand. According to (FEHY, 2011a; FEHY, 2011b) the sediment plumes and sediment deposition are of low intensity and within a narrow range. These effects are located in the vicinity of the extraction areas. The territorial waters of Sweden and Poland will not be affected by dredging in the sand extraction areas.

Indirect impacts:
During the construction phase of the bridge a barrier effect might be expected for anadromous fish species (Atlantic salmon and sea trout) and other migrating fish species (cod, herring, sprat). These species avoid areas with a high intensity of sediment plumes and noise (construction phase). Thus, the migratory fish species might not reach areas of high importance (spawning areas) in neighboring states. However, the impacts are of low intensity and extension, and therefore only minor transboundary effects are expected by indirect impacts.

Furthermore, a barrier effect can occur during the operational phase of the bridge caused by the bridge pillars (blocking migration routes) and the noise and vibration of the traffic on the bridge. However, the results from the accompanying operational monitoring of the “Øresund Bridge” did not show any negative impacts on the migratory behaviour of the spring spawning herring (Appelberg, et al., 2005). According to the authors the fluctuations of the spring spawning stock of herring were based on natural variations (by hydrology and climate-weather conditions), and an impact of the bridge could not be identified. Therefore, only minor transboundary effects on migrating fish species are expected during operational phase of the cable-stayed bridge.

7.7 Other pressures

Several other pressures related to the bridge scenario are possible.

- *Artificial light*
  The construction work at sea implies additional artificial light from operating vessels, and this work is expected 24 hours a day during the entire construction phase. During dark hours the working areas will be illuminated and the light will penetrate the sea surface. The bridge is not planned to be enlightened except for the pilons and this light is not expected to impact the fish fauna. Artificial light is known to influence the behaviour of fish as some are phototaxic (herring, mackerel and sprat) and others are photophobic (eel and salmon smolt).

  Less than 30% of the Baltic silver eel use Fehmarnbelt as a spawning migration route. Eel swim near the surface in night time during the spawning migrations out of the Danish seas towards the Sargasso Sea from October to December. As they are photophobic the artificial light could act as a barrier for the eel migration through Fehmarnbelt during the construction phase. However, the construction will not take place along the entire alignment at one time and the light will thus not act as barrier across Fehmarnbelt. Thus, the eel migration is not expected to be impaired by these lights.

  Overall, the impact from artificial light during the bridge construction is expected to be negligible.

- *Spill of hazardous materials*
  Accidental spill of hazardous materials from the operating vessels and spill of debree might occur, but this must be assumed only to occur in a small scale and it is not considered to have measurable impact on the fish fauna.

- *Deefrost liquids*
  In the operation of the bridge liquids used to secure the road lanes during winter might pollute the waters around, but the present current regime would undoubtedly dilute the pollution very quickly and no impact on the fish fauna is expected.

- *Barrier effect*
  A barrier effect might occur due to the bridge ramps. The ramps are not planned to exceed the present piers in the ferry harbours and a barrier effect from the ramps is not expected to impact the fish fauna. Furthermore, the key migrating fish species cod, herring, silver eel, whiting and sprat are all believed to prefer open waters when migrating through Fehmarnbelt.

7.8 Project impact

In the following sub-chapter, the results of project impacts analysis for all components and associated indicators are shown. These include the results of the impact analysis of all pressures existing during both the construction phase and the operation phase. It has to be noted that the project impact analysis includes only the results of severity-of-impairment analysis.

As no or minor impairment was determined for some species within the near zone and for all species in the local zone (see chapters below), the results of project impacts analysis for these species and for the local zone are not shown.

7.8.1 Cod

Construction phase
As none of the considered pressures exceed a minor impairment during the construction phase, no significant impairments for cod are expected for the cable-stayed bridge.

Operation phase
No or minor impairment for cod from all existing pressures during the operation phase is expected. Thus, the project impact during the operation phase is classified as overall minor. Due to seabed reclamation there is a small, but medium severe loss of cod nursery in the DE near zone and in the DK near zone.

Table 7.32: Project impact on cod related to the operation of the bridge.

Impairment DE-500 m (excl. EEZ) Bridge Operation	**Permanent seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Cod										
Spawning							Minor	High	Minor	
Egg-larvae drift							Minor	High	Minor	
Nursery							Minor	Medium	Minor	Medium
Feeding							Minor	Medium	Minor	
Migration							Minor	High	Minor	
Project severity									Minor	Medium

Impairment DK-500 m Bridge Operation	**Permanent seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Cod										
Spawning							Minor	High	Minor	
Egg-larvae drift							Minor	High	Minor	
Nursery							Minor	Medium	Minor	Medium
Feeding							Minor	Medium	Minor	
Migration							Minor	High	Minor	
Project severity									Minor	Medium

7.8.2 Whiting

As none of the considered pressures exceed a minor impairment during the construction phase as well as the operation phase, no significant impairments whiting are expected for the cable-stayed bridge.

7.8.3 Herring

As none of the considered pressures exceed a minor impairment during the construction phase as well as the operation phase, no significant impairments for herring are expected for the cable-stayed bridge.

7.8.4 Sprat

As none of the considered pressures exceed a minor impairment during the construction phase as well as the operation phase, no significant impairments for sprat are expected for the cable-stayed bridge.

7.8.5 Flatfish

Construction phase
As none of the considered pressures exceed a minor impairment during the construction phase, no significant impairments for flatfish are expected for the cable-stayed bridge.

Operation phase
No or minor impairment for flatfish from all existing pressures during the operation phase is expected. Thus, the project impact during the operation phase is classified as overall minor. Due to seabed reclamation there is a small, but medium severe loss of flatfish spawning, nursery and feeding areas in the DE near zone and in the DK near zone. In the DE near zone in the EEZ there is a medium severe loss of spawning and feeding areas.

Table 7.33: Project impact on flatfish related to the operation of the bridge

Impairment DE-500 m. (excl. EEZ) Bridge Operation	**Permanent seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Flatfish										
Spawning							Minor	Medium	Minor	Medium
Egg-larvae drift							Minor	Medium	Minor	
Nursery							Minor	Medium	Minor	Medium
Feeding							Minor	Medium	Minor	Medium
Migration							Minor	Minor	Insignif.	
Project severity									Minor	Medium

Impairment DE-500 m. EEZ Bridge Operation	**Permanent seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Flatfish										
Spawning							Minor	Medium	Minor	Medium
Egg-larvae drift							Minor	Medium	Minor	
Nursery							Minor	Medium	Minor	
Feeding							Minor	Medium	Minor	Medium
Migration							Minor	minor	Insignif.	
Project severity									Minor	Medium

Impairment DK-500 m. Bridge Operation	**Permanent seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Flatfish										
Spawning							Minor	Medium	Minor	Medium
Egg-larvae drift							Minor	Medium	Minor	
Nursery							Minor	Medium	Minor	Medium
Feeding							Minor	Medium	Minor	Medium
Migration							Minor	Minor	Insignif.	
Project severity									Minor	Medium

7.8.6 Shallow water species

As none of the considered pressures exceed a minor impairment during the construction phase as well as the operation phase, no significant impairments for shallow water species are expected for the cable-stayed bridge.

7.8.7 **Eel**

As none of the considered pressures exceed a minor impairment during the construction phase as well as the operation phase, no significant impairments for eel are expected for the cable-stayed bridge.

7.8.8 **Sea stickleback**

<u>Construction phase</u>

As shown in Table 7.34, only the pressure “temporary seabed reclamation” will lead to medium impairment of spawning, nursery and feeding for sea stickleback in the Danish national territory. For all other indicator and pressures, no or minor impairment for sea stickleback is expected. Thus, the project impact during the construction phase is classified as overall medium.

Table 7.34: Project impact on sea stickleback related to the construction of the bridge.

Impairment DK-500 m Bridge Construction	**Temporary seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Sea Stickleback										
Spawning							Medium	High	Medium	
Egg-larvae drift							Medium	not relevant	Insignif.	
Nursery							Medium	High	Medium	
Feeding							Medium	High	Medium	
Migration							Minor	not relevant	Insignif.	
Project severity									Medium	

<u>Operation phase</u>

No or minor impairment for sea stickleback from all existing pressures during the operation phase is expected. Thus, the project impact during the operation phase is classified as overall minor. Due to seabed reclamation there is a small, but highly severe loss of spawning, nursery and feeding areas in the DK near zone.

Table 7.35: Project impact on sea stickleback related to the operation of the bridge.

Impairment DK-500 m Bridge Construction	**Permanent seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Sea Stickleback										
Spawning								High	Insignif.	High
Egg-larvae drift								not relevant	Insignif.	High
Nursery								High	Insignif.	High
Feeding								High	Insignif.	High
Migration								not relevant	Insignif.	
Project severity									Insignif.	High

As project impact during the construction phase as well as the operation phase is assessed as medium or minor only, no significant impairments for sea stickleback are expected for the cable-stayed bridge.

7.8.9 Snake blenny

Construction phase

None of the considered pressures exceed a minor impairment during the construction phase.

Operation phase

No or minor impairments are expected for snake blenny from the assessed pressures during the operation phase. Due to seabed reclamation there is a small, but highly severe loss of snake blenny spawning, egg-and larvae drift, nursery and feeding areas in both German and Danish near zones.

Table 7.36: Project impact on snake blenny related to the operation of the bridge.

Impairment DE-500 m. (excl. EEZ) Bridge Operation	**Permanent seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Snake blenny										
Spawning							Minor	High	Minor	High
Egg-larvae drift							Minor	High	Minor	High
Nursery							Minor	High	Minor	High
Feeding							Minor	High	Minor	High
Project severity									Minor	High

Impairment DE-500 m. EEZ Bridge Operation	**Permanent seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Snake blenny										
Spawning							Minor	High	Minor	High
Egg-larvae drift							Minor	High	Minor	High
Nursery							Minor	High	Minor	High
Feeding							Minor	High	Minor	High
Project severity									Minor	High

Impairment DK-500 m. Bridge Operation	**Permanent seabed reclamation**	**Sediment spill**	**Noise and vibration**	**Hydrological changes**	**Other pressures**	**Indirect pressures**	**Project impairment**	**Importance**	**Severity of impairment**	**Severity of loss**
Snake blenny										
Spawning							Minor	High	Minor	High
Egg-larvae drift							Minor	High	Minor	High
Nursery							Minor	High	Minor	High
Feeding							Minor	High	Minor	High
Project severity									Minor	High

7.8.10 **Legally protected species**

As none of the considered pressures exceed a minor impairment during the construction phase as well as the operation phase, no significant impairments for all legally protected species are expected for the cable-stayed bridge.

8. Assessment of climate change impacts

8.1 Impact of predicted climate changes of main tunnel and main bridge alternative

8.1.1 Cod

Climate-driven changes in environmental conditions may influence cod populations directly (e.g. growth, distribution) and indirectly (e.g. changes in food and predators, and the drastic decline in the eastern Baltic cod stock since 1980s has been related to a climate-driven reduction in reproductive success in combination with increasing fishing pressure (Köster, et al., 2003b). World-wide, a large amount of knowledge has been gained concerning such effects (mainly temperature increase) and the impacts on cod populations.

Temperature change has been shown to influence the distributional range of a population (Drinkwater, 2005), spawning time (Kjesbu, et al., 2010), as well as spawning sites (Sundby, et al., 2008). On a smaller spatial scale, habitat preference and behavior are influenced (Schaber et al., 2009). Large-scale climate signals (here: NAO) have been linked to cod recruitment (Brander, 2005; Stige, et al., 2006)). The outcome of temperature increase on individual growth (Brander, 2010) or population growth (Mieszkowska, et al., 2009) is population-specific. Cod stocks living at the upper limit of their thermal tolerance range most probably experience decrease in growth and stock production rates (Bjornsson, et al., 2002). Temperature change has also geographical explicit effects on cod recruitment. Populations located further to the north of the distributional range will likely benefit from temperature increase, while the southernmost populations (like Baltic cod) probably will suffer (Mantzouni, et al., 2010; Drinkwater, 2005). However, repeated phases of temperature increase have not always produced the same signal in population growth rates (Drinkwater, 2009).

Indirect effects of climate change act by changing the trophic structure and have been reported as temperature-dependent changes in larval food supply (Walkusz, et al., 2011; Beaugrand, et al., 2003; Beaugrand, et al., 2010) or altered predation rates due to predator-prey overlap (Kempf, et al., 2009).

Due to the special hydrographic situation, climate change in the Baltic Sea poses some special challenges to cod. Contrary to other cod stocks, living in areas where salinities are sufficient to keep eggs buoyant in the surface layer, in the central Baltic cod eggs occur exclusively in the intermediate and bottom water, concentrating in a narrow depth range within or below the halocline (Kändler, 1944; Wieland, et al., 1997). Thus, the Baltic cod stock is subjected to a clear environmental influence on reproductive success during the egg stage based on oxygen conditions in the spawning basins (e.g. MacKenzie, et al. (1996)). Baltic cod eggs are also subject to predation as high abundances of eggs are found in a relatively restricted area where they are heavily preyed upon by herring and sprat (Köster, et al., 1997). The duration of the egg stages are temperature dependent (Wieland, et al., 1994) and changes in ambient temperature will therefore cause changes in predation mortality. A few days after hatch, the larvae begin vertical migration through the halocline into less saline, shallower water layers to feed (Grønkjær, et al., 1997). Here they are subject to climate-driven changes in food supply and transport rates.

Distributional range as well as spawning sites of the adult stock is largely fixed in the semi-enclosed Baltic Sea, as spawning is restricted to the deep basins. However, small-scale changes in habitat choice are likely to occur (Schaber, et al., 2009). Individual growth might be hampered, as consumption is decreasing with predicted decreases in mean ambient oxygen levels (Teschner, et al., 2011). If food supply for adults increases as a result of indirect climate effects, the amount and quality of eggs produced might increase (Kraus, et al., 2002). The seasonal timing of spawning can be influenced by either direct (Wieland, et al., 2000) or indirect effects (Tomkiewicz, et al., 2009).

Baltic cod eggs need a minimum of 2 ml/l oxygen for successful development (Nissling, et al., 1994; Wieland, et al., 1994). Further, a minimum salinity of 11 and 15 psu is needed for activation of spermatozoa and sub-sequent fertilisation of eggs of eastern and western Baltic cod, respectively. Declining salinities and oxygen concentrations under anticipated climate change will therefore cause increased egg mortality. Furthermore, it will indirectly increase egg predation by clupeid fish (Köster, et al., 2005) through stronger predator-prey overlap. Reduced egg developmental times under higher temperatures will probably not fully counteract this effect. Less frequent inflows of North Sea water will favour spawning of the eastern Baltic cod in the Bornholm Basin, due to frequent anoxic conditions in the spawning layer at the other spawning sites (e.g. Bagge, et al. (1994) and MacKenzie, et al. (2000)).

Cod larvae might increasingly suffer from food limitation, caused by the decline in abundance of their main prey (Voss, et al., 2003) the copepod *Pseudocalanus acuspes* (Köster, et al., 2005; Hinrichsen, et al., 2002), as the abundance of this oceanic copepod is strongly correlated with salinity levels (Möllmann, et al., 2003). On the other hand, rapid larval transport to the coast is beneficial for survival (Hinrichsen, et al., 2001; Voss, et al., 1999) and thus recruitment strength. As transport mainly is wind-driven, higher wind speed associated with climate change will benefit recruitment. Cod juveniles will probably experience lower food abundance and smaller areas suitable for settlement (Hinrichsen, et al., 2009).

In summary, climatic conditions in the past decade, as well as predicted climate changes are predominantly thought to be detrimental for Baltic cod recruitment strength and stock productivity, although some counteracting factors exist. Determining the relative contribution of overfishing and climate variability in causing the stock decline in the late 1980s is difficult (Figure 8.1; (Eero, et al., in press; Lindegren, et al., 2010b)). A healthy stock structure (Casini, et al., 2008; Ottersen, et al., 2006), sufficiently high stock size (Lindegren, et al., 2010a) and the implementation of an adaptive management system, taking climate change into account (Lindegren, et al., 2009; Lindegren, et al., 2010a), will help to reduce negative effects of climate change on Baltic cod.

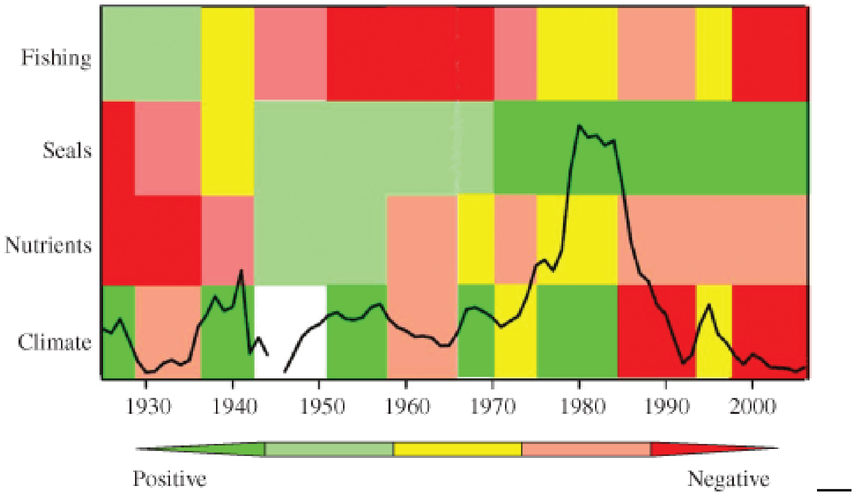

Figure 8.1: Factors affecting spawning stock biomass of eastern Baltic cod (solid line) from 1925 to 2006. The colors represent the influence (positive–negative) of different factors on cod biomass. Source: Eero et al. (2011).

8.1.2 Sprat

Baltic sprat is an ecologically important pelagic fish species (Rudstam, et al., 1994; Kornilovs, et al., 2001), being both a key prey species for top predators (e.g. cod and harbour porpoise) and predator on zooplankton and fish eggs (Arrhenius, et al., 1993; Bagge, et al., 1994; Köster, et al., 2003a). At present, sprat also represents the most abundant, commercially-exploited fish species in the Baltic Sea (ICES, 2010a). During the previous two decades, the management of Baltic sprat has been challenged by large stock fluctuations mainly caused by highly variable recruitment success. These recruitment fluctuations are not fully explained by sprat spawning stock biomass (Köster, et al., 2003b; MacKenzie, et al., 2004) but appear to be driven by a number of interacting environmental drivers. These environmental drivers are subject to climate change. Baltic sprat represents an example of a species occurring at the northern boundary of the geographical distribution (Muus, et al., 1999) and is therefore especially vulnerable to cold temperatures. Sprat is adapted to marine environments, thus low salinity and associated oxygen conditions in the brackish Baltic Sea also can be critical. Finally, variable transport of passively drifting of early life stages is important.

Baltic sprat stock productivity has been linked to large scale climate variability (North Atlantic Oscillation, NAO), suggesting that winter-time NAO is coupled to temperature conditions in the Baltic (MacKenzie, et al., 2004). Furthermore, temperature conditions have been shown to be positively correlated with recruitment strength. In recent years, more detailed, process-orientiated knowledge has been gained. This forms the basis to explore the effects of potential changes in climate-driven, environmental forcing on different sprat life stages.

The horizontal distribution of the adult stock component is variable between seasons and years (ICES, hydroacoustics). Only the far north-eastern part of the Baltic is in general avoided, due to extreme low salinity (Aro, 1989). Additionally, low temperatures as well as low oxygen levels limit the distributional range of adult sprat (Stepputtis, et al., 2011). Increasing river run-off, leading to lower salinities in the north-eastern Baltic, or decreasing oxygen conditions due to less frequent inflows of North Sea water will therefore diminish suitable sprat habitat distribution or change the relative horizontal distribution. Climate-driven temperature change will influence spawning time. Cold winters in the Baltic delay peak spawning (Grimm, et al., 1984; Karasiova, 2002), under climate change such events will most likely be less frequent. Stock reproductive potential is assumed to increase under increasing temperatures. This is due to anticipated better adult growth (Grauman, et al., 1989; Parmanne, et al., 1994) and condition, as higher temperatures are leading to higher abundance of suitable prey (Dippner, et al., 2000; Möllmann, et al., 2000). Furthermore, batch fecundity is positively correlated with food abundance in other small pelagics (Somarakis, et al., 2004; Ganias, 2009), as observed for Baltic sprat (Haslob H, IFM-GEOMAR Kiel, pers. comm.).

Survival of the eggs is influenced through climate change by (i) direct impacts on mortality and (ii) through changes in egg developmental time or egg buoyancy.

Direct impacts on egg mortality due to salinity levels are presently still difficult to assess. The salinity of water experienced during egg fertilisation might affect mortality in this life stage both directly, i.e. by setting a lower boundary for successful egg development, as well as indirectly, i.e. by influencing egg specific gravity and the depth of neutral buoyancy (Petereit, et al., 2009). Egg incubation salinity had no impact on the development rate of eggs and thus does not influence predation risk by changing the duration of the egg stage. Climate-induced changes in salinity will therefore only have limited impacts on egg survival (Petereit, et al., 2008).

Egg survival will be lower at oxygen concentrations of <2 ml/l (Nissling, et al., 2003). According to the seasonal changes in vertical distribution (Nissling, et al., 2003), eggs are in general more affected by potential low oxygen concentrations in spring. Using average conditions during peak spawning for a 30-year period (1970-2000) the relative importance of temperature and oxygen conditions was evaluated (Nissling, et al., 2003). Results suggested that variability in temperature was the most important abiotic factor affecting egg survival in the Bornholm Basin (ICES SD 25), that mainly oxygen conditions determine the survival rate in the Gotland Basin (ICES SD 28), whereas variation in both factors influenced survival in the Gdansk Deep (ICES SD 26).

Ambient temperature strongly influences the duration of the stages of sprat eggs with increasing temperature resulting in more rapid egg development rates. Besides this indirect influence on mortality, laboratory studies indicated a pronounced direct impact of temperature on egg mortality, with lower mortality at higher temperature (Thompson, et al., 1981; Nissling, 2004; Hinrichsen, et al., 2007). Temperature-recruitment correlations based on 30 years of observations confirmed the impact of water temperature during the egg stages on sprat recruitment. For depth-month combinations in which sprat eggs typically occur, significant and positive correlations were detected between temperature and recruitment (Baumann, et al., 2006b).

Strong positive correlations were observed between recruitment and temperature within surface waters during summer. This indicates a pronounced impact of temperature also on survival of larval/juvenile sprat that inhabit these water masses, presumably due to temperature-induced changes in growth rates (Baumann, et al., 2006c; Baumann, et al., 2006a). The relative importance of temperature for growth tends to decline with increasing fish size (Günther, 2008). However, temperature is inextinguishable linked to availability of food, and both factors simultaneously influence growth rates in the field. Availability of suitable food for sprat larvae and juveniles (Dickmann, et al., 2007) is likely to increase with temperature increase (Möllmann, et al., 2009). Only stronger, wind-driven transport rates might counteract the combined positive effects of increasing temperature and food availability under climate change. Increased transport to coastal areas is detrimental for recruitment success (Baumann, et al., 2006b). Most recent environmentally sensitive stock-recruitment models therefore include temperature and a transport index (Bottom depth anomaly BDA; (ICES, 2010c); Figure 8.2). Depending on relative change in these factors, long-term effects will be positive or negative.

Overall, present process understanding points to predominant positive effects of anticipated climate change on Baltic sprat stock dynamics and associated possible exploitation levels.

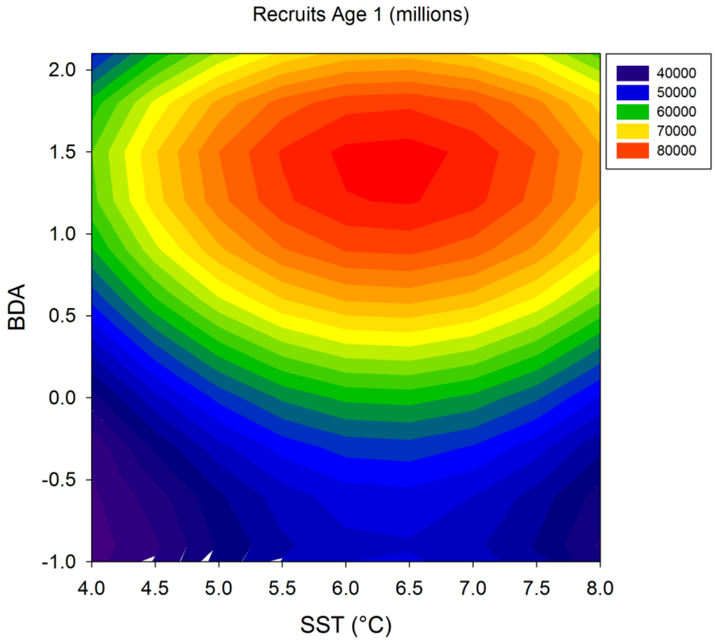

Figure 8.2: Sprat recruitment under climate change; number of recruits (age 1) in dependence of sea surface temperature in May (SST) and bottom depth anomaly (BDA, representing larval drift) for a fixed spawning stock biomass.

8.1.3 Herring

Herring is a key species in many temperate marine ecosystems (Blaxter, et al., 1982). As sprat, it forms a major link between top-predators (e.g. seals, cod) and zooplankton production (Casini, et al., 2004). In the Baltic Sea a number of distinct herring populations exist (ICES, 2007a), which are of considerable economic importance. Fisheries of nine bordering countries heavily exploit the herring stocks. According to their regional distribution, the stocks inhabit quite different local ecosystems, characterized by a large range in conditions concerning salinity, temperature and zooplankton community (ICES, 2008). Stock dynamics have been different due to variable exploitation rates and stock productivity. The by far largest stock unit, the central Baltic herring stock, has shown a pronounced decline in spawning stock biomass since the late 1970s (Cardinale, et al., 2009). The decline in biomass is at least partly explained by a strong decrease in weight-at-age (ICES, 2009). Contrary to the development of the central Baltic herring stock, the stocks in the Gulf of Riga and the Bothnian Sea herring showed an increase in SSB levels in the 1980s. Climate forcing seems to influence stock components in variable extend and in combination with other factors.

Herring stocks on the northern hemisphere are influenced in many ways by climate forcing: Changes in distribution patterns (Loeng, et al., 2007), including the loss of spawning sites (Graham, et al., 2009) have been reported in relation to increasing temperature. Migration patterns might change, leading to changes in energy transport rates from the ocean to coastal areas (Varpe, et al., 2005). Several studies address growth changes (positive as well as negative) in adult herring as a direct (temperature) or indirect (food) response to climatic changes (Rose, et al., 2008; Loeng, et al., 2007). Furthermore, recruitment success (e.g. Toresen, et al. (2000)) and the amount of skipped spawning (Engelhard, et al., 2006) have been identified to depend on temperature variability.

The Baltic Sea is among the best studied areas concerning the effect of environmental variability on herring recruitment and growth. (Axenrot, et al., 2003) established a link between the NAO as climatic index and Baltic herring recruitment. The importance of climatic signals for the production of the Gulf of Riga stock has been proven by (Kotta, et al., 2009). The influence of climate on recruitment of Baltic herring populations has recently been investigated by Cardinale, et al. (2009) and Margonski, et al. (2010). All recent developed stock-recruitment models including extrinsic factors significantly improved prediction ability (Margonski, et al., 2010). Climate impact was represented in the models as either Baltic-specific climate indices (Baltic Sea Index - BSI) or water temperature. Temperature increase generally had a positive effect on recruitment in all cases, where temperature was kept as a predictor in the final models (Cardinale, et al., 2009). However, stocks react differently and different sets of predictors have to be used.

Growth of Baltic herring has been shown to depend on climate forcing both direct as well as indirect. Möllmann, et al. (2005) postulated that herring growth depend on food abundance and sprat biomass. The direct effect of salinity, in combination with an indirect effect of sprat competition (where sprat stock levels are likely to be influenced by climate), has been demonstrated by Casini, et al. (2010). They show that growth of central Baltic herring (condition and weight-at-age) has shifted from being mainly driven by hydro-climatic forces (i.e. salinity) to an inter-specific density-dependent control. This shift in control is triggered by sprat abundance (acting as competitor).

The overall effect of projected climate change on Baltic herring stocks is hard to evaluate. Most probably the stocks will react in different ways – some might increase in stock production, abundance and fishing potential, other might decrease. In any case, the fate of the Baltic herring stocks seems closely linked to the stock dynamics of cod and sprat.

8.1.4 Species interaction

The central Baltic Sea can be described as a relatively simple ecosystem in terms of biodiversity of the higher trophic levels, i.e. the fish stocks. There is only one dominating piscivour, i.e. cod and two important planktivours, i.e. herring and sprat. However, even this rather simple system gains complexity, as numerous interactions between the different life stages exist (Figure 8.3). Adult cod prey on adult sprat and juvenile herring, but are also cannibalistic (the degree is depending on stock size and spatial overlap of age-classes). Adults of herring and sprat prey on cod eggs. Sprats are feeding on sprat eggs, i.e. are cannibalistic. Herring and sprat show food competition and adult sprat are able to exert top-down control on *Pseudocalanus acuspes*, the most important prey for cod larvae. In summary, the stock dynamics of all three species are closely linked and climate effects on one species will almost certainly also impact the other species.

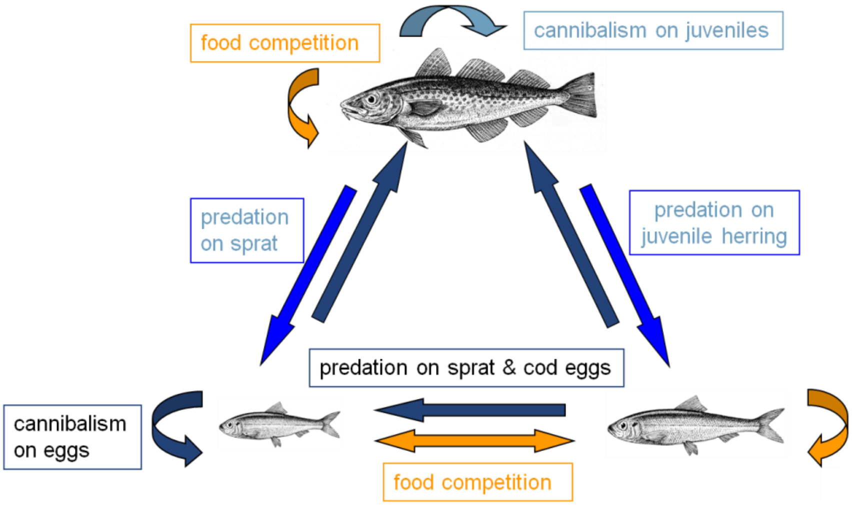

Figure 8.3: Simplified schematic diagram showing intra- and inter-specific relations between Baltic cod, herring and sprat. Source: Schnack (2003).

Further details on climate change and fish in Fehmarnbelt can be found in the FeBEC (2013).

9. Comparison of bridge and tunnel main alternatives

The project impact of the tunnel and the bridge is compared in Table 9.1. Overall only insignificant or minor impacts are expected outside the near zone for both solutions. In the near zone most impacts are expected due to footprints, where seabed reclamation in both German and Danish shallow waters reduces nursery grounds for cod and flatfish as well as habitats of shallow water species, including the protected sea stickleback. In deeper waters footprints are also expected to impact the protected snake blenny. During the construction phase cod, flatfish and snake blenny are expected to be medium impacted in the tunnel solution while only sea stickleback is impacted in the bridge solution. During operation only cod is expected to be impacted in the tunnel solution due to the physical structures in the Danish near zone.

Table 9.1: Project impact on specific components from the construction, operation and structures of the main tunnel and a bridge solution.

Severity of impairment/loss	**Tunnel**			**Bridge**		
	Construction	Operation	Footprints	Construction	Operation	Footprints
DE 10 km National						
Cod	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Whiting	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Herring	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European sprat	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Flatfish	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Shallow water species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European eel	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Sea stickleback	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Snake blenny	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Protected species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
DE 10 km EEZ						
Cod	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Whiting	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Herring	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European sprat	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Flatfish	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Shallow water species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European eel	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Sea stickleback	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Snake blenny	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Protected species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
DK 10 km						
Cod	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Whiting	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Herring	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European sprat	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Flatfish	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Shallow water species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European eel	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Sea stickleback	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Snake blenny	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Protected species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
DE 500 m National						
Cod	Medium	Minor	Medium	Minor	Minor	Medium
Whiting	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Herring	Minor	Minor	Minor	Minor	Minor	Minor

European sprat	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Flatfish	Medium	Minor	Medium	Minor	Minor	Medium
Shallow water species	Minor	Minor	Medium	Minor	Minor	Medium
European eel	Minor	Minor	Minor	Minor	Minor	Minor
Sea stickleback	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Snake blenny	Medium	Minor	Insignif.	Minor	Minor	High
Protected species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
DE 500 m EEZ						
Cod	Medium	Minor	Insignif.	Minor	Minor	Insignif.
Whiting	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Herring	Minor	Minor	Insignif.	Minor	Minor	Minor
European sprat	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Flatfish	Medium	Minor	Insignif.	Minor	Minor	Medium
Shallow water species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
European eel	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Sea stickleback	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Snake blenny	Medium	Minor	Insignif.	Minor	Minor	High
Protected species	Minor	Minor	Insignif.	Minor	Minor	Insignif.
DK 500 m						
Cod	Medium	Medium	Medium	Minor	Minor	Medium
Whiting	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Herring	Minor	Minor	Minor	Minor	Minor	Minor
European sprat	Minor	Minor	Insignif.	Minor	Minor	Insignif.
Flatfish	Medium	Minor	Medium	Minor	Minor	Medium
Shallow water species	Minor	Minor	Medium	Minor	Minor	Medium
European eel	Minor	Minor	Minor	Minor	Minor	Minor
Sea stickleback	Minor	Minor	High	Medium	Minor	High
Snake blenny	Medium	Minor	Insignif.	Minor	Minor	High
Protected species	Minor	Minor	Insignif.	Minor	Minor	Insignif.

The purpose of the comparison of tunnel and bridge is to find out which of the two alternatives are preferable in relation to the impacts on the fish communities in Fehmarnbelt and adjacent areas. The comparison is based on the assessment results of the relevant pressures in terms of the affected areas and the severity of impacts. The main comparison of the relevant pressures on fish communities is shown in Table 9.2.

Table 9.2: Comparison of the main alternatives - tunnel and bridge. ++ = clear advantage, + = advantage.

Pressure	**Tunnel**	**Bridge**	**Preferred alternative**
Hydrological changes	0	0	
Seabed reclamation		+	Bridge
Sediment spill	0	0	
Noise and vibration	0	0	
Indirect pressure	0	0	
Summary		**(+)**	**Bridge**

In general, the hydrographic regime and the background levels of suspended sediment, noise and vibration in the zero-alternative constitutes more severe pressures to fish than the expected pressures from the construction and operation of either tunnel or bridge solution. With respect to noise and vibration the existing heavy traffic of the Rødby-Puttgarden ferries produce considerable more noise than the expected noise from both solutions. The establishment of a link would presumably even reduce the noise level in Fehmarnbelt if the ferry service stops.

10. Decommissioning

The suspension bridge is planned to be decommissioned in year 2140 after 120 years of operation. In principle there is a decommissioning plan for all main structures of the bridge. For the marine environment all structures are planned to be removed apart from the pile inclusions structures beneath the seabed.

It is considered that the dismantling of the superstructures will take place at sea and eventually transported to the shore for further dismantling. The pillars and piers are all broken down on site and the pieces are transported to the shore. The pillar caissons are all transported to the shore after deballasting and re-floating. The pier caissons are also transported to the shore after removal of ballast material and scour protection.

Considering dismantling techniques as they are know today, impairment towards fish is expected to be related to activities producing noise at frequencies sensitive for fish. However, based on today’s dismantling techniques the degree of impairment is considered as minor or negligible.

11. Mitigation

A mitigation plan can outline construction and operation related measures that could reduce the potential impact from the individual fixed link alternatives. Specific actions related to the specific pressures could involve modifications of the design of the structure of the link or to the construction strategy with respect to choice of gear, deposition sites, temporary working access channels or working harbours, time schedules etc. Seasonality among many fish species regarding for example spawning time and migration could call for mitigating time schedules concerning for example dredging and piling activities.

However, the results from the environmental assessment of impacts from the establishment of both link alternatives identified mainly pressures related to reclamation of seabed areas in the near zone of the alignment. Among other potential pressures, only a medium impairment on herring egg- and larvae survival are expected from sediment spill in the near zone of the tunnel alignment, and concerning noise, only a continuous ferry service are expected to impact migration. Impacts from pressures such as hydrographical changes, light, electromagnetic fields and contaminants are considered very low or nonexistent and therefore not relevant in relation to mitigation measures. This also applies to indirect impacts caused by impairments of suitable habitats and food resources of fish.

No mitigation is considered necessary for neither the bridge nor the tunnel solution.

12. Inadequate data acquisition and knowledge gaps

12.1 Tunnel alternative

12.1.1 Noise and vibrations

The noise scenarios regarding the construction of the harbours on Lolland and Fehmarn were obtained from literature values rather than informations on the specific machinery planed to be applied, as no detailed information was avaible. Furthermore, the presens of dikes surroundding the working area complicates the predictions of noise emmited to the waters outside the dikes from the planned pile ramming and steelsheet ramming.

The noise and vibration emmited during operation of the tunnel was predicted from measurements done at the Øresund Tunnel. Only sound frequencies higher than 50 Hz were measured efficiently as the low frequent vibrations measured on top of the tunnel was impacted by the setup.

12.2 Bridge alternative

12.2.1 Noise and vibrations

The noise scenarios regarding the construction of the bridge were obtained from the predicted scenarios from the tunnel construction as no accurate informations were available on the schedule and type of machinery related to the drilling, dredging, backfilling and ramming activities and on the ship traffic related to the construction activities. Furthermore, no detailed information was available on the construction of the harbours related to the construction activities.

13. References

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14. Table of figures

15. List of tables