ENERGINET - MARINE ENVIRONMENTAL STUDIES

Hesselø – Fish populations and habitats

Energinet Eltransmission A/S

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Objective:

The objective of this report is to describe and map the fish resources in the planned Hesselø offshore wind farm area and export cable route in the Kattegat. An assessment has also been conducted on the potential impacts of developing an offshore wind farm on different species, based on their presence and sensitivity.

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1 SUMMARY

To accelerate Danish offshore wind production, the 2022 Finance Act and the Climate Agreement 2022 committed to offering an additional 6 GW of offshore wind capacity by the end of 2030. A political agreement on May 30, 2023, expanded this framework, potentially increasing capacity to 14 GW or more. The Danish Energy Agency has planned offshore wind farms (OWF) in the North Sea, Kattegat, and Baltic Sea to meet these goals.

This study is a desktop review, compiling relevant public data to describe the baseline conditions for fish species, populations, and habitats within the planned Hesselø OWF area, including the export cable route. The report also summarizes the main potential impacts of a general OWF development on relevant fish species.

Future project specific environmental impact assessments can be based on this baseline report, so that specific fish surveys do not need to be undertaken in the Hesselø OWF area and export cable route.

The Hesselø OWF will potentially cover an area of 166 km² off the coast of Zealand and connect to land via a subsea export cable making landfall at Gilbjerg Hoved on the north coast of Zealand. Key fish species in the planned Hesselø OWF and export cable route area include dab, plaice, cod, whiting, greater weever, sprat and herring. The demersal fish community in the soft bottom habitats are dominated by a variety of flatfish species with dab and plaice being the most abundant. The pelagic species sprat and herring are common in the early part of the year and much less abundant in the autumn.

There are no known spawning areas within the planned Hesselø OWF area. However, the soft bottom area within the OWF area and outer export cable corridor is used as nursery areas for dab, plaice and whiting. Close to the coast of the northern Zealand, particularly near Hornbæk Bay and Gilleleje, there may be a small local population of autumn spawning herring. Protected species in the Hesselø OWF area include cod, whiting, trout, and Atlantic salmon among others. Invasive species like the round goby are spreading and impacting local ecosystems.

Fish species vary in their sensitivity to noise, with species such as herring being highly sensitive, and cod and eel being moderate sensitive to underwater noise. Construction noise, especially pile driving, can impact fish, with reactions depending on proximity and species. High noise levels can cause temporary hearing damage and affect behaviours like reproduction and communication. Subsea cables may generate electromagnetic fields (EMF) that can affect fish orientation, behaviour, and distribution of fish, particularly species like salmonids, flatfish, and eels, which use the Earth's magnetic field for migration. Seabed infrastructure can disturb demersal fish but also create new habitats that serve as artificial reefs that attract species like cod and whiting. These structures can provide nursery, shelter, and spawning areas for fish, though changes in sediment caused by construction can negatively affect species like sandeel and flatfish that rely on specific sediment types for burying, spawning, and juvenile development. Changes in sediment conditions may also impact the spawning success of fish that lay eggs on the seabed or vegetation, such as herring. Fish can tolerate natural suspended sediment to varying degrees, but extremely high levels can be harmful, particularly to eggs, larvae, and pelagic species. Sediment can hinder oxygen uptake, cause eggs to sink, and impair feeding in larvae. Demersal species, like flatfish, are more tolerant to suspended sediments but may still experience negative effects at very high concentrations.

1.1 Abbreviations

Abbreviation	Explanation
EIA	Environmental Impact Assessment
EMF	Electromagnetic field
GPS	Global Positioning System
GW	Giga watt
HELCOM	Helsinki Commission, Baltic Marine Environment Protection Commission
ICES	International Council for the Exploration of the Sea
Landfall	Is where the cable transfers from sea to land
OWF	Offshore Wind Farm

2 INTRODUCTION

To accelerate the expansion of Danish offshore wind production, it was decided with the agreement on the Finance Act for 2022 to offer an additional 2 GW of offshore wind for establishment before the end of 2030. In addition, the parties behind the Climate Agreement on Green Power and Heat 2022 of 25 June 2022 (hereinafter Climate Agreement 2022) decided, that areas that can accommodate an additional 4 GW of offshore wind must be offered for establishment before the end of 2030. Most recently, a political agreement was concluded on 30 May 2023, which establishes the framework for the Climate Agreement 2022 with the development of 9 GW of offshore wind, which potentially can be increased to 14 GW or more if the concession winners – i.e. the tenderers who will set up the offshore wind turbines – use the freedom included in the agreement to establish capacity in addition to the tendered minimum capacity of 1 GW per tendered area.

To enable the realization of the political agreements on significantly more energy production from offshore wind before the end of 2030, the Danish Energy Agency has drawn up a plan for the establishment of offshore wind farms in three areas in the North Sea, the Kattegat, and the Baltic Sea respectively.

The planned Hesselø OWF will be located in Kattegat approximately 30 km north of Gilbjerg Hoved on the north coast of Zealand. The area for the Hesselø OWF is approximately 166 km^2 and will be connected to land via a subsea cable making landfall of the north coast of Zealand (Figure 2-1, Table 2-1).

The objective of this report is to describe and map the baseline conditions for fish species, populations, and habitats within the planned OWF area, Hesselø. Given the variability of fish stocks across space and time, this mapping includes the review of fish species and populations present in the broader Kattegat region, as well as specifically within the planned Hesselø OWF area, including export cable route.

This study is a desktop review, compiling data provided by Energinet, publicly available sources, research articles, and previous field-specific studies in the Kattegat, particularly focused on the Hesselø OWF area. The collected information provides an overview of fish species and populations in these regions, encompassing both commercial and non-commercial species. Additionally, it includes details on potential spawning and recruitment areas, as well as information on protected and invasive species. A review of knowledge about potential impacts of OWF on fish species and populations has also been conducted, i.e. it is not related to the specific Hesselø OWF project.

The report will form part of the basis for the Environmental Impact Assessment (EIA) to be undertaken by the future Concessionaire, enabling them to assess the project's potential impact on fish and if required plan appropriate mitigation measures.

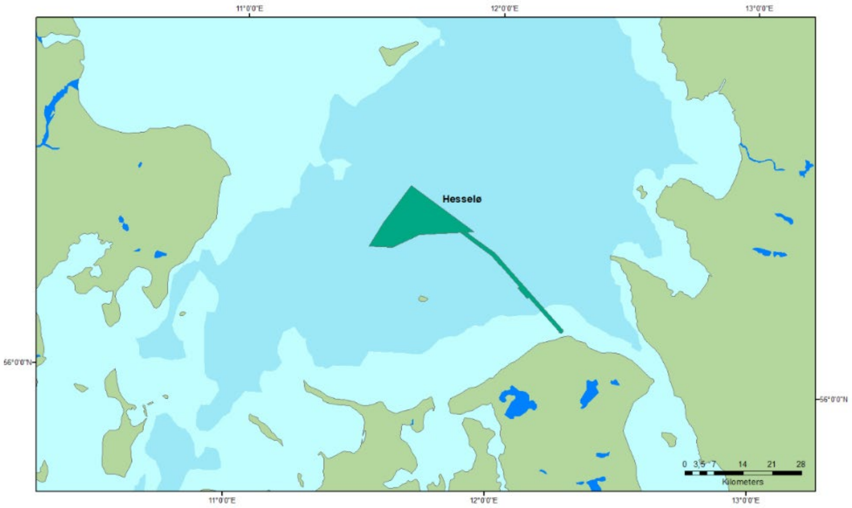

Figure 2-1. Hesselø planned offshore wind farm area and export cable route. Source: Energinet, 2023.

Table 2-1. Overview of Hesselø offshore wind farm area and export cable corridor. Source: Energinet, 2022.

Offshore wind farm area	Area (km^2)	Water depths (m)	Export cable corridor	Shortest distance to shore (km)
Hesselø	166	10-40	North coast of Zealand	30

2.1 Original Hesselø OWF area

The Hesselø OWF area was originally planned to be located further north in the Kattegat Sea (Figure 2-2). However, the original site was relocated based on preliminary seabed surveys that identified soft clay bottom in large parts of the designated site, especially in the northern and western part of the area (DCE & NIRAS, 2022). In the following, the original planned location for the Hesselø OWF area will be referred to as the “original” Hesselø OWF area. The Gilleleje export cable corridor that was investigated during the planning of the original Hesselø OWF area overlaps with the new planned export cable route.

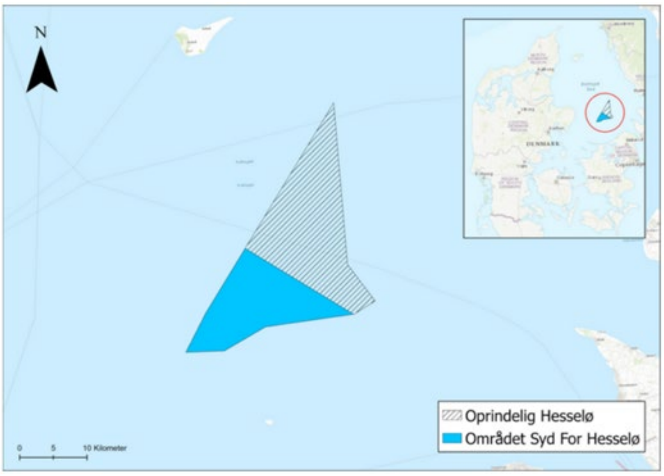

Figure 2-2. Original (shaded area) and new location (blue) for the Hesselø offshore wind farm area. Source: Energinet.

2.2 Baseline sources

Information on fish resources in the Hesselø OWF area has been gathered from previous studies conducted on behalf of the Danish authorities, studies from OWF developers, and research data from organizations such as ICES and HELCOM. Some of these studies are listed below. Please refer to the reference list for additional information.

- Hesselø Offshore Wind Farm – Fish, technical report on behalf of Energinet. NIRAS, 2022.
- Update of part of detailed screening from 2020 and new detailed screening of new areas for Offshore Wind development. COWI, 2022.
- Research information (references in text).
- ICES & HELCOM

3 FISH HABITAT

The Kattegat and the coastal region along the northern coast of Zealand is a marine area in a transition zone between the North Sea and Baltic Sea and can be characterized by being in an environmental gradient between the fully marine North Sea and the brackish Baltic Sea. An area as diversified as the Kattegat contains many different fish habitats and fish species

Fish stocks can be categorized into two groups: 1) pelagic species, which are found in the water column, such as herring, trout, and garfish; and 2) demersal species, which live on or near the seabed, such as cod, flounders, and eel. The type of seabed is crucial for the distribution of most fish species and is essential for the reproduction of many species, as their eggs are often deposited on the bottom or bottom vegetation, where larvae and fry subsequently grow. The presence of pelagic fish also depends on hydrographic conditions such as water currents, temperature, and salinity. Additionally, the immediate availability of prey influences the presence of pelagic fish in an area. In the following the hydrography and the seabed conditions in and around the Hesselø OWF area are described.

3.1 Hydrography

In Kattegat, there is a mixing of the brackish water of the Baltic Sea and salt water of the North Sea. Depending on outflow and inflow events and their extent, the salinity can vary considerably and there is typically a stratification with more salty bottom water, which is most clear during summer. The biological diversity is strongly regulated by the salinity, but also light (depth), water flow, and oxygen are conditions that may affect both the diversity and the density of the individual organisms.

The depths in the planned Hesselø OWF area range from 10- 40 m (Table 2-1). The hydrography of the water column in the original planned Hesselø OWF area was permanently stratified with a halocline situated at about 15 meters depth separating a bottom water mass of high saline water originating from the Skagerrak/North Sea from the brackish less saline surface water layer that represents a mix of Baltic water and more saline bottom water (NIRAS, 2022). Bottom salinity was approximately 30 ppt or above while the surface salinity was approximately 20 ppt; however, with considerably more temporal variation than the bottom water. Oxygen conditions were generally good and oxygen depletion events occurred only rarely in the original Hesselø OWF area. Figure 3-1 and Figure 3-2 shows the currents and average current speed in the Kattegat and specifically for the Hesselø OWF area.

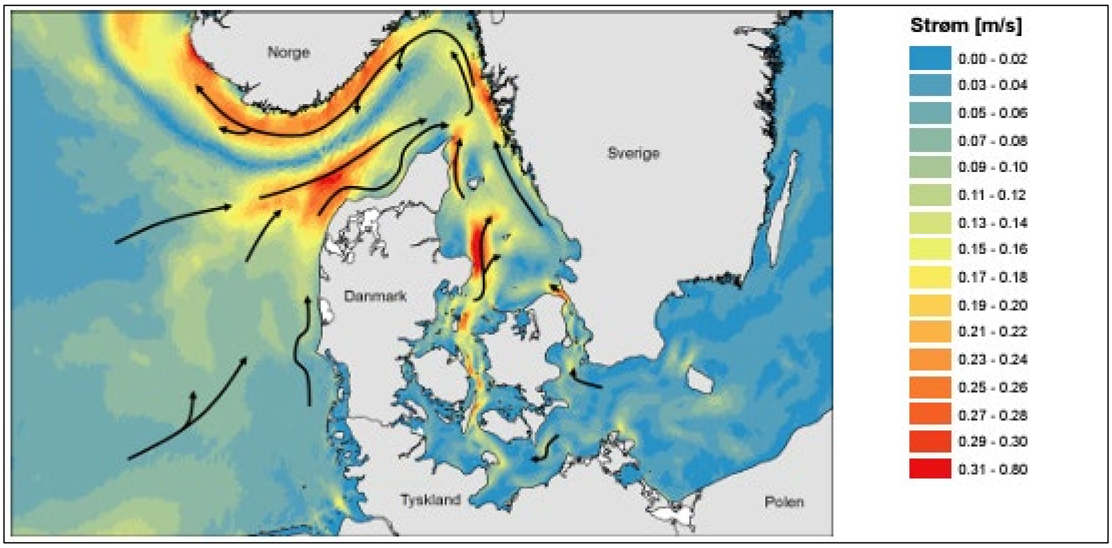

Figure 3-1. Currents and average current velocity in the Kattegat, 2013 -2016. Source: DHI, 2017 in Miljø- og Fødevareministeriet, 2019.

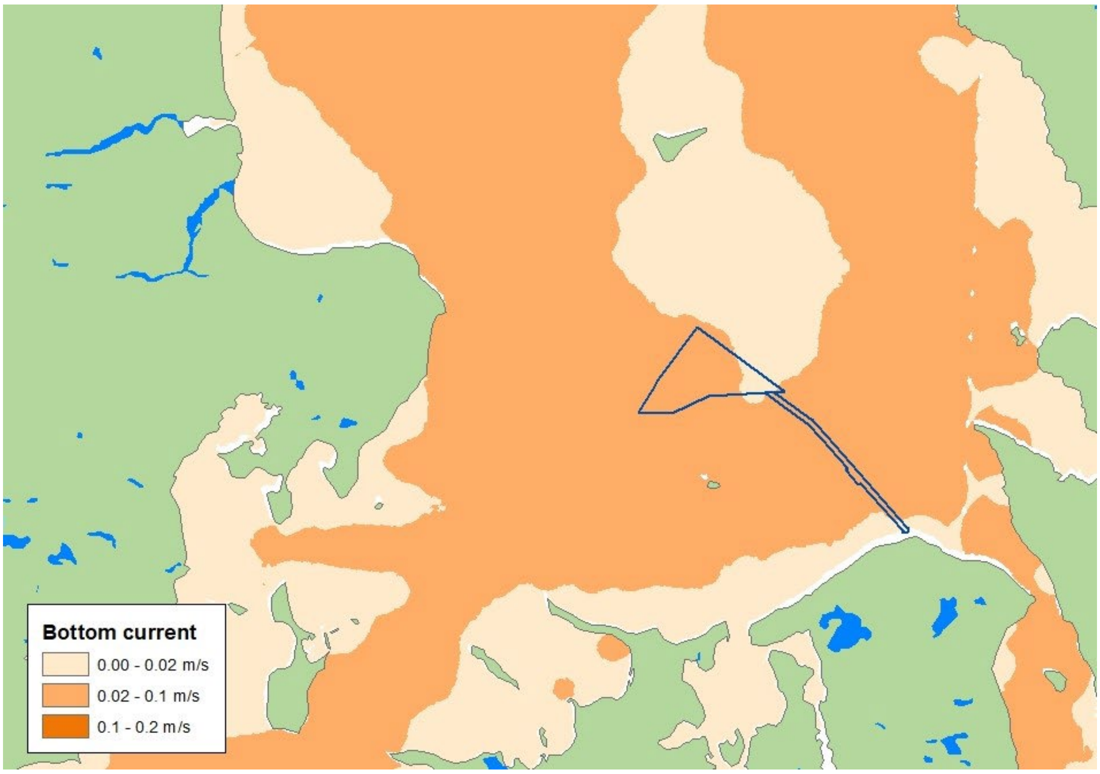

Figure 3-2. Annual mean bottom current velocity in the Hesselø OWF area. Source: The Danish Spatial and Environmental Planning Agency, 2007.

3.2 Marine substrate

A larger part of the seabed in the Hesselø OWF area consists of sand (Figure 3-3). In the central and southern part of the area the seabed consists of gravel and coarse sand, with till/diamicton (contains particles ranging in size from clay to boulders) and stones in the central part of the area. A channel structure consisting of muddy sand runs through the area with a north-south orientation. The export cable corridor passes through an area of sand, muddy sand, till/diamicton and gravel and coarse sand. Landfall is planned at the north coast of Zealand, where the coast alternates between sandy beaches and rocky coast (COWI, 2022).

Flatfish are typically found on sandy bottoms, which are crucial for their ability to hide by covering themselves or burrowing into the sand. This is also important for sandeel, which burrow at night and during long periods in winter. The more varied seabed closer to the coast create a variety of habitats, often leading to high fish species diversity. For instance, common gobies (*Gobiidae* spp.), juvenile plaice and flounder are likely abundant in these mixed habitats.

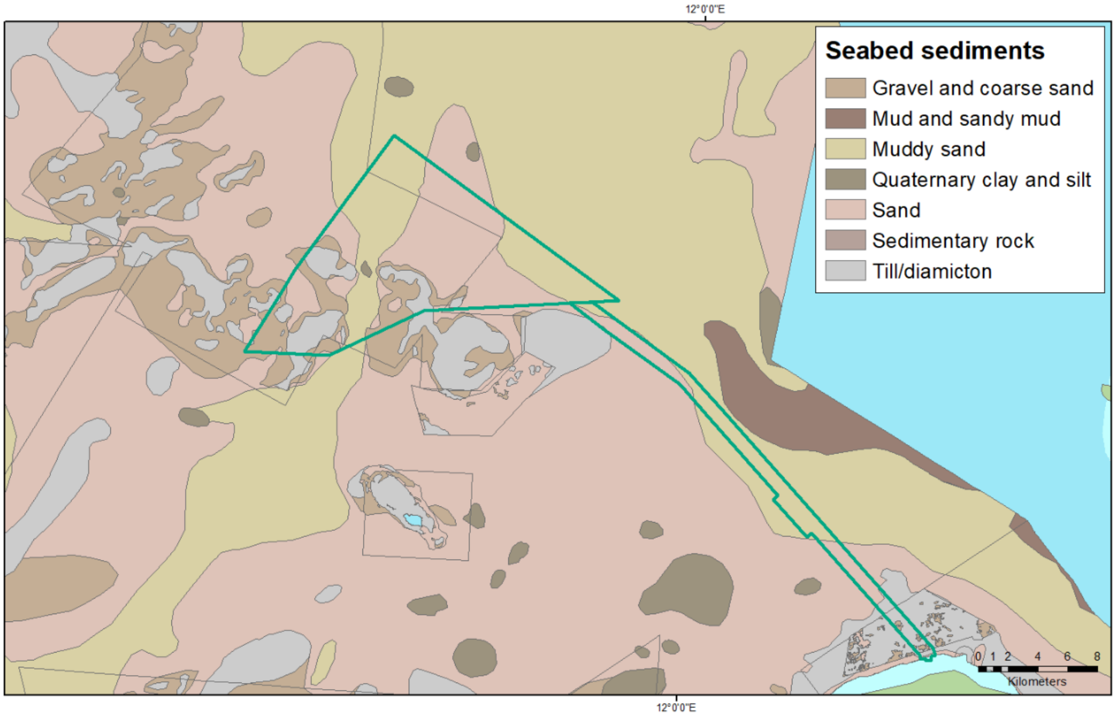

Figure 3-3. Seabed sediments in the Hesselø OWF area and export cable corridor. Source: GEUS, 2023.

4 FISH POPULATIONS

A technical report of the original Hesselø OWF presents information on the fish species and fish communities in the OWF area and export cables (NIRAS, 2022). Empirical data of fish in the planned area was acquired from fish surveys, which included two trawl surveys (one in the spring and one in the autumn) in soft bottom areas (14 trawl tracks, 0,8 – 1,5 km each) and a gillnet fish survey undertaken in the autumn in the coastal hard bottom areas in eight stations in the export cable corridor. This data was supplemented with available information from other existing sources (DTU-Aqua fish studies, ICES data, HELCOM database and the Fish Atlas project) to form a baseline description of the fish communities present in the seabed habitats within the original Hesselø OWF area and export cable route.

The results from the fish surveys registered 27 fish species during spring and 26 fish species during autumn (Table 4-1). Key species were dab, plaice, cod, whiting, greater weever, sprat and herring. General distribution, preferred habitat and biology of these key species are briefly described in Chapter 4.4.

A description of the demersal and pelagic fish species found in the fish surveys in the original Hesselø OWF area are presented in the following.

Table 4-1. Fish species caught in spring and autumn bottom trawl fish survey in the original planned Hesselø OWF area. Source: NIRAS, 2022.

Spring bottom trawl fish survey	Autumn bottom trawl fish survey
Blue whiting - *Micromesistius poutassou*	Hooknose- *Agonus cataphractus*
Atlantic herring -*Clupea harengus*	Atlantic herring -*Clupea harengus*
European anchovy- *Engraulis encrasicholus*	European anchovy- *Engraulis encrasicholus*
Grey gurnard -*Eutrigla gurnardus*	Grey gurnard -*Eutrigla gurnardus*
Atlantic cod- *Gadus morhua*	Atlantic cod- *Gadus morhua*
Boarfish- *Capros aper*	Three-bearded rockling- *Gaidropsarus vulgaris*
American plaice -*Hippoglossoides platessoides*	American plaice -*Hippoglossoides platessoides*
Common dab- *Limanda limanda*	Common dab- *Limanda limanda*
Snake blenny -*Lumpenus lampretaeformis*	Anglerfish- *Lophius piscatorius*
Haddock- *Melanogrammus aeglefinus*	Snake blenny -*Lumpenus lampretaeformis*
Whiting- *Merlangius merlangus*	Haddock - *Melanogrammus aeglefinus*
Lemon sole -*Microstomus kitt*	Whiting- *Merlangius merlangus*
Shorthorn sculpin- *Myoxocephalus scorpius*	Lemon sole -*Microstomus kitt*
Norwegian topknot -*Phrynorhombus norvegicus*	Common ling -*Molva molva*
European flounder- *Platichthys flesus*	Shorthorn sculpin- *Myoxocephalus scorpius*
European plaice- *Pleuronectes platessa*	Platichthys flesus – *European flounder*
Turbot -*Psetta maxima*	European plaice- *Pleuronectes platessa*

Thorny skate -*Raja radiata*	Red mullet- *Mullus surmuletus*
Fourbeard rockling -*Rhinonemus cimbrius*	Brill- *Scophthalmus rhombus*
Brill- *Scophthalmus rhombus*	Common sole -*Solea solea*
Common sole -*Solea solea*	Fries's goby- *Lesueurigobius friesii*
Fries's goby -*Lesueurigobius friesii*	European sprat- *Sprattus sprattus*
European sprat -*Sprattus sprattus*	Common dragonet- *Callionymus lyra*
Common dragonet -*Callionymus lyra*	Greater weever -*Trachinus draco*
Red mullet -*Mullus surmuletus*	Atlantic horse mackerel -*Trachurus trachurus*
Greater weever -*Trachinus draco*	Scaldfish- *Arnoglossus laterna*
Scaldfish -*Arnoglossus laterna*	

4.1 Demersal fish

In the relatively homogeneous soft bottom habitat in the original Hesselø OWF area and in the export cables corridor close to the OWF, 23 species of demersal fish were caught in the spring and autumn surveys in 2021. Nine species of flatfish were caught of which juvenile dab (*Limanda limanda*) and plaice (*Pleuronectes platessa*), were consistently the most abundant demersal fish throughout the entire soft bottom habitats of the area. Another abundant demersal fish species observed in large abundance in the autumn, was the greater weever (*Trachinus draco*). Characteristic for greater weever is that its distribution and abundance can vary considerably during the year for unknown reasons. This was observed in the surveys as greater weever were more or less absent during the spring survey and very abundant in the autumn survey.

Other demersal species consistently present in the area, but in lower abundances, were grey gurnard (*Eutrigla gurnardus*), long rough dab (*Hippoglossoides platessoides*), common dragonet (*Callionymus lyra*), lemon sole (*Microstomus kitt*), and European flounder (*Platichthys flesus*), which corresponds well with these species' preference for soft bottom habitats. One or a few individuals of several other demersal species thorny skate (*Raja radiata*), monkfish (*Lophius piscatorius*), hooknose (*Agonus cataphractus*), sole (*Solea solea*), common ling (*Molva molva*), four-bearded (*Rhinonemus cimbrius*) and three-bearded rocklings (*Gaidropsarus vulgaris*), and great sandeel (*Hyperoplus lanceolatus*) among others, were also caught in the soft bottom habitats. Only 19 cod, almost all juveniles or very small adults (lengths between 14-33 cm), were caught during the surveys.

In the hard bottom habitats, including stone reef areas in the export cable corridor close to shore, the most numerous demersal fish species caught in the gillnet survey was goldsinny wrasse (*Ctenolabrus rupestris*), which together with the less abundant corkwing wrasse (*Symphodus melops*), and Cuckoo wrasse (*Labrus bimaculatus*), and snake pipefish (*Entelurus aequoreus*) that were observed during the benthic flora and fauna hard bottom survey, are species strongly associated with stone reef habitats. Other fish species in the hard bottom habitats and mixed bottom habitats included demersal species such as turbot (*Psetta maxima*), brill (*Scophthalmus rhombus*), black goby (*Gobius niger*) and the semi-pelagic codfish species whiting (*Merlangius merlangus*) and individuals of juvenile cod (*Gadhus morhua*).

This section summarizes main conclusions from the previous fish surveys on demersal fish species occurring in and around the planning area for Hesselø OWF and export cables. The data will be important in order to perform a more detailed sensitivity analysis, including pressures and effects arising from establishment of Hesselø OWF, as well as existing knowledge on fish species in relation to resistance and recovery time (NIRAS, 2022).

4.2 Pelagic fish

During fish surveys in 2021 several pelagic species were caught throughout the original Hesselø OWF area and export cable corridor. The most abundant species by number and weight were sprat (*Sprattus sprattus*) and herring (*Clupea harengus*). Combined, they accounted for 86 % of the total number of fish caught and 66.1 % of the catches by weight in the spring trawl survey, and although they were caught considerably less during the autumn survey, these two species were still present throughout most of the area. Similarly, herring and sprat were also caught in the gillnet surveys in the hard bottom habitats in the inner sections of the export cables corridor, suggesting that these species are also found in the near shore area close to shore.

Other pelagic species observed in the survey catches in less abundance, were the seasonally abundant mackerel (*Scomber scombrus*), horse mackerel (*Trachurus trachurus*), anchovy (*Engraulis encrasicholus*), and the more common semi-pelagic species whiting (*Merlangius merlangus),* with a few individuals of boarfish (*Capros aper*), haddock (*Melanogrammus aeglefinus*), and blue whiting (*Micromesistius poutassou*). Whiting was consistently caught in the bottom trawl in the fish surveys as well as in the gillnet survey in the near shore hard bottom habitats that they use as nursery areas.

This section summarizes main conclusions from the previous fish surveys on demersal fish species occurring in and around the planning area for Hesselø OWF and export cables. The data will be important in order to perform a more detailed sensitivity analysis, including pressures and effects arising from establishment of Hesselø OWF, as well as existing knowledge on fish species in relation to resistance and recovery time (NIRAS, 2022).

4.3 Spawning and nursery areas

During spawning, different fish species gather at specific spawning areas. These areas are often extensive, and their distribution may vary from year to year depending on hydrographic conditions. Pelagic species, as well as most flatfish, have pelagic eggs, which are relatively small and spawned in very large numbers. Demersal fish species, apart from most flatfish species, spawn their eggs near or on the seabed. In addition to demersal fish, pelagic species such as herring have benthic eggs. Herring spawn their eggs in the water column, from where they sink to the bottom and attach to the substrate and vegetation.

The Kattegat, including the coastal areas north of Zealand, probably contain several important spawning and nursery areas for many species, but knowledge of this is sparse (NIRAS, 2022). No spawning areas for fish that lay their eggs on the seabed in the Hesselø OWF area is registered, however there is a spawning area for herring that overlaps with the planned export cable corridor in the northern Zealand coast (Figure 4-1) (HELCOM, 2024). In this area there may be a small local population of autumn-spawning herring, particularly near Hornbæk Bay and Gilleleje (Worsøe et al., 2002 in NIRAS, 2022). Further, east and north of the Hesselø OWF there are important spawning areas for the Atlantic cod (Figure 4-2) (HELCOM, 2024). There are no known spawning areas that whiting use in the Kattegat, as larvae and juveniles generally drift into the Kattegat and inner Baltic waters from spawning areas in the North Sea (Worsøe et al., 2002). However, whiting use the near shore habitats as nursery areas, and the soft bottom areas within the OWF area and outer export cable corridor is used as nursery areas for plaice, whiting, and dab (NIRAS, 2022).

Two bottom trawl surveys were undertaken in the original Hesselø OWF area in 2021, one during spring to coincide with the spawning period of several important species and one during autumn to expose potential temporal/seasonal differences in the fish communities and to indicate the importance of this area as a potential nursery area (NIRAS, 2022). In addition, the gonad maturity status of all cod equal to or above 20 cm were investigated, and the gonad maturity status for a selection of the flatfish equal or above 15 cm were examined. The results from these investigations indicated that the area was not a primary spawning area for any of these species. In general, there were very few adults of cod, or of the most abundant fish species dab or plaice caught during all surveys, indicating that mature fish were not gathering in the area to spawn. Although survey data did not show any significant spawning events occurring in or near the original

Hesselø OWF and export cables, pelagic eggs and larvae from other spawning areas may drift with the currents and be present in the area, as they move through the Kattegat during their development. Different fish species have different spawning times, but most of them spawn between January and June (NIRAS, 2022)

This section summarizes main conclusions from the previous fish surveys on spawning and nursery areas occurring in and around the planned area for Hesselø OWF and export cables. The data will be important in order to perform a more detailed sensitivity analysis, including pressures and effects arising from establishment of Hesselø OWF, as well as existing knowledge on fish species in relation to resistance and recovery time (NIRAS, 2022).

Please refer to Chapter 4.4 for further details on key fish species and their spawning areas in and close to the Hesselø OWF area and export cable route.

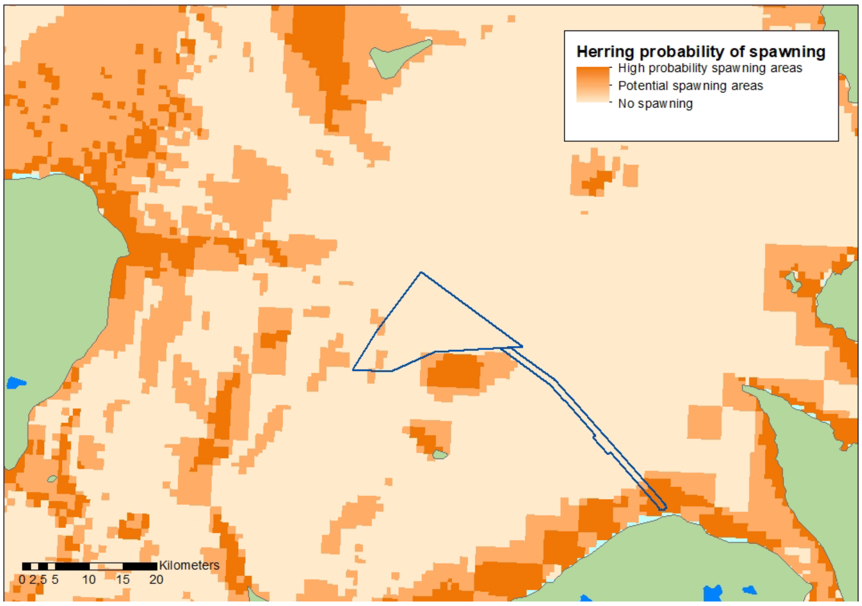

Figure 4-1. Spawning area for herring (*Clupea harengus*) is shown in orange. The polygons show the planned Hesselø OWF area and the EEC. Source: HELCOM, 2024.

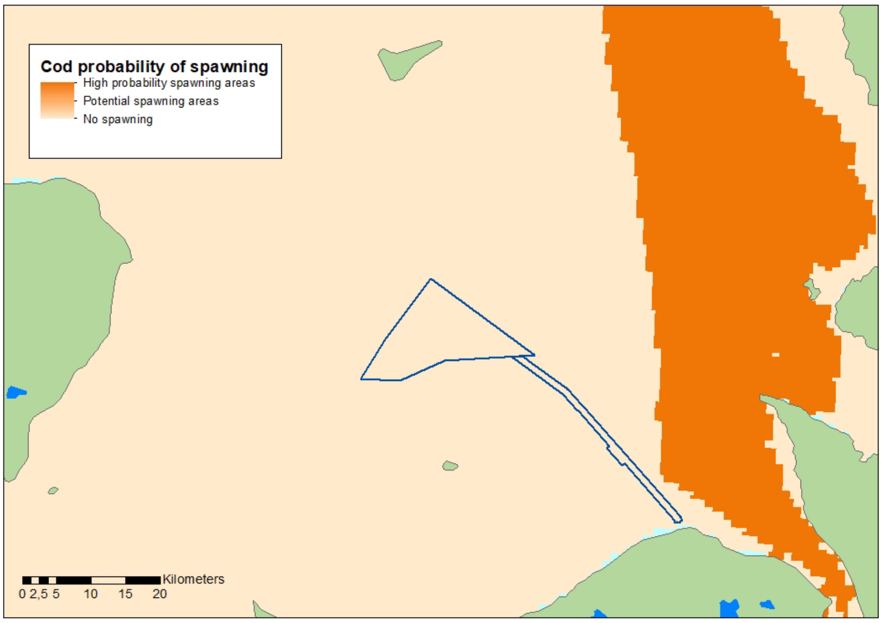

Figure 4-2. Spawning area for cod (*Gadus morhua)* is shown in orange. The polygons show the planned Hesselø OWF area and the EEC. Source: HELCOM, 2024.

4.4 Key species

4.4.1 Sprat

Sprat (*Sprattus sprattus*) is found throughout most of the Danish waters particularly in coastal areas, fjords, and in an increasing abundance towards the inner Baltic waters (Muus & Nielsen, 2006 in NIRAS, 2022). Sprat is a pelagic schooling species, which prey on zooplankton and fish eggs and functions as prey for top predators, such as cod. It feed on zooplankton and even though they do not prefer any particular habitat, they will seek to the bottom during the day to hide from predators. At night they will spread into the water column to feed. Sprat can be found at depths from 5-100 meters, often seeking deeper areas during the winter months (NIRAS, 2022).

Sprat spawn pelagically both in Kattegat and the Baltic Sea from January to July, often in general areas where large schools of sprat are present (Figure 4-3). Eggs and larvae drift with ocean currents, whereafter juveniles start to school with adults as soon as they can swim. Thus, there are no specific habitats or areas that can be considered specifically as nursery areas for sprat (Warnar et. al, 2012 in DTU, 2012).

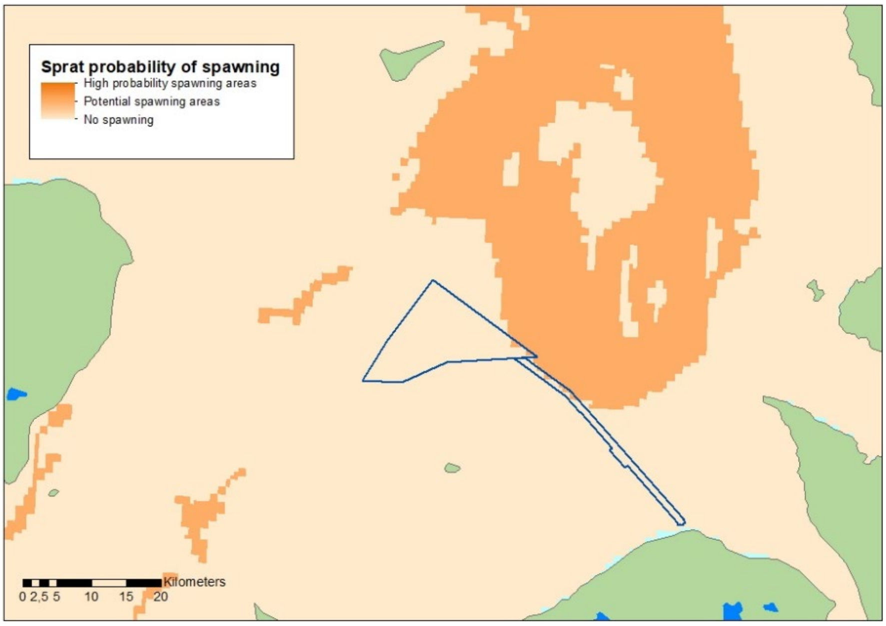

Figure 4-3. Spawning area for sprat (*Sprattus sprattus*) is shown in orange. The polygons show the planned Hesselø OWF area and the EEC. Source: HELCOM, 2024.

4.4.2 Herring

Herring (*Clupea harengus*) is a pelagic species that swim together in large schools over large areas of the Danish marine waters including the Kattegat. Herring primarily feeds in the pelagic zone, where it mainly consumes zooplankton.

Herring are split into many different populations that separate themselves both by where and when they spawn. In the Kattegat, there may be a small local population of autumn spawning herring along the northern Zealand coast, particularly near Hornbæk Bay and Gilleleje (Worsøe et al., 2002 in NIRAS, 2022), however, most herring belong to a large population that during spring migrate from the Kattegat/Skagerrak through the Øresund, to a large spawning area near Rügen in Germany (DTU, 2024).

Herring spawn in relatively shallow areas (typically 0-8 meters deep), often in locations characterized by hard bottoms or soft bottoms with erect vegetation (Figure 4-1). The specific spawning site within these areas can vary among years and within the same season, depending on hydrological factors like temperature and currents. Herring migrates to the spawning areas in early winter and then returns to the foraging areas of the Kattegat-Skagerrak after spawning. The herring schools revisit the same spawning grounds from one generation to the next (Raid, 1990 in HELCOM, 2021a). Its eggs are demersal and stick to vegetation, gravel, stones, and other solid substrates until they hatch. Juvenile herring gather in large schools along much of the Danish coastline where there is vegetation where they grow while feeding on zooplankton. After spawning the large schools of herring migrate back through the inner Danish waters towards the deeper parts of the Øresund, Kattegat and Skagerrak where they spend their winters.

4.4.3 Plaice

European plaice (*Pleuronectes platessa*) is a demersal species that prefers soft bottom habitats (such as sand or silt) where it can find its prey and even bury into the sediments. In the Kattegat, plaice can be found at depths of 5-100 meters but is most abundant at depths between 10-20 meters. During their first year, juvenile plaice are almost exclusively found in shallow water (around 1-5 meters) with sand bottom habitats. As they approach their first winter, juveniles move into deeper waters. Adult plaice are primarily found in sand bottom habitats and mixed bottom areas, where they seek refuge in places with gravel and some vegetation. Plaice feed on small crustaceans, bristle worms, and thin-shelled mussels and larger individuals may even consume small fish. There are two distinct spawning areas in Kattegat: one in the northwestern part of the Kattegat and a dominant one in the southern part (Nielsen et al, 2004) (Figure 4-4). The northern part of the Øresund, central part of Little Belt, and the outer part of Flensborg Fjord are also potential spawning areas (Støttrup et. al., 2019).

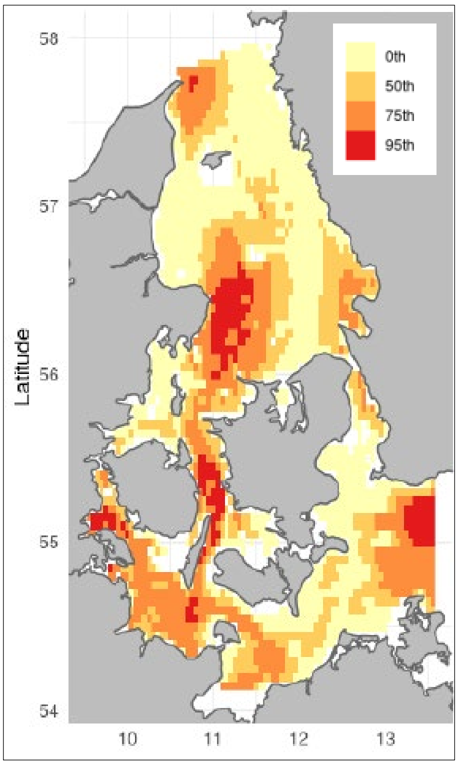

Figure 4-4. The main spawning area identified for the Kattegat plaice Q1 (January-March). The different colours represent statistical significance levels. Source: Støttrup et. al., 2019.

4.4.4 Dab

Dab (*Limanda limanda*) is a flatfish species that is widespread throughout the marine waters of Denmark. Dab prefer soft bottom habitats similar to plaice, though often on bottoms of finer material such as fine sand/silt bottoms and at depths of 20-150 meters (Muus & Nielsen, 2006 in NIRAS, 2022). Although there is some competition between dab and plaice for food, dab prey more prominently on benthic marine worms, crustaceans, and small mussels, which they have the ability to crush. Dab will also prey on small fish such as gobies. Dab spawn their eggs pelagically throughout their distribution from January-August, and juveniles prefer habitats at depths around 10-20 meters, in contrast to other common juvenile flatfish species (plaice and flounder) that often have their nursery areas in very shallow water (<2 meters).

4.4.5 Cod

Cod is found throughout the Danish marine waters from coastal regions to several hundred meters deep. Normally, cod are considered to be a demersal species spending most of their time near the seabed, however, depending on the area, season and whether they are juveniles or adults they can also be found in the pelagic. In the Kattegat, cod are found in depths of 5-100 meters (Sørensen et al., 2016 in NIRAS, 2022). Cod in the Kattegat consist of a mixture of at least two genetically distinct cod populations - Northern Shelf cod and Kattegat cod. The majority of cod (70 %) of the Northern Shelf genotype remain resident in the Kattegat during their first four years of life. Towards the autumn/winter of their fourth year of life, they start to migrate to the North Sea. Approximately 20 % of the North Sea genotype migrates to the Kattegat (ICES, 2024).

Cod are general considered to be omnivores and opportunistic feeders, preying on both benthic invertebrates and other fish. Juvenile cod eat a wide variety of benthic fauna including bristle worms and crustaceans (crabs and shrimp) while larger cod have a greater tendency to eat other fish (herring, sprat, other cod, etc.), particularly the larger they become (Hüssy K, et al., 1997 in NIRAS, 2022). Cod spawning occurs in the Kattegat from the beginning of January to the end of April, with a peak in February/March. In January-February mature cod gather in large schools over deeper waters to spawn. The main spawning areas identified for the Kattegat cod are off Falkenberg, Sweden and to the south along the Swedish coast in the south-eastern part of the Kattegat, the area around the entrance to the Øresund and the Øresund (Figure 4-2). Cod eggs are pelagic and drift with water currents over large areas as they hatch, and cod larvae grow. The effective distribution of cod spawning areas depends significantly on the prevailing hydrological regime, and the presence of spawning also relies on seasonally variable hydrographical conditions, such as temperature, salinity, and oxygen availability (HELCOM, 2021b). Fluctuations in temperature can even delay the spawning season by up to two months.

There is no targeted cod fishery in Kattegat at present, and cod is mainly taken as bycatch in the Norway lobster fishery. So far, management measures implemented such as area closure, effort restriction, and bycatch quota have not been sufficient to ensure the recovery of the stock (ICES, 2022), and there should be zero catch in 2025 and 2026 (ICES, 2024).

4.4.6 Whiting

Whiting (*Merlangius merlangus*) is a semi-pelagic codfish that can be found both near the seabed and in the pelagic zone. There are no known spawning areas in the Kattegat (Worsøe et al., 2002 in NIRAS, 2022), as larvae and juveniles generally drift into the Kattegat and inner Baltic waters from spawning areas in the North Sea. During their first year, whiting prefers soft bottom and mixed habitats, typically in coastal areas. By the age of 2-4 years, they become mature and begin to migrate back to their primary spawning areas in the North Sea. However, the exact migration routes and seasonal patterns remain poorly understood.

4.4.7 Greater weever

The greater weever (*Trachinus draco*) is a bottom living fish commonly occurring and reproducing in Kattegat (HELCOM, 2013). It is primarily associated with soft bottom habitats such as sand and sand/silt habitats and often lays buried with just the eyes and tip of first dorsal fin exposed. The first dorsal fin rays, as well as the spine on the preoperculum contain venomous spines protecting the species from predators. During night the greater weever leaves the burrow to feed on small invertebrates and fishes, particularly, gobies, and sandeel, and during the autumn on small whiting and herring (Bagge, 2004). They are also known to swim in schools in the pelagic zone at night and thus can be found throughout the water column at different times. The greater weever spawns during summer in shallow coastal waters with soft bottoms with sand or gravel. Their eggs remain pelagic where they drift with the current until hatching and juveniles seek soft bottom habitats near the coast. During winter they inhabit the muddy fine sand of the deeper (16-25 m) waters of the Kattegat, where temperatures are <6ºC (Bagge, 2004). They almost completely cease feeding, relying only on energy reserves.

4.5 Protected fish species

Several protected fish species either regularly occur or potentially occur in the Hesselø OWF area or export cable corridor (HELCOM, 2024). The HELCOM Red List adheres to the Red List criteria of the International Union for Conservation of Nature (IUCN). The eel is listed as Critically Endangered, Atlantic wolffish (*Anarhichas lupus*), maraene (*Coregonus maraena*), and common ling (*Molva molva*) as Endangered, and cod, whiting (*Merlangius merlangus*), trout (*Salmo trutta*), Atlantic salmon and sea lamprey (*Petromyzon marinus*) as Vulnerable.

The Danish Red List is restricted to freshwater fish; however, species like eels, Atlantic salmon, trout, and sea lamprey also spend varying lengths of time in marine habitats. Among the fish that might be encountered in the area of the Hesselø OWF or its export cable route are eels, listed as Critically Endangered, and Atlantic salmon and trout, which are listed as of Least Concern (Den Danske Rødliste, 2019). Sea lamprey data is inadequate for an evaluation (DD, Data Deficient).

The EU Habitats Directive Annex II includes species whose conservation requires special areas of protection. Annex II species that can potentially occur in the planned Hesselø OWF area include sea lamprey (*Petromyzon marinus*)*,* European river lamprey (*Lampetra fluviatilis),* Atlantic salmon (*Salmo salar),* twaite shad (*Alosa fallax)* and allis shad (*Alosa alosa)* (EEA, 2024).

Fishing, whether targeted for commercial or recreational purposes or as bycatch, is one of the most significant threats to many red-listed protected fish species (HELCOM Red List, 2019). Activities such as bottom trawling, coastal development, and industrial activities can destroy or degrade essential fish habitats, including spawning grounds and nursery areas critical for the survival of fish populations (HELCOM, 2023). Other threats are chemical pollutants, such as heavy metals, pesticides, and other toxins, which can affect fish health and reproductive success. Nutrient pollution, leading to eutrophication, can also cause algal blooms that deplete oxygen levels in the water. Changes in sea temperature, ocean acidification, and altered salinity levels can affect fish species by disrupting their natural life cycle and habitats. In addition, warmer temperatures can shift the distribution of species and affect the availability of prey (IPPC, 2019).

4.6 Invasive fish species

Globally, about 2000 marine non-indigenous species have been introduced to new locations through human-mediated movements. A few of those have economic value, but most have had negative ecological, socioeconomic or human health impacts. With increased trade and climate change, biological invasions are likely to increase (Therriault et. al., 2021). In the southern part of the Kattegat a key invasive fish species is round goby (*Neogobius melanostomus*) which has spread to various parts of European seawaters, including the Kattegat. Round goby is a highly adaptable species that competes with native fish for food and habitat, particularly affecting benthic (bottom-dwelling) species. The round goby is a strong competitor because it is larger and more aggressive than most fish species with the same lifestyle in the invaded areas (Thor et al., 2023; Jensen et al., 2023).

5 POTENTIAL IMPACTS OF OFFSHORE WIND

The installation, operation, and decommissioning of OWFs and related infrastructure can potentially impact fish primarily due to sediment suspension, sedimentation, underwater noise, electromagnetism, and habitat changes. The following chapter summarizes the main potential impacts of a general OWF development, i.e. it is not directly related to the specific Hesselø OWF project and does not provide an impact assessment of the project.

5.1 Noise disturbance

Fish detect sound and vibrations through their inner ear, possibly in combination with a swim bladder, and through the lateral line organ. The ability to perceive sound varies significantly among fish species, depending on their anatomical structures. Fish with both a well-developed inner ear and a swim bladder, known as "hearing specialists," have excellent hearing. Those with less developed hearing structures are termed "hearing generalists," which can further be categorized based on the presence or absence of a swim bladder.

Fish species that commonly occur in Kattegat and their sensitivity to noise are shown in Table 5-1. Hearing specialists, such as herring and sprat, have specialized anatomy. Cod, whiting, and eel, which possess swim bladders, are moderately sensitive to noise. Fish without a swim bladder or specialized anatomy rely on water movement rather than sound. Flatfish, whose swim bladder degenerates in the larval stage, generally tolerate sound well.

Noise from pile driving, seismic activities, and wind turbine operations predominantly falls below 1,000 Hz, within the hearing range of most fish (Thomsen et al., 2006). Many fish species hear between 30 Hz and 1 kHz, with some demonstrating capabilities in the infrasonic and ultrasonic ranges (Thomsen et al., 2006). Construction activities are most critical due to acute noise effects. Noise from the demolition of wind turbine foundations can be detected by species like herring and cod at distances over 80 km, while flatfish can hear noise several kilometres away (Thomsen et al., 2006). However, not all fish react to noise, and reactions vary by species and noise intensity (Kastelein et al., 2008).

Fish close to construction may suffer negative impacts, while those 100-1,000 meters away might exhibit behavioural responses depending on sound intensity (Gill & Bartlett, 2010). Proximity to pile driving and seismic activities can cause death or tissue damage in fish (Hastings & Popper, 2005). High noise levels can lead to temporary hearing damage, though no permanent damage has been detected as hair cells regenerate (FFI, 2020).

Escape behaviour is common in response to high noise levels. Cod and tongue have shown changes in swimming behaviour and a "freeze" reaction to sound (Müeller-Blenkle et al., 2010). Noise can also interfere with communication related to territory defence and reproduction (Thomsen et al., 2006), and the effect diminishes quickly with increasing distance, and that the effect on species without a swim bladder (tongue) will be significantly reduced at 30-40 meters (Mueller-Blenkle et al., 2010).

Continuous noise can affect important behaviours such as grazing, defence behaviour, reproduction, and communication, however, the extent of these effects is unknown (IMR, 2020).

The key pressures for the fish receptors in a sensitivity analysis in the Hesselø OWF area were underwater noise from pile driving, for which the sensitivity was medium/high for pelagic and demersal fish communities and high for the early life stages of fish (fish eggs and larvae) (NIRAS, 2022). For the pelagic and demersal fish sensitivity to the pressures of increased underwater noise from vessel activity and turbines during operation was ranked as low/sensitive.

Table 5-1. Anatomical adaptations among fish species commonly found in Kattegat and their sensitivity to noise. Source: Dong, 2007.

Fish species	**Anatomical adaptation**	**Sensitivity**
Eel (*Anguilla anguilla*)	No adaption	Moderate
Herring (*Clupea harengus*)	Particularly specialized anatomy	High
Sprat (*Sprattus sprattus*)	Particularly specialized anatomy	High
Cod (*Gadus morhua*)	No adaption	Moderate
Sandeel (*Ammodytes* sp.)	No swim bladder	Low
Dab *(Limanda limanda)*	No swim bladder	Low
Short-spined Sea scorpion (*Myoxocephalus scorpius*)	No swim bladder	Low
Blue whiting *(Merluccius merluccius)*	No adaption	Moderate
Mackerel *(Scomber scombrus)*	No adaption	Moderate
Plaice *(Pleuronectes platessa)*	No swim bladder	Low

5.2 Electromagnetic effects

There is potential for subsea cables to generate electromagnetic fields (EMF) which could affect the sense of orientation, behaviour, distribution, and abundance of fish e.g. salmonids, flat fish, and gadoids. Several marine fish can sense the Earth's geomagnetic field and use it to orient during migration, including during the larval stages. Studies have demonstrated that EMFs could alter the swimming and spatial distribution of marine species (Nyqvist et al., 2020; Hutchison et al., 2020; Wyman et al., 2018; Westerberg & Lagenfelt, 2008, all in Cresci et al., 2022a). Other experiments have shown no significant effects in various fish species due to electromagnetic underwater cables (Woodruff et al., 2012). Localized electric and magnetic fields are associated with operational power cables that will include the inter array cables that are buried within the wind farm area and export cables placed in the cable corridor to land. Due to the difference in current strengths, the electromagnetic fields around the inter array cables connecting the turbines will be significantly lower than the export cable to land. In general, the intensity of the magnetic fields weakens quickly with increasing distance (meters) and depth of burial to the cable and the propagation of the magnetic field is directly dependent on the current flowing through in the cable. Only limited information is available on the potential effects on fish resulting from this pressure (Öhman et al, 2007, in NIRAS, 2022).

Certain fish species are generally believed to use their ability to detect magnetic fields for migration to and from spawning and rearing areas. This is particularly relevant for sea lamprey, Atlantic salmon, eel, trout, and European plaice which are species that have shown sensitivity to electric and magnetic fields depending on the strength of the electromagnetic fields (Gill et al., 2012). Atlantic salmon, trout, and eel are likely to encounter EMF from subsea cables either during their adult migration or during the early life stages in shallow coastal waters near natal rivers (Gill & Bartlett, 2010). These species may react to EMF from subsea cables through short-term attraction or avoidance, potentially wasting time and energy, which could delay migration or alter movement and distribution patterns. However, there is no clear evidence that anthropogenic EMFs cause significant attraction or repulsion effects on Atlantic salmon, trout, or eel (Gill & Bartlett, 2010).

A limited number of fish species that are sensitive to EMF pressures from electric cables were found in the original Hesselø OWF area.

These include cartilaginous fish (sharks and rays) with electroreceptors used to perceive electromagnetic fields around prey and for orientation (Kalmijn, 1978, in NIRAS, 2022). There is also evidence that some bony fish such as plaice and eel have the ability to use magnetic signals in orientation of their surroundings (Metcalfe et.al., 1993; Karlson, 1985, both in NIRAS, 2022). In a study around the SwePol HVDC cable (between Sweden and Poland), a magnetic field of 200µT 1 meter from the cable did not have an effect on the migration pattern of observed fish, including eel (Westerberg & Lagenfelt, 2008).

Further, a study on the impact of a subsea cable on migrating European eel in the Baltic Sea revealed significantly reduced swimming speed around the cable, but the cables did not form a barrier to their migration (Westerberg & Lagenfelt, 2008). However, the details of their behaviour during passage and the physiological mechanisms involved remain unclear. Notably, a significant portion of the eel's migration occurs near the surface, with up to 95 % of swimming time spent within 0.5 meters of the surface (Westerberg, et al., 2007). During daylight, eels rest on the seabed at depths of 2–36 meters, suggesting that magnetic field influences from cables on or in the seabed during these periods are possibly minimal depending on the water depth.

Intensity of EMF produced will affect degree to which they may impact marine organisms (Copping and Hemert, 2020 in DSC, 2022). Intensity is dependent on type of current (AC or DC), characteristics of the cable (e.g. length, water current speed, and other environmental factors (Bochert and Zettler, 2006; Tricas and Gill, 2011; Taormina et.al 2018; Copping and Hemert, 2020; Scott et al., 2021 all in DSC, 2022). Current knowledge suggests that EMFs from subsea cables and cabling orientation respective to the migratory route may interact with migrating eels (and possibly salmonids) if their migration or movement routes take them over the cables, particularly in shallow waters (Gill & Bartlett, 2010). A cabling orientation parallel to the migration route will most likely have no influence (Öhman et al., 2007 in Gill & Bartlett, 2010). Based on current understanding, there may be a limited effect on organisms with migratory routes perpendicular or oblique to the cables (Westerberg & Langenfelt, 2008 in Gill & Bartlett, 2010). It is important to note that relatively few studies have described the migratory routes of anguillid eels, and those that do suggest that ocean currents may play as significant role in migration as magnetic orientation (Fricke & Kaese,1995; Knights, 2003; Tsukamoto, 2009, all in Gill & Bartlett, 2010)).

Another study examined the effect of AC cables connecting Nysted Havmøllepark to the transmission network on fish (Hvidt et al., 2004, in NIRAS 2022). The study conducted two years before and after the cable's commissioning, found no change in fish fauna on either side of the cable post-commissioning, and no effect on eel or other species' migration was demonstrated. However, the experiments indicated a potential blocking effect on eels, although many recaptured eels likely passed the live cable. Whether this modest effect was due to EMF or changes in the seabed was not determined.

Cresci et al. found that for marine fish, the risk of EMF exposure is particularly relevant during early life stages when fish have limited swimming capacity (Cresci et al., 2022a). Laboratory experiments have shown impacts of magnetic fields on larval swimming or orientation behaviour that could affect their dispersal, potentially influencing survival and recruitment. High voltage DC cables can reduce the swimming activity of haddock larvae (*Melanogrammus aeglefinus*) (Cresci et al., 2022a), while the magnetic fields from offshore wind farm DC cables have shown no effect on the spatial distribution or swimming behaviour of lesser sandeel larvae (Cresci et al., 2022b). Rainbow trout embryos and larvae exposed to EMF had no significant effect on embryonic or larval mortality, hatching time, larval growth, or the time of larvae swim-up from the bottom, however, EMF enhanced the yolk-sac absorption rate (Fey et al., 2019). Also, haddock larvae exposed to electromagnetic fields showed a slight significant decrease in swimming speed in a few hours after the exposure (IMR, 2022). Further, elasmobranchs have shown to be quite sensitive to EMF, including documented negative effects on behaviour and prey/predator interactions (Hutchison et al., 2018).

Overall, results from studies have various conclusions depending on different factors such as e.g. strength of the EMF and no final conclusion has yet been made on effects on fish from EMF. However, a sensitivity analysis undertaken on the various life stages of the fish species in the Hesselø area, concluded that none of the species are sensitive to EMFs from the array cables and/or export cables (NIRAS, 2022). The sensitivity analysis concerning EMF pressure on all life stages of fish regarded their sensitivity as not sensitive/low within the area. (NIRAS, 2022).

5.3 Habitat changes

The physical presence of seabed infrastructure, such as foundations, cables, and anchors, may disturb demersal species and affect the availability of prey for other fish species. However, this infrastructure can also serve as a nursery, shelter, or spawning area for various fish species.

When solid substrates like concrete, steel, or stone are introduced to areas typically dominated by softer or more homogeneous bottom types, these substrates can function as artificial reefs. This is also the case for cable routes that use protective materials like rocks and gravel. Such new habitats are colonized by both fauna and flora through migration from the immediate area and the settling of larvae or spores. The location's nature, including depth and flow conditions, along with the structure and material of the infrastructure, influences the effectiveness of these artificial "reefs." They can serve as a "pantry" and shelter for several fish species. As different fish species have distinct preferences for the different bottom sediments, this can lead to changes in their distribution within an area. Species like cod and whiting are particularly attracted to heterogeneous structures such as rock formations. Alterations in food supply can affect the ecosystem, impacting growth and production, and thereby influencing the distribution of species that serve as prey for fish.

Sedimentation of suspended material can alter the grain size distribution in the upper sediment layer, affecting demersal fish species that prefer specific sediment types. For example, sandeel prefer medium-fine to coarse sand with grain sizes between 0.25 and 1.2 mm and avoid areas where the sediment contains more than 6% fine sand/silt/clay (Wright et al., 2000; Jensen et al., 2003; Temming et al., 2004 in NIRAS, 2015). Sandeel bury themselves at night and for extended periods during winter, laying their eggs on the seabed in the same areas where they live. Flatfish also have specific preferences for certain sediment types, which they use for hiding or burrowing into the seabed. Their preferred sediment composition is dominated by silt and fine sand. Juvenile flatfish are particularly impacted by suspended material and changes in bottom conditions during the transition from their pelagic larval stage to the benthic juvenile stage (Van der Veer et al., 1991).

A sensitivity analysis concerning the pressure of habitat loss/change in the original Hesselø OWF area, considered the sensitivity as medium for the early life stages of fish (NIRAS, 2022).

5.4 Suspended sediments

Suspended sediment or turbid water is a natural phenomenon to which fish are adapted to varying degrees. However, harmful effects can occur at exceptionally high levels of suspended material, especially if these levels deviate significantly from the "natural state”. In general, demersal fish have a higher tolerance threshold for suspended material than pelagic fish (FeBEC, 2013). Activities such as installation work in contaminated areas can release harmful substances, posing risks to fish and other organisms. The sensitivity of fish to suspended matter depends on the species and life stage. Fish eggs and larvae, as well as juvenile fish, are typically more vulnerable than adults because they are less mobile. Juvenile and adult fish tend to avoid areas with high concentrations of suspended material. The effect also depends on both the concentration and exposure time. Suspended sediments can also expose or stir up food items (e.g. mussels, brush worms), attracting certain fish species (NIRAS, 2015).

5.4.1 Eggs and larvae

Fish larvae are generally more sensitive to suspended sediment than fish eggs of the same species. The effects can be both sub-lethal and lethal (Engell-Sørensen & Skyt, 2002). Egg mortality is rarely observed, except under extreme conditions where concentrations reach grams per litre.

At Hesselø OWF area there is a potential spawning area near the coast for herring. Further, east and north of Hesselø OWF there are important spawning areas for the Atlantic cod, and whiting larvae and juveniles generally drift into the Kattegat from spawning areas in the North Sea. Suspended sediment primarily impacts pelagic eggs. The survival of pelagic eggs depends on their ability to remain in the upper parts of the water column where abiotic conditions are optimal. Suspended sediment particles can cause pelagic fish eggs to sink, increasing the risk of oxygen deficiency. If the eggs sink to the bottom, high mortality rates can be expected due to benthic predation or mechanical and physiological stress (Engell-Sørensen & Skyt, 2002). Additionally, sediment sticking to the surface of fish eggs, whether pelagic or benthic, can hinder oxygen transport and affect egg development.

Herring eggs become very sticky a few hours after spawning, attaching to stones, plants, etc., on the seabed. Research has shown that Pacific herring (*Clupea pallasi*) eggs exposed to suspended sediment concentrations above 250 mg/l exhibit lethal and sub-lethal effects (Griffin et al., 2008). However, another study found no effect on herring egg development at concentrations of 300 and 500 mg/l for one day, indicating limited or non-existent damage at these levels (Kiørboe et al., 1981). Cod eggs exposed to 5 mg/l of suspended sediment were still able to float, while exposure to 100 mg/l significantly increased mortality (Westerberg et al., 1996). At 5 mg/l, cod eggs in the Øresund would sink to the bottom within four days. Experiments have shown a nearly linear decline in the buoyancy of cod eggs with increasing suspended sediment concentrations (4-49 mg/l) (FeBEC, 2013).

Many fish species, including cod larvae, rely on sight for food searching (Brawn, 2011). Moving particles are followed by eye movements and captured by swimming forward and snapping if the particles move in front of the head. Fish larvae cannot survive more than a few days without feeding before reaching a point where they are too weak to feed (Engell-Sørensen & Skyt, 2002). Experiments with herring larvae found earlier hatching, shorter hatching lengths and reduced feeding of herring larvae (Messieh, 1981). Suspended sediment can directly affect larval oxygen uptake by clogging the gills (Engell-Sørensen & Skyt, 2002). Lethal effects on herring larvae have been demonstrated at concentrations above 100 mg/l (Hansson, 1995).

Another study found no significant effects on the eggs and larvae of cod or flounder at concentrations up to 1000 mg/l, while herring showed negative effects on fertilization at concentrations of 500-1000 mg/l, and on hatching rates at 1000 mg/l (FeBEC, 2013).

A sensitivity analysis concerning the pressure of suspended sediments in the original Hesselø OWF area, considered the sensitivity as medium for the early life stages of fish (NIRAS, 2022).

5.4.2 Juvenile and adult fish

Demersal fish species, such as flatfish, eels, and species linked to coastal zones, are generally less sensitive to periodically elevated concentrations of suspended matter due to their adaptation to habitats with naturally high turbidity.

Significant adverse effects on juvenile and adult fish, primarily on the gills, are rare and occur only under extreme conditions were suspended sediment concentrations are in the order of grams per litre (Engell-Sørensen & Skyt, 2002). Other adverse effects may include reduced oxygen uptake due to gill clogging. Bottom-dwelling fish, like flatfish, are more tolerant of suspended matter than pelagic species like herring and sprat. For example, plaice have survived exposure to 3000 mg/l of suspended clay and silt for 14 days (Engell-Sørensen & Skyt, 2002). Pelagic fish species, such as herring, are particularly vulnerable as their gills act as a sieve that can filter out very small particles from the water (Engell-Sørensen & Skyt, 2002).

Avoidance may occur for pelagic and demersal species when suspended sediment concentrations exceed 3 mg/L and are likely to occur at greater 10 mg/L (Page, 2014). In addition, for herring and cod, laboratory experiments have shown avoidance reactions at particle concentrations at 3 mg/l (Westerberg et al., 1996). Threshold values for avoidance behaviour in pelagic fish species like cod is reported to be 10 mg/l. For flatfish, eels (including migrating eel larvae), and species living in shallow water, threshold values were reported to be 50 mg/l (FeBEC, 2013).

A sensitivity analysis concerning the pressure of suspended sediments in the original Hesselø OWF area, considered the sensitivity as not sensitive/low for demersal and pelagic species (NIRAS, 2022).

5.5 Summary of sensitivities

The sensitivity of fish species to a general OWF development varies based on several factors, including their life stage, behaviour, and habitat preferences. However, some species are more likely to be affected than others due to their specific ecological requirements and behaviours. In the Kattegat, the fish species that are considered most sensitive to an OWF development include those that rely heavily on specific habitats, are sensitive to noise, or have particular spawning grounds in the area. The following are some of the key species:

- Cod (*Gadus morhua*)
    - Eggs and larvae: Cod eggs and larvae are sensitive to changes in suspended sediment concentrations, which can affect their buoyancy and increase mortality rates. Cod larvae rely on visual cues to feed, so increased turbidity can reduce their ability to find food.
    - Juvenile and adult: Cod are attracted to heterogeneous structures like those found around wind farm foundations, which might alter their natural distribution and behaviour.
- Herring (*Clupea harengus*)
    - Eggs and larvae: Herring spawn in specific areas, often near the coast, and their eggs are sensitive to suspended sediments, which can affect their buoyancy and survival rates. The larvae are also sensitive to changes in water quality and suspended sediments, which can impact their feeding and growth.
    - Juvenile and adult: Herring is particularly sensitive to underwater noise, which can be generated during pile driving.
- European eel (*Anguilla anguilla*)
    - Migratory routes: Eels migrates through the Kattegat, and EMFs from subsea cables may affect their migration behaviour. Changes in sediment conditions and seabed structures due to an OWF can also impact their habitat.
- Plaice (*Pleuronectes platessa*):
    - Juvenile habitats: Plaice juveniles depend on sandy or gravelly seabed. Construction activities can degrade these habitats, affecting juvenile survival rates.
- Sprat (*Sprattus sprattus*)
    - Spawning and early life stages: Like herring and cod, sprat eggs and larvae are sensitive to suspended sediments and changes in water quality. Turbidity and sedimentation can affect their survival and development.

6 SUMMARY

Key fish species in the planned area for Hesselø OWF and export cable corridor include dab, plaice, cod, whiting, greater weever, sprat and herring. The demersal fish community in the soft bottom habitats are dominated by a variety of flatfish species with dab and plaice being the most abundant. The pelagic species sprat and herring are common in the early part of the year and much less abundant in the autumn.

There are no known spawning areas within the planned Hesselø OWF area. However, the soft bottom area within the OWF area and outer export cable corridor is used as nursery areas for dab, plaice and whiting. Close to the coast of northern Zealand, particularly near Hornbæk Bay and Gilleleje, there may be a small local population of autumn spawning herring. Protected species in the Hesselø OWF area include cod, whiting, trout, and Atlantic salmon among others. Invasive species like the round goby are spreading and impacting local ecosystems.

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