ENERGINET - MARINE ENVIRONMENTAL STUDIES

Kriegers Flak II North & South – Fish populations and habitats

Energinet Eltransmission A/S

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Applicable contract(s) governing the provision of this Report:

Objective:

The objective of this report is to describe and map the fish resources in Kriegers Flak II North & South in western Baltic Sea. 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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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 KF II OWF area. The report also summarizes the main potential impacts of a general OWF development.

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 Kriegers Flak area.

The Kriegers Flak II OWF will consist of two sub-areas, North and South, covering 175 km² off the coast of South Zealand and Møn. The OWF will connect to land via subsea cables near Rødvig. Key species in the western Baltic Sea include cod, whiting, flounder, plaice, turbot, herring, sprat, sandeel, and eel. Cod, flounder, and plaice are constantly present, while herring and sprat occur periodically in large numbers. There are no known spawning areas for fish that spawn their eggs near or on the seabed within the KF II OWF areas, although, close to the coast of both Stevns and Møn, there are large spawning areas.

Fish species such as cod, flounder, and sprat have potential spawning areas that overlap with the KF II OWF areas. As several key fish species such as European flounder, plaice, and sprat primarily spawn in the deeper parts of the Baltic Sea, it is unlikely that these species will spawn in the relatively shallow areas, including the areas for the planned KF II OWF. Whiting, flounder, plaice, herring, sprat, turbot, and sandeel have distinct spawning and feeding behaviours, and their presence in the area varies seasonally. Cod is a crucial predator in the western Baltic Sea and have experienced a decline in the overall stock biomass due to environmental and human impacts.

Protected species in the western Baltic Sea include eel, cod, and Atlantic salmon, among others. Invasive species like the round goby are spreading and impacting local ecosystems, and mitigation measures such as releasing turbot to control their population, have been initiated.

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

1 INTRODUCTION

In order 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.

In order 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 area for Kriegers Flak II (KF II) Offshore Wind Farm (OWF) consists of two sub-areas: North and South. The areas are located 25-50 km off the coast of South Zealand and Møn. Kriegers Flak II North is located approximately 15 km from the east coast of Møn, while Kriegers Flak II South is located approximately 30 km southeast of Møn. The area for the Kriegers Flak II OWF is approximately 175 km^2, divided into 99 km^2 for North and 76 km^2 for South. The Kriegers Flak II OWF will be connected to land via subsea cables making landfall close to Rødvig on South Zealand.

The objective of this report is to describe and map the baseline conditions for fish species, populations, and habitats within the planned OWF area, Kriegers Flak II North and South (Figure 1-1, Table 1-1). The report will form part of the basis for the Environmental Impact assessment to be undertaken by the future Concessionaire.

Given the variability of fish stocks across space and time, this mapping includes the identification of fish species and populations present in the broader western Baltic Sea region, as well as specifically within the KF II OWF areas.

This study is a desktop review, compiling data provided by Energinet, publicly available sources, research articles, and previous field-specific studies in the western Baltic Sea, particularly focused on the Kriegers Flak 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. An assessment has also been conducted on the main potential impacts of a general OWF development, i.e. it is not related to the specific KF II OWF project.

This baseline study will contribute to a future project-specific environmental impact assessment (EIA) for the Kriegers Flak II North and South area, enabling OWF developers to evaluate the project's potential impact on fish and plan appropriate mitigation measures.

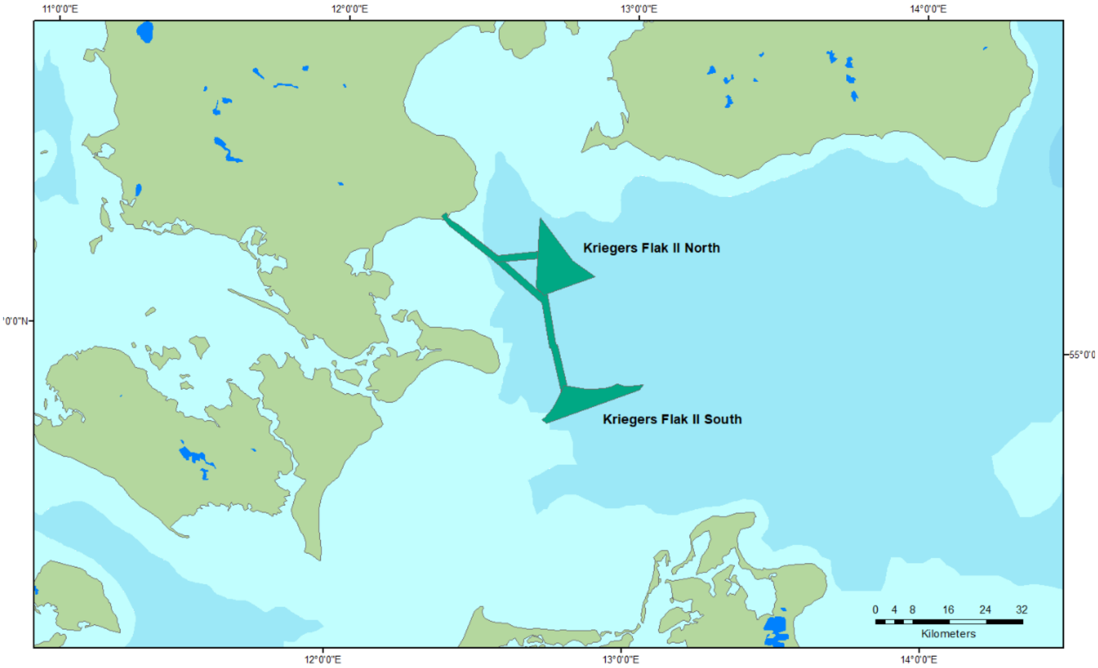

Figure 1-1. Kriegers Flak II North and South planned offshore wind farm area and export cable routes. Source: Energinet, 2023.

Table 1-1. Kriegers Flak II North and South planned offshore wind farm area and export cable corridors. Source: Energinet, 2022.

Offshore wind farm area	Area (km^2)	Water depths (m)	Export cable corridor	Shortest distance to shore (km)
Kriegers Flak II North	99	25-40	Southern part of Zealand.	15
Kriegers Flak II South	76	10-50	Southern part of Zealand.	15

1.1 Baseline sources

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

- Fish and fishery background report for Kriegers Flak Wind farm. NIRAS, Krog Consult and BioApp, 2015.
- Update of part of detailed screening from 2020 and new detailed screening of new areas for Offshore Wind development. COWI, 2022.
- Essential fish habitats in the Baltic Sea – Identification of potential spawning, recruitment, and nursery areas. HELCOM,2021a.
- Research information (references in text)
- ICES & HELCOM.
- Previous field surveys in connection with OWF developments at Kriegers Flak on both Danish, German, and Swedish part of Kriegers Flak.

2 FISH HABITAT

Fish play a crucial role in the Baltic Sea ecosystem as consumers of plankton and benthic invertebrates, and they serve as prey for marine top predators. The fish species in the Baltic Sea include a mix of marine and freshwater species adapted to brackish conditions (water with low salinity). Approximately one hundred fish species inhabit the Baltic Sea, with about 70 marine species dominating the Baltic Proper, and around 30-40 freshwater species occurring in the coastal and innermost areas (NIRAS, 2015).

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 KF II OWF area are described.

2.1 Hydrography

In prehistoric times, the area where Kriegers Flak II North and South is located was a freshwater lake. Consequently, the Baltic Sea is considered a geologically young water body with relatively low biodiversity. The salinity in the area is approximately 7-11 PSU at a depth of seven meters (NIRAS, 2015). High salinity currents and relatively dense water from the North Sea flow into the Kattegat through the Øresund and into the Baltic Sea. Here, these water masses mix with brackish water, and the outflow of Baltic Sea water, characterized by low salinity, typically occurs as northwestern surface currents (COWI, 2021).

The depths in the planned KF OWF area range from 10-50 m (Table 1-1). The planned Kriegers Flak OWF area has a central position in the water exchange between the North Sea and the Baltic Sea. Heavy bottom currents through the Øresund generally flow north of Kriegers Flak but can, if strong enough, cover the entire area (NIRAS, 2015). Figure 2-1 and 2-2 shows the currents and average current velocity in the Baltic Sea and specifically for the Kriegers Flak OWF area.

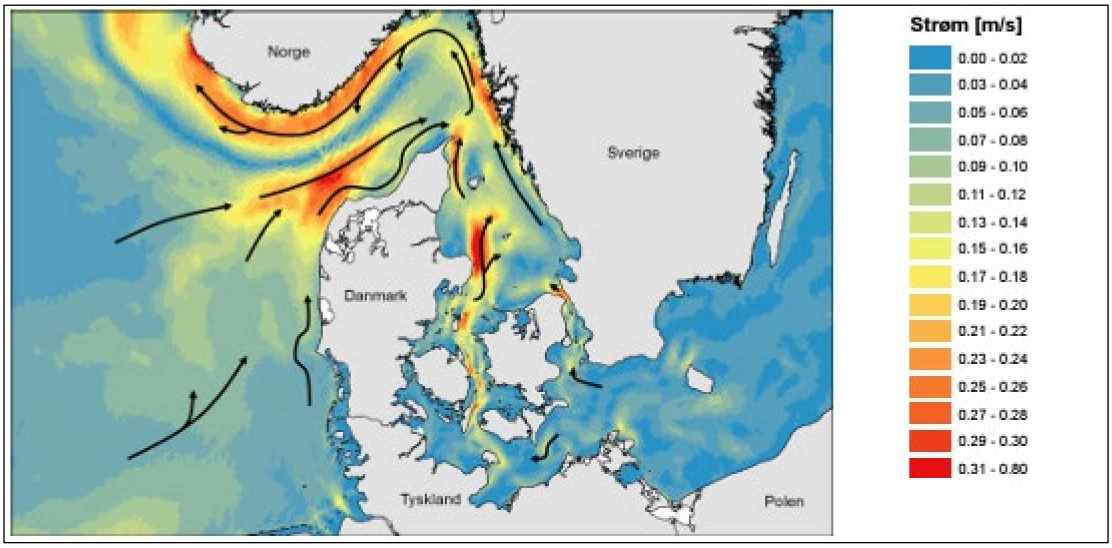

Figure 2-1. Average current speed, 2013 -2016. Source: DHI, 2017 in Miljø- og Fødevareministeriet, 2019.

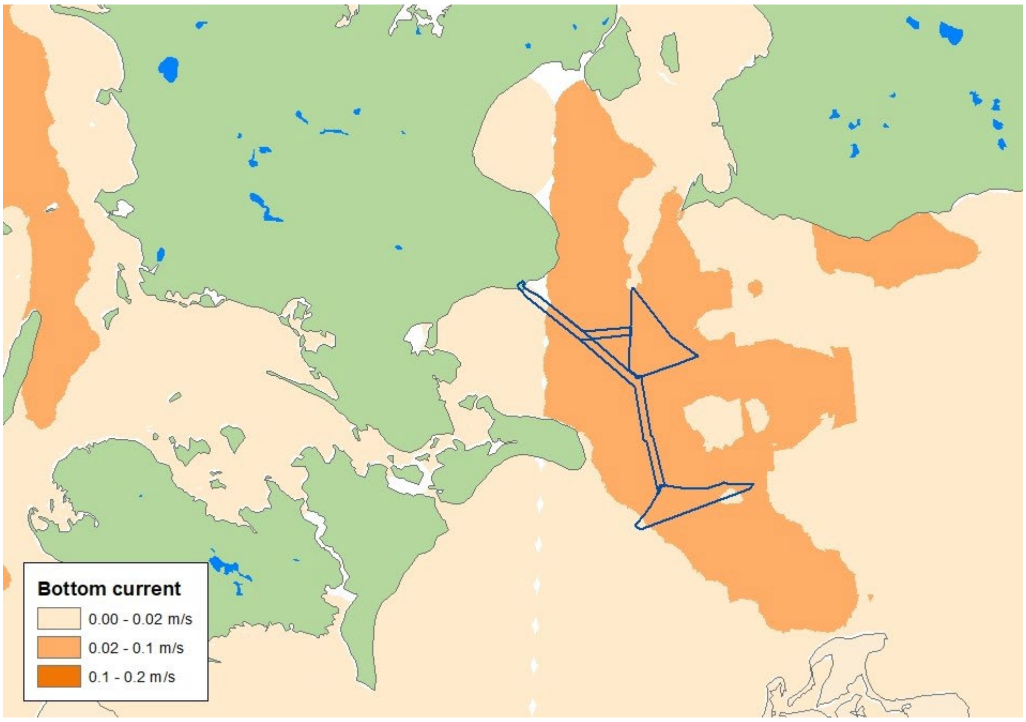

Figure 2-2. Annual mean bottom current velocity in the Kriegers Flak OWF area. Source: The Danish Spatial and Environmental Planning Agency, 2007.

2.2 Marine substrate

Large parts of the Kriegers Flak II North area are covered by muddy sand (Figure 2-3). In this region, as in the rest of the western Baltic Sea, there is typically a weak flow, allowing marine muddy sand to accumulate over the last 5000 years (Naturstyrelsen, 2014 in COWI, 2022). A significant area in the western part of Kriegers Flak II North consists of till (a mixed sediment type of glacial origin, often covered by a thin layer of sand, gravel, boulders, and/or sandy mud washed out from the till) / diamicton (containing particles ranging in size from clay to boulders). The hard bottom composed of moraine, rock bottom, and rock in the Kriegers Flak II North area is vital for specific fish species that inhabit hard substrates.

The eastern part of Kriegers Flak II South is covered by muddy sand, while the western and central parts are covered by sand (Figure 2-3). The export cable corridors will cross areas of till/diamicton, muddy sand, sand, gravel, and coarse sand. Closer to shore, near Faxe Bugt, the cable corridor will cross an area of sedimentary rock (Figures 2-3 & 2-4).

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 sand eel, 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.), sand eel, and juvenile plaice and flounder are likely abundant in these mixed habitats.

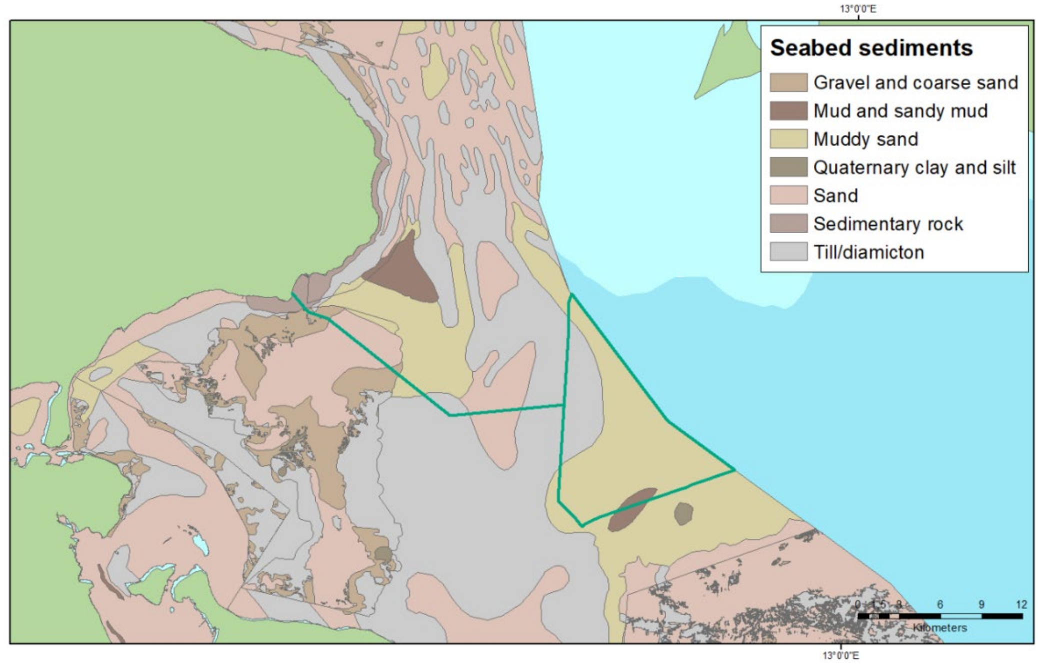

Figure 2-3. Seabed sediments in the Kriegers Flak II North OWF area and export cable corridor. Source: GEUS, 2023.

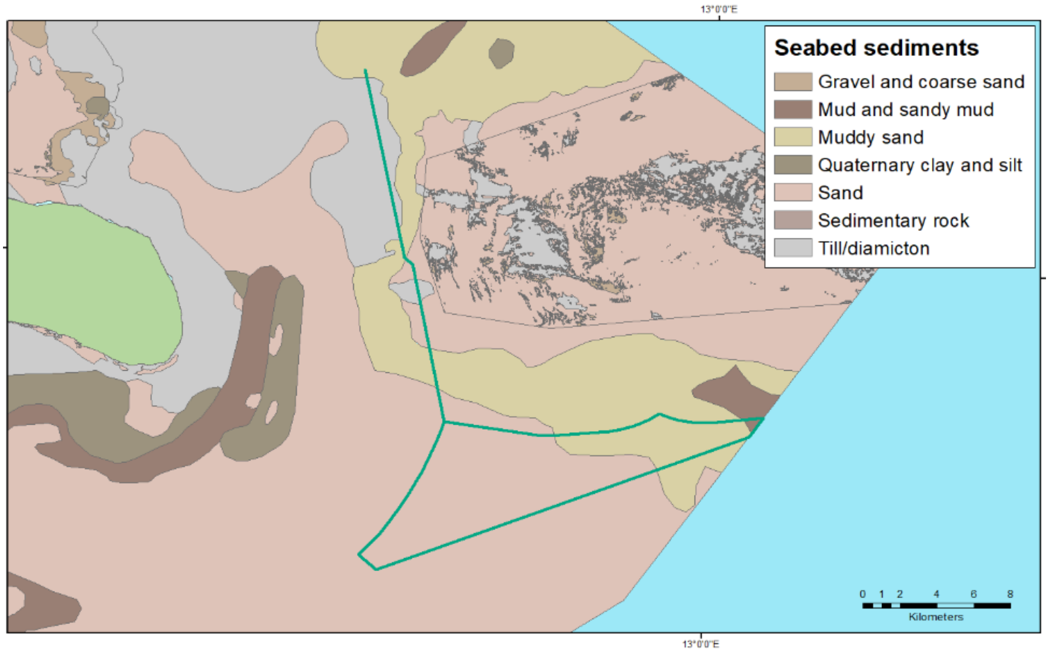

Figure 2-4. Seabed sediments in the Kriegers Flak II South OWF area and export cable corridor (which meet the border of Kriegers Flak II North and continues in the same corridor to land). Source: GEUS, 2023.

3 FISH POPULATIONS

In connection with previous offshore wind projects, fish surveys have been conducted in the Danish, Swedish, and German parts of Kriegers Flak (Vattenfall, 2004a; 2004b, NIRAS, 2015). The results from the German and Swedish parts of Kriegers Flak were assessed to be representative for the Danish part as well (NIRAS, 2015).

A total of 44 fish species were recorded in these field surveys, and 37 fish species were recorded in the export cable corridor (Tables 3-1 & 3-2) (NIRAS, 2015). The export cable corridor for the existing Kriegers Flak OWF is similar, or close to, the planned export cable for the KF II OWF areas. Key species included cod (*Gadus morhua*), whiting (*Merlangius merlangus*), European flounder (*Platichthys flesus*), plaice (Pleuronectes platessa), turbot (Psetta maxima), herring (*Clupea harengus*), sprat (*Sprattus sprattus*), sandeel (*Ammodytes* sp.), and eel (*Anguilla anguilla*). Cod, flounder, and plaice are species that are continuously present in the area. Herring and sprat are species that can periodically occur in great numbers, making them of significant ecological importance. Additionally, six fish species were registered during diving surveys: black goby (*Gobius niger*), transparent goby (*Aphia minuta*), gunnel (*Pholis gunnellus*), striped seasnail (*Liparis liparis*), two-spotted goby (*Gobiusculus flavescens*), and short-spined sea scorpion (*Myoxocephalus scorpius*).

It is also assumed that black seabream (*Spondyliosoma cantharus*), various species of wrasses, gunnel (*Pholis gunnellus*), viviparous blenny (*Zoarces viviparus*), and lemon sole (*Microstomus kitt*) occur in significant numbers in the Kriegers Flak area (Angantyr, 2007 in COWI, 2022).

Table 3-1. Fish species in the western Baltic Sea that have most of their life cycle in the area. Source: NIRAS, 2015*.

Fish species	Habitat
Herring *(Clupea harengus)*	In shoals, < 200 m depth, pelagic.
Sprat *(Sprattus sprattus)*	In shoals, pelagic.
Garfish *(Belone belone)*	Migrating, pelagic.
Horse mackerel (*Trachurus trachurus*)	Migrating, sporadic, pelagic.
Three-spined stickleback (*Gasterosteus aculeatus*)	Close to shore, in shoals offshore outside spawning, pelagic.
Transparent goby (*Aphia minuta*)	In shoals 0-80 m, pelagic.
Salmon (*Salmo salar*)	Migrating, pelagic.
Trout (*Salmo trutta trutta*)	Migrating, pelagic.
Smelt (*Osmerus eperlanus*)	In shoals, migrating, mostly coastal, pelagic.
Thicklip grey mullet (*Chelon labrosus*)	In shoals, mostly coastal, pelagic.
Twaite shad (*Alosa fallax*)	In shoals, migrating, mostly coastal, pelagic.
Plaice *(Pleuronectes platessa)*	Sandy or mixed seabed, 10-50 m depth, demersal.
Dab *(Limanda limanda)*	Sandy seabed, <100 m, demersal.
Flounder *(Platichthys flesus)*	Soft seabed, <100 m, demersal.
Turbot *(Scophthalmus maxima)*	Sandy and rocky seabed, < 70 m depth, demersal.

Brill *(Scophthalmus rhombus)*	Sandy seabed, < 50 m depth, demersal.
Striped seasnail (*Liparis liparis*)	Hard or rocky seabed, benthic.
Viviparous blenny (*Zoarces viviparus*)	2-20 m, deeper during winter, benthic.
Gunnel (*Pholis gunnellus*)	2-30 m, deeper during winter, benthic.
Goldsinny wrasse (*Ctenolabrus rupestrus*)	1-20 m depth, benthic.
Short-spined sea scorpion (*Myoxocephalus scorpius*)	Mixed seabed, 0-20 m depth, benthic.
Long-spined bullhead (*Taurulus bubalis*)	Mixed seabed, 0-20 m depth, benthic.
Armed bullhead (*Agonus cataphractus*)	Soft seabed, coastal in winter, benthic.
Fourbeard rockling (*Enchelyopus cimbrius*)	Soft seabed, >20 m, benthic.
Striped red mullet (*Mullus surmuletus*)	Hard or rocky seabed, <100 m, benthic.
Sand goby (*Pomatoschistus minutus*)	Sandy and soft seabed, coastal, benthic.
Black goby (*Gobius niger*)	Sandy and soft seabed, coastal <50 m depth, benthic.
Cod *(Gadus morhua)*	Demersal, periodically pelagic.
Lumpsucker (*Cyclopterus lumpus*)	Benthic in spawning, pelagic migration.
Sand eel (*Ammodytes* sp.)	Benthic (buried) at night and in winter, pelagic during day.
Great sand eel (*Hyperoplus lanceolatus*)	As for Ammodytes. Buried at night.
Eel (*Anquilla anguilla*)	Demersal and pelagic in migration.
Two-spotted goby (*Gobiusculus flavescens*)	Benthic/pelagic, <20 m depth.

* The table has summarized information from several references. Please refer to NIRAS, 2015 for all references used the table.

Table 3-2. Fish species registered in the western Baltic Sea that have a sporadic occurrence in the area. Source: NIRAS, 2015*.

Fish species	Habitat
Whiting *(Merlangius merlangus)*	Close to shore, <100 m depth, pelagic.
Saithe *(Pollachius virens)*	In shoals, <250 m depth, pelagic.
Blue whiting *(Merluccius merluccius)*	70-200 m depth, close to seabed daytime, pelagic.
Anchovy *(Engraulis encrasicolus)*	Migrating, sporadic, pelagic.
Mackerel *(Scomber scombrus)*	Migrating, pelagic.
Long rough dab *(Hippoglossoides platessoides)*	Soft seabed, >10 m depth, demersal.
Lemon sole *(Microstomus kitt)*	Hard or rocky seabed, 20-200 m depth, demersal.

Common sole *(Solea vulgaris)*	Sandy or soft seabed, < 60 depth, demersal.
Snake blenny (*Lumpenus lampretaeformis*)	Soft seabed, >50 m depth, demersal.
European river lamprey (*Lampetra fluviatilis)*	Coastal, migrating, demersal.
Haddock *(Melanogrammus aeglefinus)*	10-200 m depth, benthic.

* The table has summarized information from several references. Please refer to NIRAS, 2015 for all references used in the table.

3.1 Spawning 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.

There are no known spawning areas for fish that spawn their eggs near or on the seabed within the KF II OWF areas. However, close to the coast of both Stevns and Møn, there are large spawning areas (Figure 3-1) (HELCOM, 2024). Herring has potential spawning areas close to the coast (Figure 3-6).

Fish species such as cod, European flounder, Baltic flounder, and sprat have potential spawning areas that overlap with the KF II OWF areas. As several key fish species such as European flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*), and sprat (*Sprattus sprattus*) primarily spawn in the deeper parts of the Baltic Sea, it is unlikely that these species will spawn in the relatively shallow areas, including the areas for the planned KF II OWF. Please refer to Chapter 3-2 for further details on key fish species and their spawning areas in and close to the KF II OWF areas.

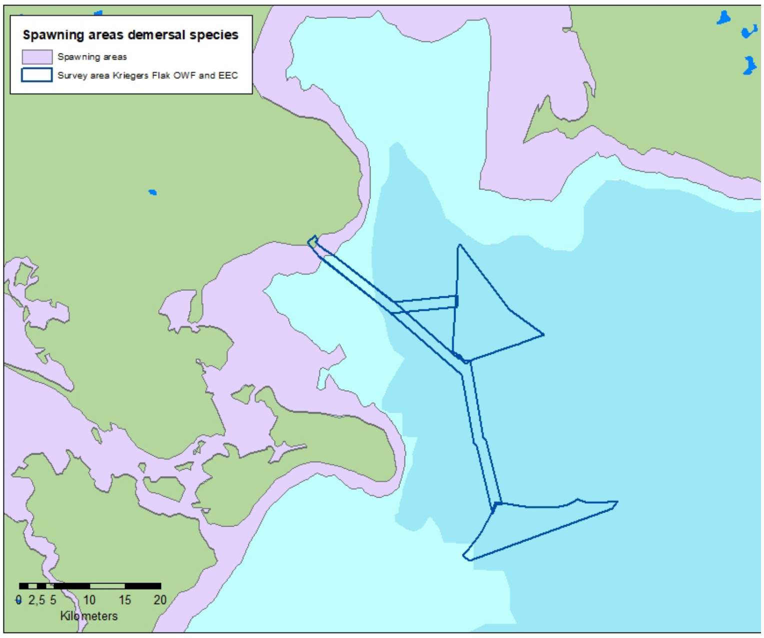

Figure 3-1. Spawning areas for fish that spawn their eggs near or on the seabed in the coastal areas surrounding the Kriegers Flak II North and South areas, including the landfall area of the export cables. Source: HELCOM, 2024.

3.2 Key fish species

3.2.1 Cod

Cod (*Gadus morhua*) is the most widely distributed predatory fish species in the Baltic Sea. As the predominant predatory fish species in the open sea, cod serves as a central link in the food web connecting benthic and pelagic systems (HELCOM, 2021a). In the Baltic Sea, cod is represented by three stocks: Eastern Baltic, Western Baltic, and Kattegat cod (HELCOM, 2020).

The Western Baltic stock is characterized as highly productive but also highly fluctuating. Typically, cod is a demersal species, spending most of their time near the seabed. However, depending on factors such as location, season, and life stage (juvenile or adult), they can also be found in the pelagic zone. Cod exhibit omnivorous and opportunistic feeding behaviour, preying on both benthic invertebrates and other fish. Juvenile cod consume a wide variety of benthic fauna, including bristle worms and crustaceans (such as crabs and shrimp), while larger cod tend to feed on other fish species like herring, sprat, and other cod (Hüssy et al., 1997 in NIRAS, 2022).

The spawning period for Western Baltic cod (ICES subdivisions 22-24) occurs from January to May, with the main spawning peak in March and April (HELCOM, 2021a). Environmental conditions play a critical role in successful spawning. Suggested threshold values include a salinity range of 18-33 PSU to ensure egg development and survival, along with a minimum temperature of > 2°C. However, the hydrographical conditions in the western Baltic, are less critical, and instead cod population abundance and age structure are relatively more important factors for recruitment. The Arkona deep is considered to be a functional spawning ground for Western Baltic cod stocks (Figure 3-2).

In January and February, mature cod gather in large schools over deeper waters to spawn. Spawning is often limited to areas where the water salinity is high enough—around 15-16 per thousand for cod in the western part of the Baltics. 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.

Fish surveys with a particular focus on cod fry were conducted at Kriegers Flak in February and May 2013 (NIRAS, 2015). Only a few cod ready for spawning were caught in this area, leading to the conclusion that it does not constitute a definite spawning area for cod (NIRAS, 2015). However, the results revealed a large occurrence of small cod with a length between 24-28 cm, indicating that the Danish part of Kriegers Flak could be of importance as a breeding area for cod (NIRAS, 2015). Similar findings were observed in the Swedish and German parts of Kriegers Flak, where the catch of immature individuals (<30 cm) suggests that the area serves as both a breeding and foraging ground for cod. However, these fish surveys are more than 10 years old, and the status of the western Baltic Sea cod stock is now critical due to a combination of overfishing, habitat degradation, pollution, and changes in the ecosystem (ICES, 2023d). Seasonally poor oxygen conditions in the bottom water adversely affect the habitat, benthic food supply, and metabolism of cod. During summer, poor oxygen conditions accumulate below the halocline in the western Baltic Sea due to eutrophication and rising temperatures associated with climate change. Simultaneously, warmed surface waters restrict cod habitat use during summer and autumn (HELCOM, 2023b). These factors have led to poor recruitment rates and a decline in the overall stock biomass of the western Baltic Sea cod.

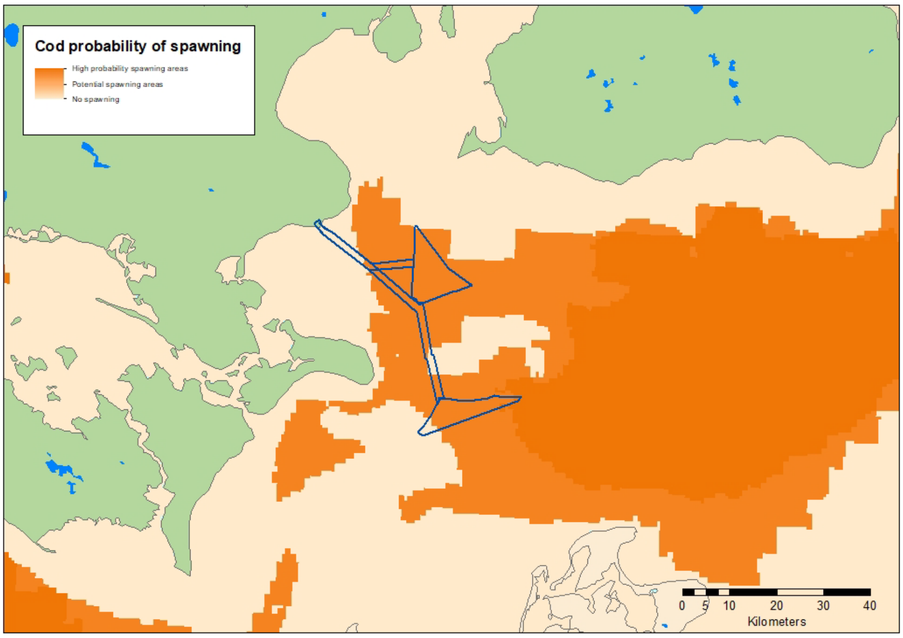

Figure 3-2. Spawning areas for cod (*Gadus morhua*) in the western Baltic Sea shown in orange. The polygons show the planned Kriegers Flak OWF area and the EEC. Source: HELCOM, 2024.

3.2.2 Whiting

Whiting (*Merlangius merlangus*) is a semi-pelagic codfish that can be found both near the seabed and in the pelagic zone. Whiting occurs sporadically in the Baltic Sea, and during certain periods or years, they occur in very large numbers (NIRAS, 2015). Whiting was consistently caught in bottom trawls during fish surveys in 2013, as well as in gillnet surveys in near-shore hard bottom habitats that serve as their nursery areas.

The western Baltic Sea serves as breeding and foraging areas for whiting, and the same is assumed to apply to Kriegers Flak (NIRAS, 2015). This assumption is supported by field surveys conducted in the German and Swedish parts of Kriegers Flak, where most individuals measured between 10-30 cm in length (Vattenfall, 2004a). There are no known specific spawning grounds for whiting in the Baltic Sea or adjacent waters. 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 (NIRAS, 2015). However, the exact migration routes and seasonal patterns remain poorly understood.

3.2.3 Flounder

The two flounder species in the Baltic Sea, the European flounder (*Platichthys flesus*) and the Baltic flounder (*Platichthys solemdali*), exhibit different reproductive strategies, and their principal spawning areas are spatially and temporally separated. Specifically:

- The Baltic flounder spawns in shallow waters, while the European flounder spawns in deeper areas (Figure 3-3 & 3-4).
- Despite these differences, larvae of both species settle in shallow areas, resulting in the two species sharing the same nursery habitat (Figure 3-5).

- Both European and Baltic flounder spawn in spring: the former from late winter to spring, and the latter in spring and early summer.
- Young-of-the-year fish can be observed from June to September on shallow seabed, primarily composed of sandy substrates (HELCOM, 2021a).

European flounder plays a key role in the central and south-western sub-basins of the Baltic Sea (HELCOM, 2021a). Its life cycle involves migration between coastal and open sea areas. During summer, adults feed in shallow coastal regions and then move to deeper areas in winter, where spawning occurs in spring. European flounder exclusively spawns in deep offshore basins of the south-western and central Baltic Sea. Here, the salinity is high enough for successful fertilization, and water density allows the eggs to float in the water column, avoiding anoxic bottom waters (Nissling et al. 2002; Ustups et al. 2013 in Helcom, 2021a). Early juvenile stages reside in shallow coastal areas until they recruit to the adult population. In November, fry migrate from coastal zones to depths of 5-10 meters, where water temperatures are higher. In spring, they return to very shallow areas in search of food (DTU, 2012).

Adult Baltic flounder exhibits a migratory behaviour, feeding in coastal areas during summer and moving to deeper regions in winter (HELCOM, 2021a). Baltic flounder spawns in shallow coastal areas and on offshore banks. In these spawning grounds, the eggs sink to the bottom. Demersal spawning flounders have been observed laying their eggs on sandy and rocky bottoms or on rocky substrates covered with algae. Early juvenile life stages also reside in shallow coastal areas until they recruit to the adult population (HELCOM, 2021a). Successful spawning for demersal spawning Baltic flounder is expected at salinities around 5-7. Low oxygen concentration poses a less significant restriction to spawning, as coastal near-shore spawning waters are generally well oxygenated (HELCOM, 2021a).

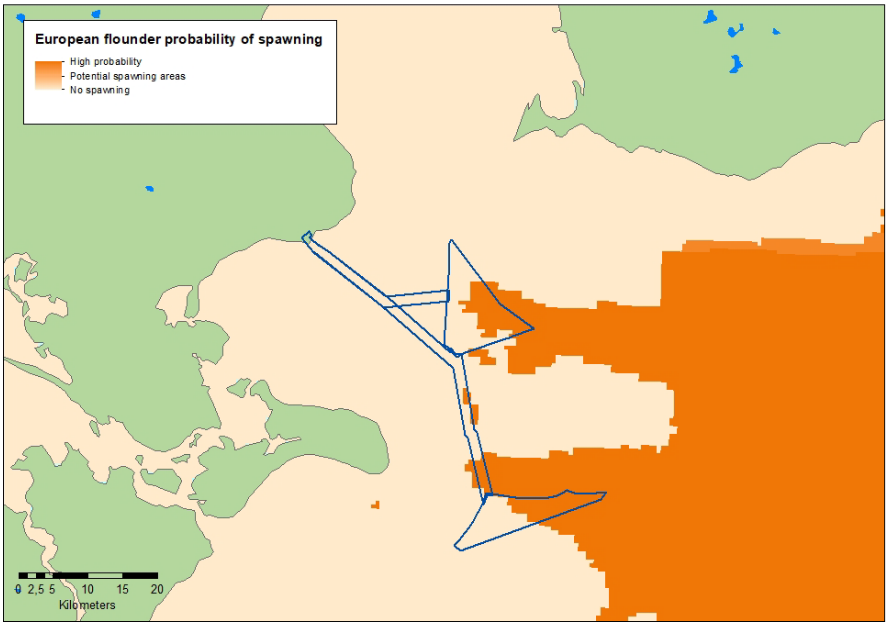

Figure 3-3. Spawning area for European flounder (*Platichthys flesus*) in the western Baltic Sea is shown in orange. The polygons show the planned Kriegers Flak OWF area and the EEC. Source: HELCOM, 2024.

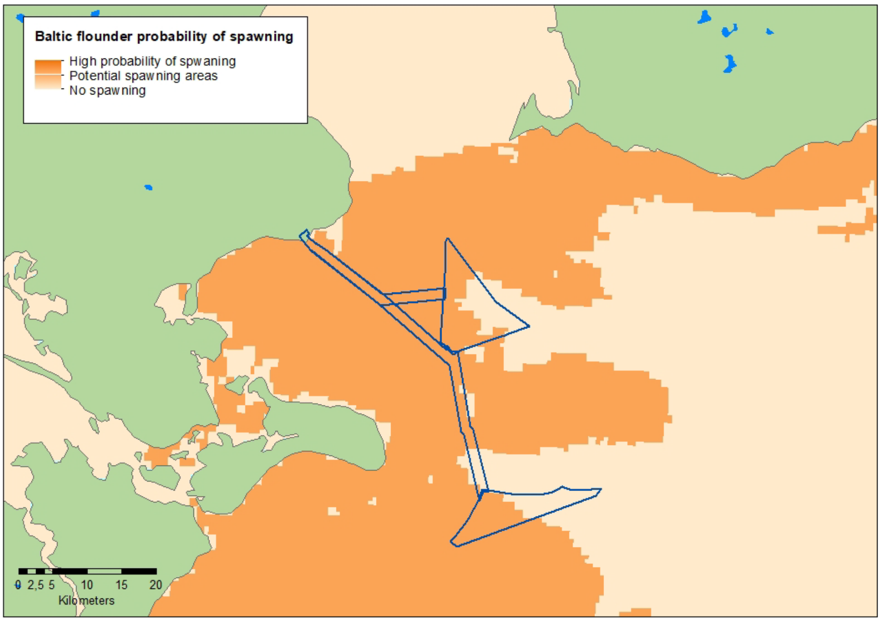

Figure 3-4. Spawning area for Baltic flounder (*Platichthys solemdali*) in the western Baltic Sea is shown in orange. The polygons show the planned Kriegers Flak OWF area and the EEC. Source: HELCOM, 2024.

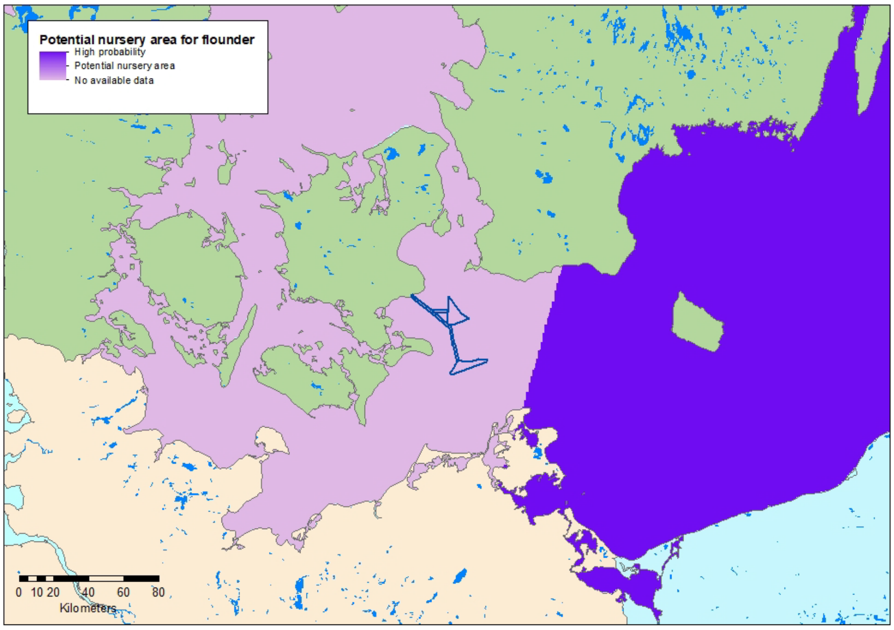

Figure 3-5. Potential nursery area for flounder. Source: HELCOM, 2024.

3.2.4 European 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. 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 also 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 (Muus & Nielsen, 1999 in NIRAS, 2022a). Larger individuals may even consume small fish. Plaice in the Baltic Sea have in the recent years been experiencing extraordinarily high recruitment from the year classes 2019, 2020, and 2021 (ICES, 2023a).

3.2.5 Herring

Herring (*Clupea harengus*) is widely distributed in the Baltic Sea and is common in the western Baltic Sea. Compared to herring in the Atlantic, Baltic Sea herring is smaller and well adapted to the low salinity of its environment. Herring primarily feeds in the pelagic zone, where it mainly consumes zooplankton. It serves as an important prey for cod and marine mammals and holds significant commercial importance throughout the Baltic Sea (HELCOM, 2021a).

Genetic studies and observations on spawning behaviour suggest that herring exhibits strong local population structure in the Baltic Sea. There are populations of both spring-spawning and autumn-spawning herring in the region, with spring-spawning herring currently dominating (HELCOM, 2021a). The herring in the western Baltic belongs to the spring-spawning herring stock, which spawns in both the Kattegat and the Baltic Sea.

Herring spawns in relatively shallow areas (typically 0-8 meters deep), often in locations characterized by hard bottoms or soft bottoms with erect vegetation (Figure 3-6). Its eggs are demersal, which are attached to the seabed substrate. 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 (Figure 3-7). The herring schools revisit the same spawning grounds from one generation to the next (Raid, 1990 in HELCOM, 2021a).

The western Baltic herring, which is a crucial resource for small-scale fisheries in the region, has been producing fewer offspring since 2004 (Polte et al., 2021 in HELCOM, 2021a). ICES advises a zero catch in 2024 (ICES, 2023b). However, quantifying the impact of cumulative non-fisheries anthropogenic factors (such as climate change effects, eutrophication, and spawning habitat degradation) on the reproductive capacity of the stock remains challenging. Non-fishing impacts significantly affect the survival of early life stages in the western Baltic spring-spawning herring population.

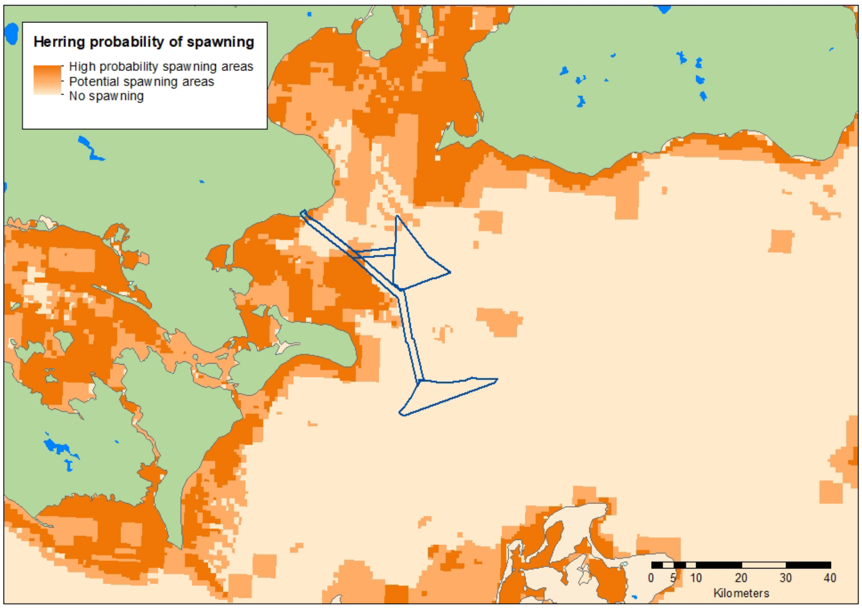

Figure 3-6. Potential spawning areas for herring (*Clupea harengus*) in the western Baltic Sea is shown in orange. The polygons show the planned Kriegers Flak OWF area and the EEC. Source: HELCOM, 2024.

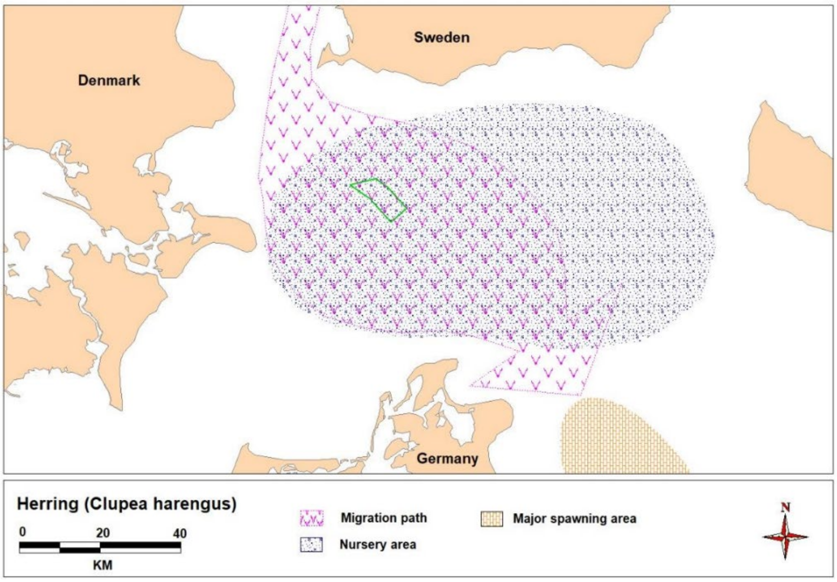

Figure 3-7. A qualitative schematic overview of expected migration paths, nursery, and spawning areas for the western Baltic herring, both spring and autumn spawning. Green area: Kriegers Flak Offshore Wind farm, Sweden. Source: BioApp, 2018.

3.2.6 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, 2022a). Sprat is a pelagic schooling species, which preys 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 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. However, the highly stratified, deep basins in the central Baltic are known to be the major spawning grounds of Baltic sprat (Figure 3-8). The overall recruitment success varies tightly with temperature (Baumann et al. 2006 in NIRAS, 2015). Sprat eggs are pelagic and are assumed to have a minimum limit for survival and buoyancy at a salinity of 6 (Petereit et al. 2009 in HELCOM, 2021). 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).

Sprat represents one of the most important commercially exploited fish species in the Baltic Sea (HELCOM, 2021a), and the catches in the Baltic Sea have been relatively stable the last years (Statistics Denmark, 2023). However, the two most recent recruitment estimates are among the lowest historical assessments done, and if such poor recruitment continues, the declining trend in spawning stock biomass will continue (ICES, 2023e).

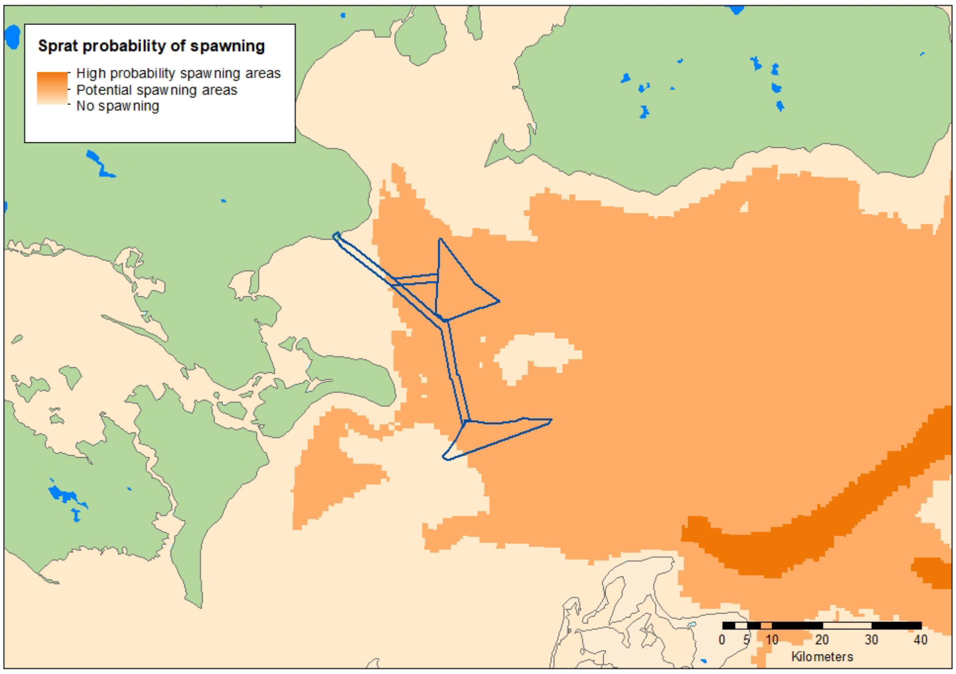

Figure 3-8. Spawning area for sprat (*Sprattus sprattus*) in the western Baltic Sea is shown in orange. The polygons show the planned Kriegers Flak OWF area and the EEC. Source: HELCOM, 2024.

3.2.7 Turbot

The turbot (*Scophthalmus maximus*) is predominantly stationary but migrates between shallower waters and deeper areas in the spring and autumn. Spawning occurs during the summer. At salinities lower than 20 ‰, the eggs sink to the bottom, rendering them predominantly demersal in the Baltic Sea. Spawning takes place at depths of 10 to 40 meters, and the larvae/fry move towards shallower coastal waters (Florin, 2005 in NIRAS, 2015).

3.2.8 Sandeel

Sandeel (*Ammodytidae*) are a crucial part of the diet for larger fish. They typically inhabit sandy seabed, where they have specific requirements for both habitat and spawning conditions. Sandeel prefer medium-fine to coarse sand with grain sizes between 0.25 and 1.2 mm, avoiding areas where fine sand, silt, or clay content exceeds 6 % (Wright et al., 2000; Jensen et al., 2003; Temming et al., 2004 in NIRAS, 2015). At night and during winter, sandeel burrow into the seabed. They lay their eggs in the same sandy areas they inhabit. While the larvae are pelagic, juveniles (35-40 mm) return to these specific seabed types (Jensen, 2001 in NIRAS, 2015). Sandeel is reproducing in Kattegat, and it is unknown how far into the Baltic Sea this marine species can be found (Figure 3-9) (HELCOM, 2024).

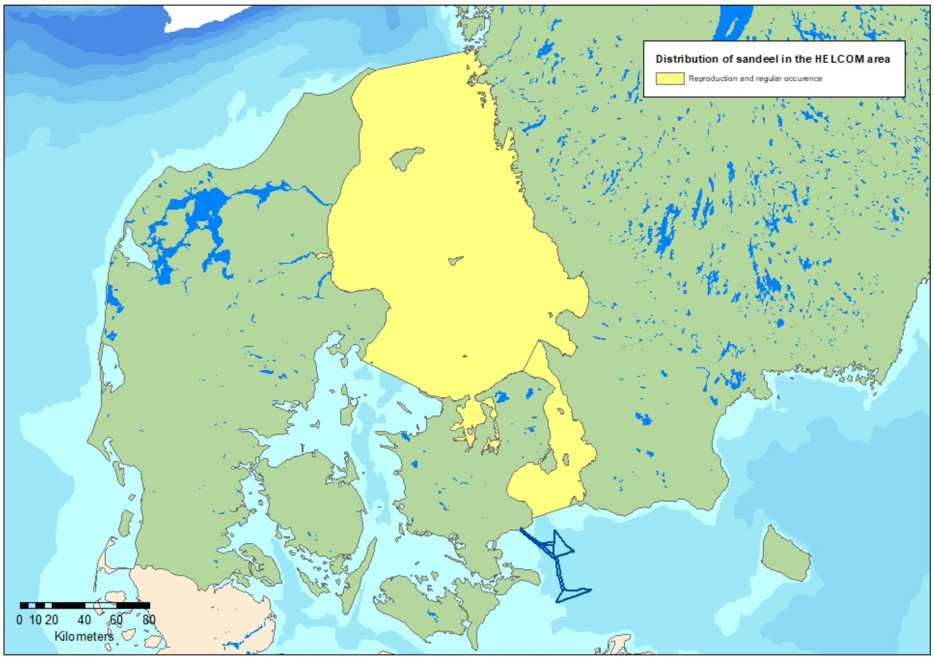

Figure 3-9. HELCOM area where sandeel (*Ammodytes marinus*) is known to occur regularly and to reproduce Source: HELCOM, 2024.

3.2.9 Eel

Eels (*Anguilla Anguilla*) spawn in the Sargasso Sea, and the larvae migrate into Danish waters and the Baltic Sea with the currents. The eels' return migration to the Sargasso Sea primarily occurs at night from August to November. During this migration, they swim under the cover of darkness, usually near the surface, with several dives to deeper water layers. During the day, they remain more passive near the bottom (Westerberg et al., 2007). Recruitment has shown a significant decline over the past several decades and is now at the historically lowest levels, at 1-5 % of pre-1980 levels (ICES, 2023c). ICES advises zero catches in all habitats in 2024, including both recreational and commercial fishing.

3.3 Protected fish species

Several protected fish species either regularly occur or potentially occur in the KF II OWF areas or export cable corridor (HELCOM, 2024).

Fish species classified as endangered or highly endangered in the western Baltic Sea include the eel (*Anguilla anguilla*), cod (*Gadus morhua*), European river lamprey (*Lampetra fluviatilis*), Atlantic salmon (*Salmo salar*), twaite shad (*Alosa fallax*), sea lamprey (*Petromyzon marinus*), Atlantic sturgeon (*Acipenser oxyrinchus*), houting (*Coregonus oxyrinchus*), maraene (*Coregonus maraena*), and allis shad (*Alosa alosa*).

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, maraene as Endangered, and cod, whiting (*Merlangius merlangus*), trout (*Salmo trutta*), and Atlantic salmon as Vulnerable (HELCOM Red List, 2019). The Atlantic sturgeon is considered Regionally Extinct in the HELCOM area.

The Danish Red List covers only freshwater fish, but the eel, Atlantic salmon, and sea lamprey are also found in marine environments for varying periods; eel is classified as Critically Endangered, and the Atlantic salmon as of Least Concern (Den Danske Rødliste, 2019). For sea lamprey there is insufficient information to make an assessment (DD, Data Deficient).

The EU Habitats Directive Annex II includes species whose conservation requires special areas of protection. In the western Baltic Sea, Annex II species include Atlantic salmon, houting, twaite shad, allis shad, and European river lamprey (*Lampetra fluviatilis*) (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, 2023b). 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).

3.4 Invasive fish species

The round goby (*Neogobius melanostomus*) is a relatively small demersal fish, likely introduced to the Baltic Sea via ballast water. It is currently one of the most widespread invasive fish species in Europe, expanding along the Danish coastline in the western Baltic Sea at a rate of about 30 km per year from 2008 to 2013 (Azour et al., 2015). Due to its life cycle and environmental adaptability, it is expected to spread into any remaining uninvaded areas (Thor et al., 2023).

The round goby has become predominant in many coastal areas (fig 3-10), exerting significant predatory pressure on epibenthic molluscs. It has also become an important prey species in regions where it is abundant, benefiting some piscivorous fish, like turbots, at an individual level (HELCOM, 2018). In August 2023, 3,000 small turbots were released into the sea at Stevns as a mitigation measure to limit the distribution of the round goby (ODDF, 2023).

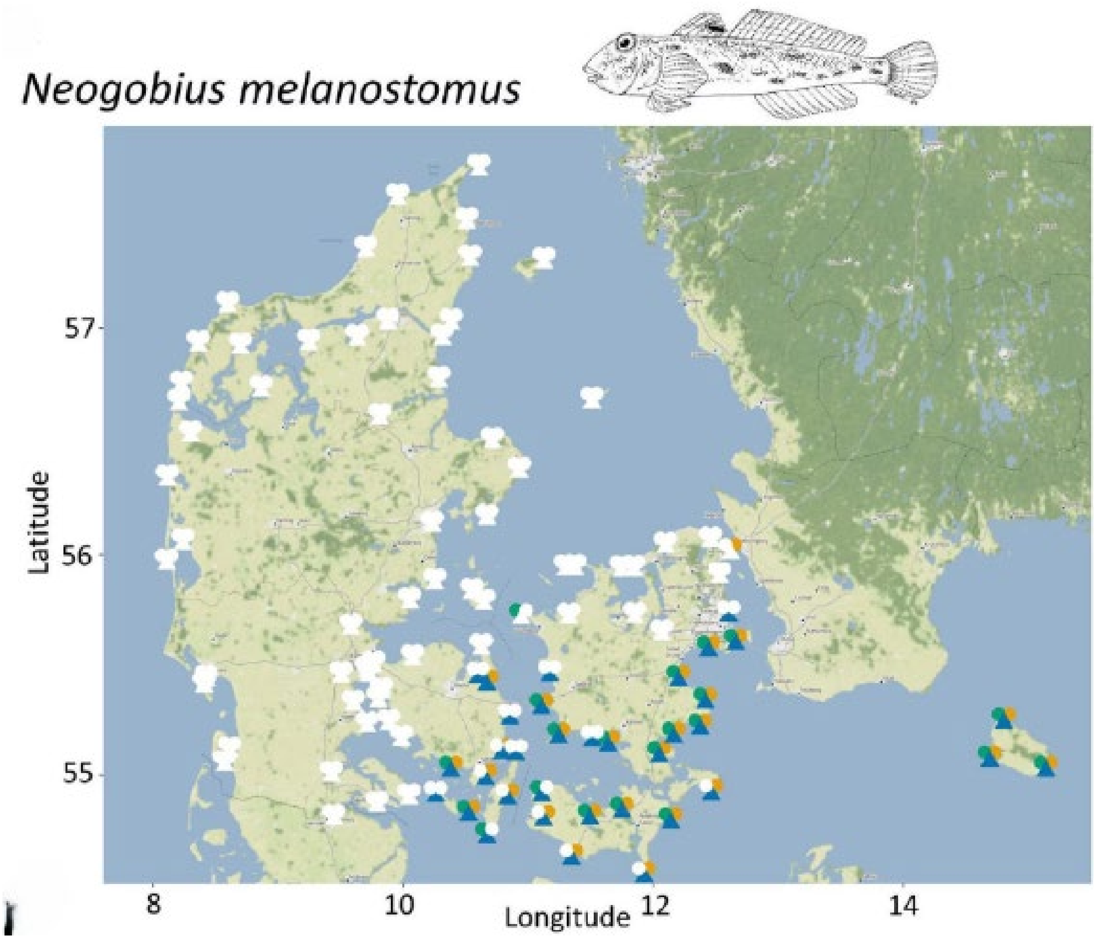

Figure 3-10. The figure show of distribution round goby (*Neogobius melanostomus*), an invasive species with an eastern distribution and an ongoing western expansion detected with eDNA during spring (bluish green) or autumn (orange) are represented by the "left" and "right" circle, respectively. Registrations by the Fish Atlas (blue) are represented by triangles. White coloured triangles or "left" and "right" circles indicate that the species is not detected on the location for the particular dataset. Fish drawing by Steen Wilhelm Knudsen, NIVA Denmark (Agersnap, S. et. Al, 2022).

4 POTENTIAL IMPACTS OF OFFSHORE WIND

The installation, operation, and decommissioning of OWFs and related infrastructure can 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 related to the specific KF II OWF project.

4.1 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 regularly found in the Kriegers Flak area and their sensitivity to noise are shown in Table 4-1. Hearing specialists, such as herring and sprat, have specialized anatomy, see Table 4-1. 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 (Popper & Hastings, 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 impact on fish from underwater operating noise from the Kriegers Flak OWF was assessed to be negligible (Energistyrelsen & Naturstyrelsen, 2015).

Table 4-1. Anatomical adaptations among fish species commonly found in the Kriegers Flak area 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

4.2 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 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 eel and salmon at Kriegers Flak. Among the species found in the Kriegers Flak/western Baltic Sea region, sea lamprey, Atlantic salmon, eel, trout, and European plaice 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).

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. Additionally, EMFs from subsea cables might interact with migrating eels and possibly salmonids if their migration routes cross the cables, particularly in shallow waters (< 20 meters). The effects might range from temporary changes in swimming direction to more serious avoidance behaviours or delays in migration, but the biological significance of these effects is not yet determined (Gill & Bartlett, 2010). 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). A lack of 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 a 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). The study conducted two years before and after the cable's commissioning, the study 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.

For marine fish, the risk of EMF exposure is particularly relevant during early life stages when fish have limited swimming capacity and are still developing (Cresci et al., 2022a). Impacts of magnetic fields on larval swimming or orientation behaviour 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). However, 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). The species in the Kriegers Flak area are to a large extent the same as found in the Hesselø area analysis and the negative impact will most likely be at the same level.

4.3 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 true 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 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).

Changes in sediment conditions can negatively affect the spawning success of fish species that deposit their eggs on the seabed and vegetation. This applies to several benthic species and to pelagic species like herring, which have specific requirements for spawning habitats and are thus sensitive to habitat changes.

4.4 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. However, suspended sediments can also expose or stir up food items (e.g., mussels, brush worms), attracting certain fish species (NIRAS, 2015).

4.4.1 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 (Engell-Sørensen & Skyt, 2002).

At Kriegers Flak, potential spawning areas are near the coast for herring, and within the OWF area for cod, European flounder, Baltic flounder, and sprat. 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).

4.4.2 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). Limit values for avoidance behaviour in pelagic fish species like cod are set at 10 mg/l. For flatfish, eels (including migrating eel larvae), and species living in shallow water, the limit is set at 50 mg/l (FeBEC, 2013).

4.5 Summary of sensitivities

The sensitivity of fish species in the western Baltic Sea to an 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.

The most sensitive species to an OWF development are:

- 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.

- 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.
- Flounder
  - Spawning areas: Flounder spawns in the western Baltic Sea, and changes in sediment conditions can negatively impact their spawning success. Flounder eggs and larvae might be affected by suspended sediments and changes in seabed composition.
- European Eel (*Anguilla anguilla*)
  - Migratory routes: Eels migrate across the western Baltic Sea, and electromagnetic fields (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.
- 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.
- Atlantic Salmon (*Salmo salar*) and trout (*Salmo trutta*)
  - Migratory routes and spawning: Both species use magnetic fields for navigation during migration. EMFs from subsea cables might alter their migration patterns, potentially causing delays or changes in their movement.
- Sea Lamprey (*Petromyzon marinus*)
  - Migratory behaviour: Sea lampreys also migrate in the western Baltic Sea, and like eels, they may be affected by EMFs from subsea cables. Changes in seabed conditions might impact their migratory routes and habitat use.
- Sandeel (*Ammodytes* ssp.)
  - Spawning and adults: Changes in sediment type and seabed disturbance can make habitats less suitable. Higher levels of suspended sediments can impact burrowing behaviour and prey availability. EMFs from subsea cables might impacts on behaviour and physiology.

5 SUMMARY

Key species in the western Baltic Sea include cod, whiting, flounder, plaice, turbot, herring, sprat, sandeel, and eel. Cod, flounder, and plaice are constantly present, while herring and sprat occur periodically in large numbers. There are no known spawning areas for fish that spawn their eggs near or on the seabed within the KF II OWF areas, although, close to the coast of both Stevns and Møn, there are large spawning areas.

Fish species such as cod, flounder, and sprat have potential spawning areas that overlap with the KF II OWF areas. As several key fish species such as European flounder, plaice, and sprat primarily spawn in the deeper parts of the Baltic Sea, it is unlikely that these species will spawn in the relatively shallow areas, including the areas for the planned KF II OWF. Whiting, flounder, plaice, herring, sprat, turbot, and sandeel have distinct spawning and feeding behaviours, and their presence in the area varies seasonally. Cod is a crucial predator in the western Baltic Sea and have experienced a decline in the overall stock biomass due to environmental and human impacts.

Protected species in the western Baltic Sea include eel, cod, and Atlantic salmon, among others. Invasive species like the round goby are spreading and impacting local ecosystems, and mitigation measures such as releasing turbot to control their population, have been initiated.

REFERENCES

Agersnap, S., Sigsgaard, E. E., Jensen, M., Avila, M., Carl, H., Møller, P. R., Krøs, S. L., Knudsen, S. W., Wisz, M.S., Thomsen, P. F., 2022. A National Scale "BioBlitz" Using Citizen Science and eDNA Metabarcoding for Monitoring Coastal Marine Fish. Frontiers in Marine Science. Vol. 9, 2022. https://www.frontiersin.org/articles/10.3389/fmars.2022.824100

Angantyr, L. R. (2007). Fisk i Øresund. Øresundsvandsamarbejdet.

Azour, F., Deurs, M., Behrens, J., Carl, H., Hüssy, K., Greisen, K., Ebert, R., Møller, P, 2015. Invasion rate and population characteristics of the round goby *Neogobius melanostomus*: effects of density and invasion history. Aquatic Biology. Vol. 24: 41–52, 2015.

Bioapp, 2018. Impact from piling noise on fish from the Kriegers Flak offshore wind farm, Sweden. Bilag 2. Vattenfall. Note 005-2018.

Brawn,V.M., 2011. Feeding Behaviour of Cod (Gadus morhua). April 2011Journal of the Fisheries Research Board of Canada 26(3):583-596.

COWI, 2021. Miljøvurdering af Danmarks havplan. Miljørapport.

COWI, 2022. Opdatering af dele af finscreeningen fra 2020 samt finscreening af nyt havareal til etablering af havvindmølleparker.

Cresci, A., Durif, C., Larsen, T. Bjelland R., Skiftesvik, AB., Browman, H., 2022a. Magnetic fields produced by subsea high voltage DC cables reduce swimming activity of haddock larvae (*Melanogrammus aeglefinus*). PNAS Nexus, Volume 1, Issue 4, September 2022, pgac175, https://doi.org/10.1093/pnasnexus/pgac175

Cresci, A., Perrichon, P., Durif, C., Sørhus, E., Johnsen, E., Bjelland R., Larsen, T. Skiftesvik, AB., Browman, H., 2022b. Magnetic fields generated by the DC cables of offshore wind farms have no effect on spatial distribution or swimming behavior of lesser sandeel larvae (*Ammodytes marinus*). Marine Environmental Research Volume 176, April 2022, 105609.

Den Danske Rødliste, 2019. AU Ecoscience - Den danske Rødliste

DONG, 2007. Horns Rev 2 havmøllepark. Vurdering af virkninger på miljøet VVM-redegørelse. Oktober 2006. Dong energy.

DSC (2022): Literature review on barrier effects, ghost fishing, and electromagnetic fields for floating windfarms. Literature Review No. 1, for Equinor ASA, by Ocean Science Consulting Limited, Spott Road, Dunbar, Scotland, 99 pp

DTU, 2012. Fiskebestandenes struktur Fagligt baggrundsnotat til den danske implementering af EU's Havstrategidirektiv, 254_2012_fiskeestandenes_struktur_baggrundsnotat_til_havstrategi.pdf (dtu.dk)

EEA, 2024. https://eunis.eea.europa.eu/references/2325/species

Energinet, 2022. Scope of services. Document no. 22/03837-6.

Energinet, 2023. Data downloded from Gis-portal.

Energistyrelsen & Naturstyrelsen, 2015. Kriegers Flak Havmøllepark. VVM-redegørelse. Del 3 Det marine miljø.

Engell- Sørensen, K. & Skyt, P.H., 2002. Evaluation of the Effect of Sediment Spill from Offshore Wind Farm Construction on Marine Fish. Bio/consult as.

FeBEC, 2013. Fish Ecology in Fehmarnbelt. Environmental Impact assessment Report. Report no. E4TR0041 – Volume I

Fey, D., Jakubowska, M., Greszkiewicz, M., Andrulewicz, E., Otremba, Z., Urban-Malinga, B., 2019. Are magnetic and electromagnetic fields of anthropogenic origin potential threats to early life stages of fish? Aquatic Toxicology. Volume 209, April 2019, Pages 150-158

FFI, 2020. Effekter av støyforurensning på havmiljø - kunnskapsstatus og forvaltningsrådgiving. Forsvarets forskningsinstitutt (FFI), Havforskningsinstituttet, Miljødirektoratet. FFI-RAPPORT 20/01015. Miljødirektoratet M-1670|2020.

GEUS, 2023. Kartdata er lastet ned fra: Geus webshop

Gill, A., Bartlett, M., and Thomsen. F., 2012. Potential interactions between diadromous fishes of U.K.conservation importance and the electromagnetic fields and subsea noise from marine renewable energy developments. Journal of fish biology, 81, 664– 695.

Gill, A., & Bartlett, M., 2010. Literature review on the potential effects of electromagnetic fields and subsea noise from marine renewable energy developments on Atlantic salmon, sea trout and European eel. Scottish Natural Heritage, Commissioned Report No.401.

Griffin, F., Smith, E., Vines, C. & Cherr, G., 2008. Impacts of Suspended Sediments on Fertilization, Embryonic Development, and Early Larval Life Stages of the Pacific Herring, *Clupea pallasi*. A Report to the U.S. Army Corps of Engineers and the Long-Term Management Strategy Environmental Windows Science Work Group.

Hansson, S. 1995. En litteraturgenomgång av effekter på fisk av muddring och tippning, samt erfarenheter från ett provfiske inför Stålverk 80. I Strategier för fiskeribiologiska undersökningar relaterade till byggföretag i vatten. TemaNord 1995:513. Redigerad av Olsson, I., Bay, J. och Hudd, R. Nordiska Ministerrådet, Köpenhamn. S. 78-84.

Hastings, M. C. and Popper, A. N., 2005. Effects of sound on fish. California Department of Transportation Contract 43A0139 Task Order, 1.

HELCOM, 2013. HELCOM Red List

HELCOM Red List, 2019. Red List of Fish and Lamprey Species – HELCOM

HELCOM, 2020. HELCOM Metadata catalogue

HELCOM, 2021a. Essential fish habitats in the Baltic Sea. Identification of potential spawning, recruitment and nursery areas.

HELCOM, 2021b. HELCOM Map and data service

HELCOM, 2018, HELCOM Baltic Sea Environment Fact Sheets 2018 Microsoft Word - BSEFS-Abundance and distribution of round goby.doc (helcom.fi)

HELCOM, 2023, basic facts Basic Facts – HELCOM

HELCOM, 2023b. State of the Baltic Sea 2023. Third HELCOM holistic assessment 2016-2021. https://helcom.fi/wp-content/uploads/2023/10/State-of-the-Baltic-Sea-2023.pdf

HELCOM, 2023c, HELCOM Map and data service

HELCOM, 2024. https://maps.helcom.fi/website/mapservice/

Hutchinson, Z. L, Secor, D.H., Gill, A.B., 2018. The Interaction between resources species and electromagnetic fields associated with electricity production by Offshore wind Farms. Pacific Northwest National Laboratory.

Hvidt et al., 2004. Fish along the cable trace Nysed Offshore Wind Farms - final report. Dong Energy A/S.

ICES, 2023a. Plaice (Pleuronectes platessa) in subdivisions 21–23 (Kattegat, Belt Seas, and the Sound, Plaice (Pleuronectes platessa) in subdivisions 21–23 (Kattegat, Belt Seas, and the Sound) (figshare.com)

ICES, 2023b. Herring (Clupea harengus) in subdivisions 20–24, spring spawners (Skagerrak, Kattegat, and western Baltic). Herring (Clupea harengus) in subdivisions 20–24, spring spawners (Skagerrak, Kattegat, and western Baltic) (figshare.com)

ICES, 2023c. European eel (Anguilla anguilla) throughout its natural range. In Report of the ICES Advisory Committee, 2023. ICES Advice 2023, ele.2737.nea. https://doi.org/10.17895/ices.advice.21907860

ICES, 2023d. https://www.ices.dk/news-and-events/news-archive/news/Pages/baltic_advice.aspx

ICES, 2023e. https://ices-library.figshare.com/articles/report/Sprat_Sprattus_sprattus_in_subdivisions_22_32_Baltic_Sea_/21820581

IMR, 2020. Potensielle effekter av havvindanlegg på havmiljøet. Karen de Jong, Henning Steen, Tonje Nesse Forland, Henning Wehde (HI), Daniel Nyqvist (HI / Politecnico di Torino), Anne Christine Utne Palm, Kjell Tormod Nilssen, Jon Albretsen, Tone Falkenhaug, Martin Biuw, Lene Buhl-Mortensen og Lise Doksæter Sivle (HI) . Rapport fra Havforskningen 2020-42. Dato 04.11.2020.

IPPC, 2019. Chapter 5: Changing Ocean, Marine Ecosystems, and Dependent Communities. 14 June 2019

Kastelein, RA., van der Heul, S., Verboom, WC, Jennings, N.van der Veen, J., de Haan D, 2008. Startle response of captive North Sea fish species to underwater tones between 0.1 and 64 kHz. Marine Environmental Research Volume 65, Issue 5, June 2008, Pages 369-377. https://doi.org/10.1016/j.marenvres.2008.01.001

Kiørboe, T., Frantsen, E., Jensen, C. & Sørensen, G., 1981. Effects of suspended sediment on development and hatching of herring (Clupea harengus) eggs. Estuarine, Coastal and Shelf Science Volume 13, Issue 1, July 1981, Pages 107-111.

Miljø- og Fødevareministeriet, 2019. Danmarks Havstrategi II. Første del. April 2019.

Messieh, S.N, Peterson, R.H., Wildish, D.J.,1981. Possible impact from dredging and spoil disposal on the Miramichi Bay herring fishery.

Mueller-Blenkle, C., McGregor, P.K., Gill, A.B., Andersson, M.H., Metcalfe, J., Bendall, V., Sigray, P., Wood, D.T. & Thomsen, F. (2010) Effects of Pile-driving Noise on the Behaviour of Marine Fish. COWRIE Ref: Fish 06-08, Technical Report. 31st March 2010.

NIRAS, 2015. Kriegers Flak Havmøllepark, Fisk og fiskeri VVM-redegørelse Teknisk baggrundsrapport.

NIRAS, 2022. Hesselø Offshore Wind Farm. Fish. Technical report. Energinet Eltransmission A/S. Date 18. March 2022.

Nyqvist, D., Durif, C., Johnsen, M.G., De Jong, K., Forland, T.N., Sivle, Lise.Doksæ.,2020. Electric and magnetic senses in marine animals, and potential behavioral effects of electromagnetic surveys, Marine Environmental Research (2020), doi: https://doi.org/10.1016/ j.marenvres.2020.104888

ODDF, 2023. https://odff.dk/

Page, M., 2014. Effects of total suspended solids on marine fish: Pelagic, demersal and bottom fish species avoidance of TSS on the Chatham Rise Prepared for Chatham Rock Phosphate.

Polte et. al., 2021. Reduced Reproductive Success of Western Baltic Herring (Clupea harengus) as a Response to Warming Winters. Frontiers | Reduced Reproductive Success of Western Baltic Herring (Clupea harengus) as a Response to Warming Winters (frontiersin.org)

Popper, A. N. and Hastings, M. C., 2005. Effects of sound on fish. California Department of Transportation Contract 43A0139 Task Order, 1.

Statistics Denmark, 2023. https://www.dst.dk/en/Statistik/emner/erhvervsliv/fiskeri-og-akvakultur/fiskeri

Thomsen, F., Lüdemann, K., Kafemann, R. And Piper, W., 2006. Effects of offshore wind farm noise on marine mammals and fish, biola, Hamburg, Germany on behalf of COWRIE Ltd.

Thor, P., Naddafi, R., Nadolna-Ałtyn, K., Oesterwind, D., Henseler, C., Behrens, J.W., Erlandsson, M., Florin, A.-B., Jakubowska-Lehrmann, M., Jaspers, C., Lehtiniemi, M., Putnis, I., Quirijns, F.J., Rakowski, M., Rozenfelde, L., Ustups, D., Wandzel, T., Witalis, B. and Woźniczka, A., Invasive species in the Baltic Sea and their impact on commercial fish stocks, European Commission, Publications Office of the European Union, Luxembourg, 2023, doi:10.2926/175875

Van der Veer, H, Bergman, M., Dapper, R., & Witte, J., 1991. Population dynamics of an intertidal 0-group flounder *Platichthys flesus* population in the western Dutch Wadden Sea. Marine Ecology Progress Series Vol. 73, No. 2/3.

Vattenfall, 2004a. Fiskar vid svenska sidan Kriegers Flak, undersökningar.

Vattenfall, 2004b. Fiskar vid Kriegers Flak.

Westerberg H, Rönnbäck, P. & Frimansson, H., 1996. Effects of suspended sediment on cod egg and larvae and the behaviour of adult herring and cod. ICES Marine Environmental Quality Commitee, CM 1996/E:26.

Westerberg, H., Lagenfelt, I., and Svedäng, H. 2007. Silver eel migration behaviour in the Baltic. – ICES Journal of Marine Science, 64: 1457–1462

Westerberg and Lagenfelt, 2008. Sub-sea power cables and the migration behaviour of the European eel. Fisheries Management and Ecology, 15, 369-375.

Woodruff DL, IR Schultz, KE Marshall, JA Ward, and V. Cullinan. 2012. Effects of Electromagnetic Fields on Fish and Invertebrates. Task 2.1.3: Effects on Aquatic Organisms – Fiscal Year 2011 Progress Report. PNNL-20813, Pacific Northwest National Laboratory, Richland, Washington.

Wyman, M.T., Klimley, A.P., Battleson, R.D., Agosta, T.V., Chapman, E.D., Haverkamp, P.J, Pagel, M.D. & Kavet, R., 2018. Behavioral responses by migrating juvenile salmonids to a subsea high-voltage DC power cable Mar. Biol., 165 (8) (2018), 10.1007/s00227-018-3385-0

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