Bilaga 2

Utredning fisk

Impact from piling noise on fish from the Kriegers Flak offshore wind farm, Sweden

Note

Note 005-2018

Introduction

The technology within offshore wind industry is heading towards development of increasingly larger turbines and foundations. Vattenfall AB, Sweden has previously obtained permission from the Swedish authorities to construct and operate an offshore wind farm on Kriegers Flak in the Western Baltic, based on wind turbines up to 5 MW. This permission was granted in 2006, extended in 2015 and currently expires in 2018. As part of an application for a renewal of the permit, including the option to install larger wind turbines up to 20MW, an update of the impact assessment concerning fishes has been requested by the Swedish authorities.

Except for underwater noise during pile driving of foundations, the overall impact on fishes and fish communities, from increasing size of turbines at Kriegers flak is expected to be within the same magnitude as already assessed for 5MW turbines in the previous EIA, (Vattenfall, 2006) .

Increasing the size of turbines leads to an increase in foundation size as well. The present note serves as a background document for the updated environmental impact assessment (EIA) and describes in brief the fish community in the area and evaluates the impact from increased piling noise on fishes.

Existing knowledge about fish at Kriegers Flak.

The distribution of fish in the Baltic Sea is predominantly determined by salinity. In the Kattegat and Western Baltic, 97 marine fish species are registered. The number of species in the Baltic Sea is reduced from west to east and from south to north (Thiel et al., 1996). In general, especially non-commercial fish species suffer from relatively limited knowledge of species distribution, habitat requirements, genetic diversity, ecology and population status in the Western Baltic (HELCOM, 2002).

The fish community on Kriegers Flak has been surveyed in both the Danish, Swedish and German parts, using a wide range of fishing gear, (Vattenfall, 2004a) (Vattenfall, 2004a) (BioApp & Krogconsult, 2015). In total 23 species were caught in surveys associated with wind farm development projects and 6 additional species were observed in a diving investigation. The results showed that cod (*Gadus morhua*) is the most abundant benthopelagic and plaice, flounder and dab are the most abundant flatfish species in the area. This indicate that Kriegers Flak contains several habitat types among others sand bed, soft bottom and hard substrate habitats. Baltic herring and sprat were also caught, but these catches were more random because of their pelagic lifestyle. A total of 44 fish species have been recorded in the area around Kriegers Flak (BioApp & Krogconsult, 2015). Of these, 29 species occur regularly in the area. The catadromous European eel use the region as nursery and feeding area, while lump sucker (*Cyclopterus lumpus*) and garfish commence spawning migrations from the Atlantic into the Baltic Sea. The remaining 12 species have a sporadic occurrence and reside most of their lives outside the Baltic. For a complete list please see (BioApp & Krogconsult, 2015).

The fish communities in the Baltic Sea can in general be divided into two categories by way of life: Pelagic fish species living in the water column (e.g. Baltic herring (*Clupea harengus membras*), sprat (*Sprattus sprattus*), Atlantic salmon (*Salmo salar*), trout (*Salmot trutta*), twaite shad (*Alosa fallax*), garfish (*Belone belone*), sand eel (*Ammodytes ssp.)* (daytime) and demersal fish species living on - or near the seabed (e.g. Baltic cod (*Gadus morhua*), flatfishes, European eel (*Anguilla Anguilla*), sea scorpions several gobies.

Table 1. List of fish species caught in special designed surveys (benthic herring nets) at Kriegers Flak, (Vattenfall, 2004a), (Vattenfall, 2004b) (BioApp & Krogconsult, 2015).

Species caught	Swedish area				German area		*Danish area*	
	Fry trawl (bottom)	Fry trawl (pelagic)	Nordic Survey gill net	Driftnets	Special windfarm trawl		*Modified herring gillnets*	
					trawl 2002	trawl 2003	01-02-2013	01-05-013
	Number	Number	Number	Number	Number	Number	Number	Number
	pr. 1000 m²	pr. 1000 m²	per net	per net	pr. 1000 m²	pr. 1000 m²	per net	per net
Cod (*Gadus morhua*)	9,57	0,24	3,27	9,06	281,14	193,19	7,55	11,88
Whiting (*Merlangus merlangius*)	0,51	0,08	0,64	5,06	45,06	30,01	0,05	-
Saithe *(Pollachius virens)*	-	-	-	-	0,07	-	-	0,17
Hake (Merluccius merluccius)	-	-	-	-	0,22	0,89	-	-
European smelt (*Osmerus eperlanus*)	-	-	-	-	0,5	-	-	-
Herring (*Clupea harengus*)	0,59	4,22	-	1,12	24,96	16,34	0,02	0,03
Sprat (*Sprattus sprattus*)	2,51	4,78	-	-	6,51	27,55	-	-
Great sand eel (*Hyperoplus lanceolatus*)			0,18	-	0,15	-	-	-
Sand goby (*Pomatoschistus minutus*)					-	0,39*	-	-
Red mullet (*Mullus barbatus barbatus*)	-	-	-	-	0,07	63,22	-	-
Horse Mackerel (*Trachurus trachurus*)				-	0,34	1,14	-	-
Four beard rockling (Enchelyopus cimbrius)	-	-	-	-	1,72	0,31	-	-
Lump sucker (*Cyclopterus lumpus*)	-	-	-	-	0,08	-	-	-
Turbot (*Scophthalmus maximus*)	0,03	-	-	-	0,65	0,65	-	0,02
Plaice (*Pleuronectes platessa*)	0,27	-	0,09	-	77,34	63,22	0,02	0,05
Flounder *(Platichthys flesus)*	1,06	-	0,27	0,18	80,86	69,36	0,25	0,10
Dab (*Limanda limanda*)	0,63	-	-	-	10,93	44,05	-	-
American plaice (*Hippoglossoides platessoides*)	-	-	-	-	-	0,15	-	-
Eelpout (*Zoarces viviparus*)	-	-	-	-	0,07	-	-	-
European eel (*Anguilla anguilla*)	-	-	-	-	1,23	0,37	-	-
Longspined bullhead *(Taurulus bubalis)*	-	-	-	-	-	-	0,05	-
Hooknose *(Agonus cataphractus)*	-	-	-	-	-	-	0,02	-
Short-spined sea scorpion *(Myoxocephalus scorpius)*	-	-	-	-	-	-	0,45	0,70

In present assessment note, herring and Baltic cod are selected as key-species because they are the most abundant and significant fish species regarding both the ecosystem as well as the fisheries in the Baltic Sea. The stocks of these species have been monitored for many years, and for cod stocks, registrations date back to the mid-1940s. Because of the importance of herring and Baltic cod these two species are selected as key species in this assessment.

Cod

The cod population reached a historically high level in the period 1975-1985, (Hutniczak et al., 2015). Since the 1980s, the survival of cod has been reduced considerably because of a climatic reduction of the available reproductive water volume, i.e. of the amount of water with favourable conditions (oxygen, salinity) for successful hatching of cod eggs (ICES, 2007b). Combined with a very high fishing pressure, this resulted in a very low cod stock in the 1990s, and a hi-low level was achieved in 2004-2005, after which the stock has increased again. The cod stock in the western Baltic Sea is biologically different from the Eastern cod stock, but the stocks are mixing in the Kriegers Flak area. The western stock characterizes a very productive, highly fluctuating stock. After reaching a historically low level in 1992, this stock has since increased to a sustainable level (Hutniczak et al., 2015).

Reproduction

The Western- and the Eastern Baltic cod populations both perform spawning migrations. Common for both sub-populations is that they seek the deeper parts of the Baltic Sea (> 40 m), when the spawning period is approaching. The most important spawning areas for the eastern stock are the Bornholmer-deep, Gotland-deep and Arkona-deep. The western populations spawn in Kiel Bay, Fehmarn belt, Mecklenburg Bay and Arkona-deep, Figure 1. Thus, there is a geographic overlap in spawning area between the two sub-populations at the Arkona-deep east of Kriegers Flak, (Hüssy, 2011).

In the Baltic Sea, the cod spawn through a period of 6-7 months, with concentrated spawning activity for one to two months. Spawning starts in the Belt Sea/Øresund and in the western Baltic Sea (January-February) and ends in the eastern Baltic Sea (July-August). In the Arkona Basin, spawning activity has been registered from February to September, with peaks in February-April and June-July. It is assumed that spawning in the first part of the period is attributable to cod from the western stock, while cod from the eastern stock spawn later (Hüssy, 2011). Thus, the Western Baltic area is closed for fisheries after cod in February and March as this period is assumed to be the most important spawning period.

A study of gonad development in cod from the Danish part of Kriegers Flak in May 2013 showed that 62.5% of large female cod had either mature eggs or had already spawned. No fish with running roe was observed. Thus, Kriegers Flak is not expected to be a significant spawning area for cod but has proven to function as cod nursery area, due to the high number of juveniles caught in the area, (BioApp & Krogconsult, 2015).

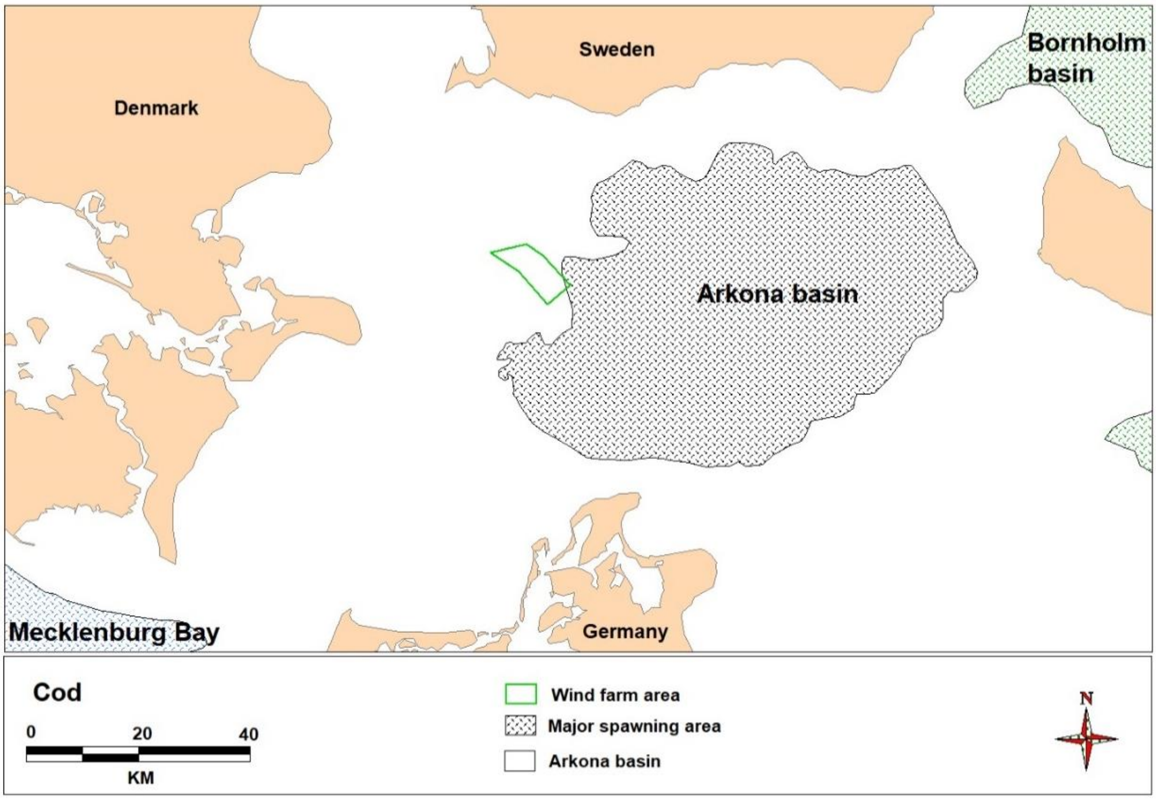

FIGURE 1.SPAWNING AREAS FOR COD IN THE SOUTHWESTERN PART OF THE BALTIC SEA. AFTER (HÜSSY, 2011).

Herring

The pelagic Baltic herring (*Clupea harengus membras*) is a subspecies of the Atlantic herring (*Clupea harengus*). At least two subpopulations of herring are found in the Baltic, spawning during the autumn in the southwestern part and during spring in a broader area from the Western Baltic to the Bothnian bay respectively. The distribution of the two subpopulations overlap periodically to a large extent, however. The autumn spawning herring spawn in September-October and the spring spawning herring spawn in March-May. The spring spawning herring utilises the shallow coastal areas as spawning area, whereas the autumn spawning herring utilises more offshore sites. The autumn-spawning Baltic herring is considered threatened. (HELCOM, 2007).

Reproduction

The female herring spawn her slightly sticky eggs in the water column where they are fertilized by the male, before sinking to the bottom, attaching to hard substrate and vegetation. The 7-9mm long yolk sac larvae appears after 12-14 days of incubation. The larvae are pelagic and drift passively with the water current. The yolk sac is depleted within a week after which the larvae start to feed on planktonic organisms.

Migration

Both the autumn- and the spring-spawning herring subpopulations migrate from the spawning areas of the western Baltic Sea to the Belt Sea and the Kattegat, where they forage (ICES, 2007a). It is estimated that about 80% of spawning herring (age of 2+) passes through Øresund two times (one summer and one spring) each year (Femern Bælt A/S, 2013a), thus most likely passing through Kriegers Flak during migration to the shallow coastal spawning areas in Germany, Denmark and Sweden and to the main spawning site at Rügen, (Parmann et. al., 1994), (Ulrich et. al., 2012). The distance to the closest Swedish coastal spawning, including the nature reserve "Falsterbohalvöns havsområde", is more than 20 km. Most of the juvenile herring is believed to remain in the Western Baltic Sea throughout their first two years.

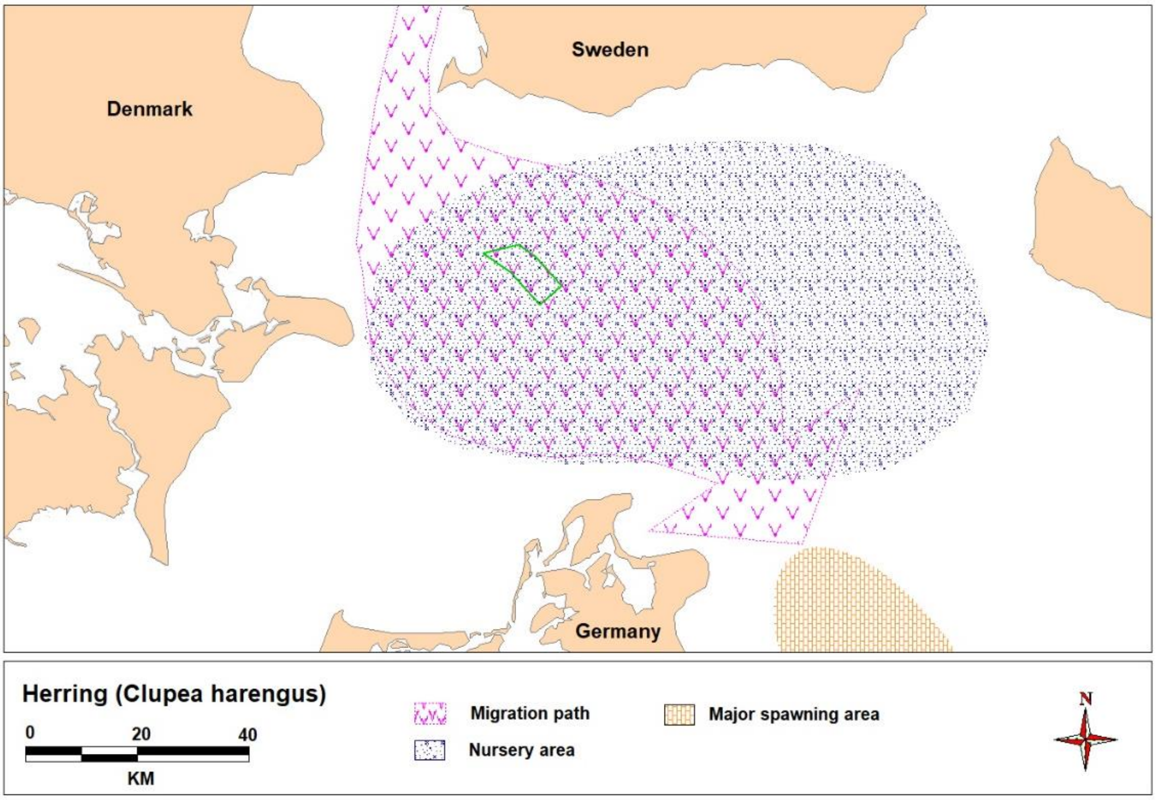

FIGURE 2. A QUALITATIVE SCHEMATIC OVERVIEW OF EXPECTED MIGRATION PATHS, NURSERY- AND SPAWNING AREAS FOR THE WESTERN BALTIC HERRING, BOTH SPRING AND AUTUMN SPAWNING, MODIFIED AFTER (ULRICH ET. AL., 2012).

Fish and hearing

Fish detects sound and vibration in two different ways: through the inner ear, possibly in combination with a swim bladder, and with the the lateral line system, which is a collection of flow sensors located on the sides and the head of the fish (Vella et al., 2001). There are significant differences in the ability of fish species to detect sound and vibration. This difference is caused by physiological differences between species, mostly related to the swim bladder. Fish that lack a swim bladder are basically almost deaf and rely on the ability of the lateral line and inner ear to detect particle movements and sound pressure, in the range of a few Hz to several thousand Hz, between the fish and the surrounding water (Popper & Fay, 1993).

The hearing ability of fish with a swim bladder can be divided into two main groups. Fish having specializations (e.g. Weberian ossicles, swim bladder diverticulae and gas filled bullae) that enhance hearing is referred to as hearing "specialists", whereas fish that do not have such specializations are referred to as hearing "generalists". Hearing "specialists" tend to detect sound better and across a broader frequency spectrum than "generalists".

TABLE 2. PHYSIOLOGICAL ADAPTIONS IN FISH THAT IS FOUND IN KRIEGERS FLAK AND THEIR SENSITIVITY TO NOISE. DATA FROM (NEDWELL. ET AL, 2003).

Species	Common name	Family	Swim bladder connection	Sensitivity
Anguilla anguilla	European eel	*Anguillidae*	None	Medium
Clupea harengus	Herring	*Clupeidae*	Prootic auditory bullae	High
Sprattus sprattus	Sprat	*Clupeidae*	Prootic auditory bullae	High
Myoxocephalus scorpius	Short-spined sea scorpion	*Cottidae*	No swimbladder	Low/"deaf"
Gadus morhua	Atlantic cod	*Gadidae*	None	Medium
Merluccius merluccius	European hake	*Gadidae*	None	Medium
Pleuronectes platessa	Plaice	*Pleuronectidae*	No swim bladder	Low/"deaf"
Limanda limanda	Dab	*Pleuronectidae*	No swimbladder	Low/"deaf"
Ammodytidae indet.	Sandeel indet.	*Ammodytidae*	No swimbladder	Low/"deaf"

Most fish with swim bladder have an upper detection limit of approx. 1000 Hz, but in fish without swim bladder, the hearing decreases rapidly at frequencies above 100-200 Hz.

The Atlantic herring is an example of a "hearing specialist" species, which is reported to be able to detect sound at a frequency of over 3kHz, the best hearing is, however, between 300 and 1000 Hz, (Popper, 2003). Sprat, which occasionally are very abundant at Kriegers Flak, is closely related to herring and is as such expected to have a noise-sensitivity similar to herring.

In the Kriegers Flak area some of the most abundant species are categorized as hearing "generalists". This group of species includes cod, whiting and European eel, all having a swim bladder. Cod and whiting can detect sound frequencies up to 500 Hz but are most sensitive in the range of 100-300Hz (Chapman, 1973).

Flatfish have a low sensibilities sound as the swim bladder degenerates at the end of the larvae stage. Thus, flatfish will probably not hear sound frequencies> 250 Hz (Engell-Sørensen & Skyt, 2002a). Other demersal fishes that are abundant in the Kriegers Flak area, such as Short-spined sea scorpion, lump sucker and species of gobies, also lack or have a very small swim bladder and are therefore not particularly sensitive to sound.

Threshold levels for impact from piling noise on fish

In Denmark and Sweden there are no guidelines regarding how underwater noise is to be described and/or assessed, in terms of impact on fish. In the United States, the major states along the west coast, in collaboration with NOAA and the US Fish and Wildlife Service, prepared in 2008 guidelines for impacts from pile driving on fish and mammals. The guidelines are based on accumulated Sound Exposure Level: $SEL_{(cum)}$ (NOAA, 2008). In 2016 the Swedish Naturvårdsverket published the report: A framework for regulating underwater noise during pile driving. This report provides recommendations and thresholds for impact from pilling noise on marine mammals and fish based on SEL-values and $SPL_{(peak)}$-values (Andersson et. al., 2016). SEL-values is estimated to have a larger impact area than $SPL_{(peak)}$values. The recommended noise threshold level for injury in fish from piling noise is based on studies of multiple species with different hearing abilities, and do not provide thresholds for specific species or groups. The threshold levels for injury in fish within this assessment is based on the conservative SEL-values from Andersson et. al., 2016 and is provided in Table 3.

TABLE 3. SEL THRESHOLD VALUES FOR IMPACT ON FISH ((ANDERSSON ET. AL., 2016)

Effect	Adult	Egg and larvae
Mortality and potential mortal injury	174 dB re 1 µPa^{2}s SEL_{SS} 204 dB re 1 µPa^{2}s $SEL_{(cum)}$	187 dB re 1 µPa^{2}s SEL_{SS} 207 dB re 1 µPa^{2}s $SEL_{(cum)}$

Setting the boundaries for impact on fish to a specific $SEL_{(cum)}$ value must be done with caution, because the same $SEL_{(cum)}$ value can be achieved in different ways, either through a few high intensity single strike $SEL_{(SS)}$ or through many low intensity single strikes $SEL_{(SS)}$. The former having the greatest impact on juvenile and adult fish, due to the limited time to escape.

Modelling noise impact

Noise from piling of monopile foundations for 20MW turbines has been modelled by NIRAS in a winter and a summer situation at two locations representing the worst-case in terms of noise propagation (for further information on the modelling please consult the technical report on marine mammals). The model is used to estimate the noise propagation and map the horizontal ranges for the specific SEL-values where adult fish, larvae and eggs are expected to be lethally injured, Table 3. Identified as a necessary mitigation for marine mammals, the noise modelling results presented includes the use of noise attenuating measures, corresponding to what can be achieved using a Big Bubble Curtain (BBC) The laws of physics cause noise to spread further in cold water than in warm water, thus a larger area will be influenced by underwater noise in the winter time. Hence the model results for winter time is used in this assessment because winter levels represent the worst-case scenario.

Figure 3 and Figure 4 shows the result of scenarios where the fishes (and life stages of fishes) are incapable of fleeing from the noise, due to either limited mobility e.g. eggs and larvae or because the energy is caused by a high single strike, $SEL_{(ss)}$-value, giving no time to escape.

Egg and larvae

In general, little is known about the effect of pile driving on eggs and larvae. The noise modelling show that $SEL_{(ss)}$187 dB re 1 µPa^{2}s values cover a radius of 250 meters around the piling activities. Within that zone eggs and larvae, should they be present, may die or receive fatal injuries from a single strike as one strike provided enough energy to reach this threshold. Accumulated noise levels of 207 dB re 1 µPa^{2}s is also potentially lethal for fish egg and larvae. The result of the noise model show that a SEL(cum) value of - or above 207 dB re 1 µPa^{2}s occur in the range of up to 4.2-6.5 km and cover an area up to 120km^2 around for the worst-case pile locations, Figure 3 and Figure 4.

Juvenile and adult fish

The threshold where adult fish are expected to die or receive fatal injuries from a single strike, as one strike provide enough energy to be fatal is set to $SEL_{(ss)}$174 dB re 1 µPa^{2}s. This threshold extends to a radius of approximately 2 km from the piling activity, and cover an area of approximately 13km^2, for the worst-case pile locations, Figure 4.

Juvenile and adult fish have the capability to flee from the piling noise. Modelling the distance where adult fish will be exposed to a $SEL_{(cum)}$ value of 204 dB re 1 µPa^{2}s, the threshold where adults is expected to die or incur fatal injuries, incorporates fleeing behaviour in terms of swimming speed. According to Andersson et. al., 2016, cod are capable swimming 550-1,300m in 24 min (0.38-0.9 m/s) and herring can swim 1,500m also in 24 min (1.04 m/s), of cause depending on the size of the fish. The result of the model incorporating swim speed is presented in Table 4.

TABLE 4. DISTANCES WHERE ADULT FISH MAY EXPERIENCES MORTALITY AND POTENTIAL MORTAL INJURY AS A CONSEQUENCE OF PILING NOISE.

Threshold distance, fleeing behaviour			Distance [m] to threshold	Area [km²] with threshold
Fleeing Speed	**Month**	**Location**	**204 dB SEL(cum)**	**204 dB SELcum)**
0.38 m/s	January	P1	2,650 m	22,05
		P2	3,350 m	35,24
	June	P1	1,750 m	9,62
		P2	2,000 m	12,56
0.90 m/s	January	P1	180 m	0,10
		P2	370 m	0,43
	June	P1	65 m	0,01
		P2	95 m	0,03
1.04 m/s	January	P1	80 m	0,02
		P2	155 m	0,08
	June	P1	35 m	0,00
		P2	45 m	0,01

Impact from piling noise on cod and herring

Cod

The outcome of the noise model shows an impact range for egg and larvae (applying a threshold of 207 dB re 1 µPa²s SEL(cum)) covering an area of approximately 100-120km² for the worst-case pile locations. For the worst-case piling scenario (P1 - winter) approximately 35km² overlaps with the Arkona basin which covers approx. 4,000km², Figure 3. Thus, only foundations located in the southeasterly part of the wind farm area is expected to overlap with the cod spawning area. Both the Western - and the Eastern Baltic cod stocks spawn in the Arkona basin. Beside spawning in the Arkona-basin the Western Baltic cod stock also spawn in the southern part of Kattegat, Mecklenburg bay and Kiel Bay whereas the Eastern Baltic cod also stock spawn in Bornholm and the Gotland basins, (Hüssy, 2011). Thus, the area of potential lethal impact and mortality on cod egg and larvae from the piling activities represents far less than 1% of the total spawning areas. Furthermore, eggs and larvae are a life stages where pelagic spawning fish experiences extremely high mortality, and the increased mortality from piling noise is expected to be small on that scale. The impact on both the Western - and Eastern Baltic cod populations through impact on egg and larvae stages is therefore assessed to be negligible.

The results of the noise model show that adult cod may achieve SEL(cum) values above 204 dB re 1 µPa²s at a distance of 370-3,350 metres from the piling activities, larger fish being less vulnerable (higher escape velocity) than smaller fish e.g. juvenile. The fish surveys made on both the Danish, Swedish and German parts of Kriegers Flak, all indicates that the area function as a nursery area for young cod (BioApp & Krogconsult, 2015) (Vattenfall, 2004b) (Vattenfall, 2004a). Thus, an impact on the young cod will in worst case occur locally (in the worst-case within a radius of 3.35km ~ 35km²) from the piling activities and restricted to the easternmost part of Kriegers Flak. At Kriegers Flak suitable nursery area for young cod (inhomogeneous bottom) is roughly estimated from depths contour lines to cover approx. 360km² of which, in worst-case approx. 10% overlap with the mapped area of SEL(cum) values at or above 204 dB re 1 µPa²s for each piling . Propagation of noise from piling foundations in the central and western parts of the wind farm area will be much less, due to the lower water depths in these areas. Apart from Kriegers Flak, shallow water (<10m) areas along the coasts of Lithuanian and Latvian have been found to be very important nursery areas for the Eastern Baltic cod stock, (Hinrichsen et al., 2009) and young Western Baltic cod has been found in high densities along the coasts of Lolland and to a lesser extent also around the Isle of Fehmarn (FeBEC, 2013). Kriegers Flak as nursery ground for young cod is therefore of local importance and impact from the pilling activities on both the Western and Eastern Baltic cod populations is assessed to be minor.

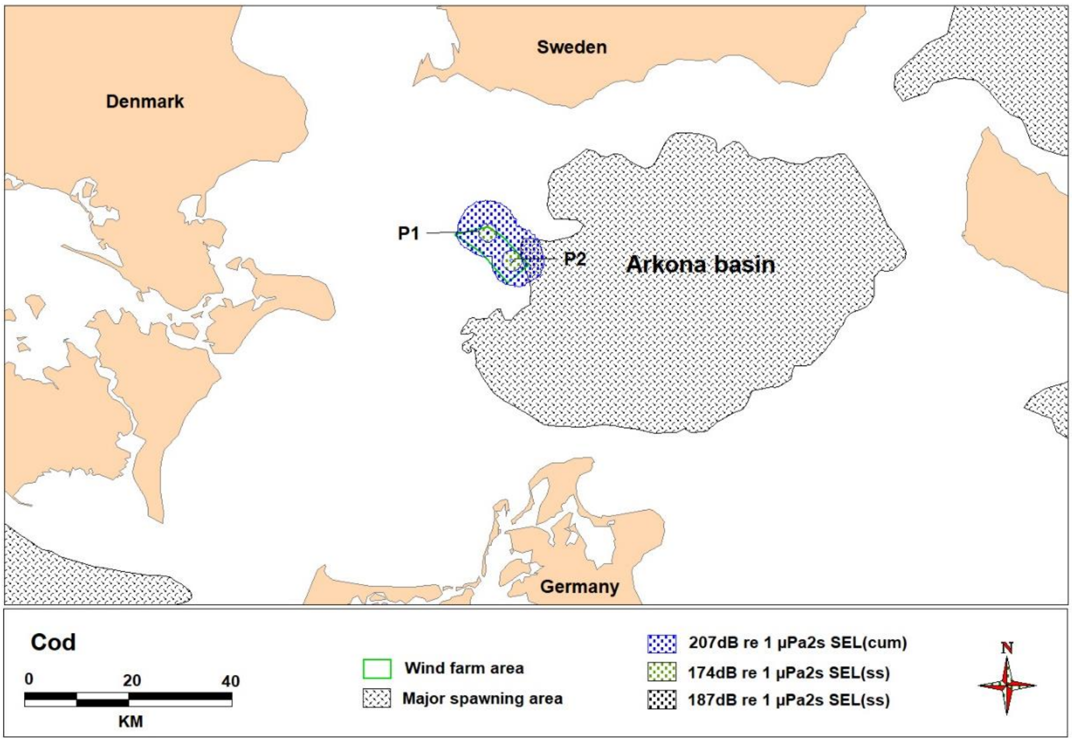

FIGURE 3.THE PROPAGATION OF UNDERWATER NOISE LEVELS FROM PILING (P1 AND P2 – TWO MODELLED PILING LOCATIONS), IN RELATION TO COD SPAWNING AREAS, TABLE 3. NOISE LEVELS SET BY (ANDERSSON ET. AL., 2016).

Herring

The piling activity is assessed not to have any effect on herring eggs and larvae, since the herring is spawning in the coastal area of Denmark and Germany and particularly in an area around Rügen, more than 35-40 nautical miles from the nearest area, having modelled SEL-values above the thresholds of 207 dB re 1 µPa^{2}s SEL$_{(cum)}$ leading to a lethal impact from piling noise.

A large area in and around the Arkona-basin has been mapped to function as a nursery area for juvenile herring, (Ulrich et. al., 2012). Herring is not linked to a specific benthic habitat except during the spawning season. The juvenile herring is like the adult attracted to hydrographical fronts by the large amounts of zooplankton located in these areas. In this assessment the fronts and thereby juvenile herring is anticipated to be equally distributed in the nursery area of approximately 6,000-6,500 km^2 outlined in Figure 4.

The modelled impact area of SEL$_{(cum)}$ values of 204 dB re 1 µPa^{2}s, the threshold where adults is expected to die or incur fatal injuries, is in worst case 0.075km^2,or less the 0,01‰ of the nursery area. The impact from piling noise on juvenile herring is therefore, local and overall negligible.

The Baltic herring migrates from the overwintering grounds in The Sound to the coastal areas in the Western Baltic Sea. The exact migration route(s) for herring is unpredictable and changes from year to year, because they most likely follow hydrographical fronts, (Axenrot, 2005). The cross-section of the most likely migration path outlined in Figure 4 is approximately 60km and the potentially blocking cross-section, where herring will experience mortality or lethal injury is only approximately 0.3km, Table 4, less than 1%, and negligible impact from blocking the migration routes is expected. The sparse existing knowledge of impact from piling noise on masking and behavioural changes, makes it very difficult to make a quantitative assessment. However, spawning migrating herring may locally be influenced by piling noise, increasing the migration distance from the Sound to Rügen, but it is less likely that the prolonged migration will be of a magnitude, that will affect the herring population in the Western Baltic Sea. Hence, the overall impact on herring populations (both sub-populations) in the western Baltic is assessed to be negligible.

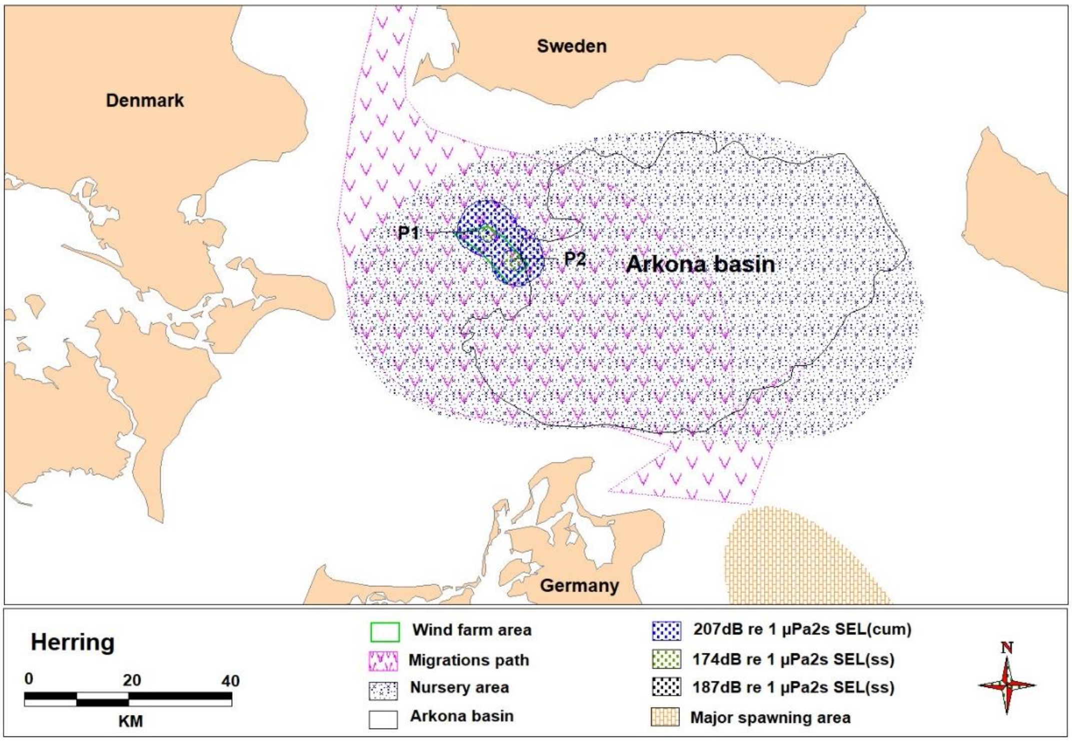

FIGURE 4.THE PROPAGATION OF UNDERWATER NOISE LEVELS FROM PILING (P1 AND P2 – TWO MODELLED PILING LOCATIONS), IN RELATION TO HERRING MIGRATION AND NURSERY GROUND.

Conclusion

For a 20 MW turbine monopile, and under a number of worst-case assumptions, the outcome of the noise model shows an impact range for egg and larvae (applying a threshold of 207 dB re 1 μPa^2s $SEL_{(cum)}$) covering an area of approximately 100 -120km^2 and a range for $SEL_{(ss)}$187 dB re 1 μPa^2s values cover a radius of 250 meters around the piling activities. Within these zones eggs and larvae may die or receive fatal injuries. Thus, piling will induce a local impact on Baltic cod and herring. However, overlap between area used for spawning for these species and the area having noise levels fatal for cod and herring, is very marginal and the overall impact on eggs and larvae is assessed to be negligible.

The results of the noise model show that juvenile and adult cod may achieve $SEL_{(cum)}$ values above 204 dB re 1 µPa^2s at a distance of 370-3,350 metres from the piling activities, larger and pelagic fish being less vulnerable, due to higher escape velocity and endurance swim speed. Thus, the impact on juvenile and adult fish is assessed to occur on a local scale only. The nursery- and foraging areas of Baltic cod and herring in the Baltic sea are large, and for herring only a minor overlap with areas of expected lethal impact from piling noise exist. Thus, the overall impact on the herring population in the western Baltic Sea is assessed to be negligible. For cod a greater overlap (approx. 10%) between the nursery area at Kriegers Flak and $SEL_{(cum)}$ values above 204 dB re 1 µPa^2s has been estimated. Thus, impact on cod in the western Baltic is assessed to be minor.

The overall impact on these key Baltic fish species from a Kriegers Flak wind farm project with monopiles suited for 20 MW turbines is assessed to be no more than minor, i.e. with no long-term consequences for the respective populations. This is taking into consideration the fact that Baltic cod is very important to the ecosystem in the Baltic.

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