KATTEGATT SYD OFFSHORE WIND FARM

Assessment of impact from pre-project surveys

Scientific Report from DCE – Danish Centre for Environment and Energy No. 423 2021

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Data sheet

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Abstract: An offshore windfarm is planned for Kattegatt Syd by Vattenfall Vindkraft AB. This report assesses impacts on marine mammals of proposed pre-investigations from use of a sparker, a parametric Sub Bottom Profiler and a small seismic airgun. The assessment found that negligible to minor impacts are expected on harbour seals, grey seals and harbour porpoises. The close by Natura 2000 site could potentially be affected if the survey vessel is closer than 2-3 km to the border of the wind farm (mean and maximum values, respectively). The impact on the Natura 2000 site is of short duration and assessed as acceptable with regards to the JNCC guidelines.

Keywords: Marine mammals, noise, disturbance, Natura 2000, offshore renewables.

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Contents

Preface

DCE, Aarhus University, has been commissioned by Vattenfall Vindraft AB to conduct an impact assessment for marine mammals concerning pre-investigations at Kattegatt Syd Offshore Wind Farm. These pre-investigations include surveying of the proposed site for the offshore wind farm and cable corridors with a suite of instruments to map the details of the seabed and topmost layers of sediment. The survey equipment on which the assessment is based was decided in consultation with Vattenfall Vindkraft AB, and was at the time of writing considered to be best available knowledge for the intended job, expected to represent a realistic scenario for conduction of the surveys. It is expected that the assessment will need to be revisited when more accurate details on survey equipment and extent of surveys becomes available. For calculation of impact ranges, modelling was performed by Rambøll. The report contains an overview of relevant marine mammal species in the area; assessment of potential impact on these species as well as on nearby Natura 2000 sites; and an evaluation of proposed mitigation measures to reduce impacts on marine mammals.

Vattenfall Vindkraft AB was given opportunity to comment on an earlier draft of this report. Assessments and conclusions remains the sole responsibility of the authors, however.

Summary

Impacts of use of three specific instruments for pre-investigations at the potential offshore windfarm site Kattegatt Syd was assessed with regard to harbour porpoises and seals. The assessed instruments were a sparker, a sub bottom profiler of specified source level, frequency and duty cycle and a small seismic air gun. Impact ranges were modelled by Rambøll (Rambøll, 2021).

Impact magnitude and significance was assessed for two types of impact: noise-inflicted permanent hearing loss (PTS) and behavioural disturbance.

The assessment showed that the risk of inflicting hearing loss by the survey equipment is **negligible**, provided the equipment is turned on with a suitably designed soft start sequence. The survey equipment is assessed to be able to disturb porpoise behaviour at maximum distances up to estimated 3-4 km (mean and max values) from the survey ship (using a sparker as source), and the consequences of this behavioural disturbance on the population of seals and porpoises in southern Kattegat is assessed as **minor.**

The disturbance of Natura 2000 sites from the mini-airgun, sub-bottom profiler, and sparker was assessed as **acceptable** following JNCC guidelines**,** and impact inside Natura 2000 sites can be avoided, if the vessel keeps a distance of 1 km or 3 km to the border of the windfarm site with the Sub Bottom Profiler and Sparker, respectively, based on maximum values. The range between the Natura 2000 sites and the potential windfarm area is 1 km.

1 Kattegatt Syd Offshore Wind Farm area

The Kattegatt Syd Offshore Wind Farm is situated in the southern part of Kattegat in the Swedish Exclusive Economic zone (**Figure 1.1**) bordering Denmark between the reefs of *Stora* and *Lilla Middelgrund*. The suggested wind farm is situated between two major traffic separation routes: west of the traffic separation route S that runs along the Swedish coast into the Sound and east of the route T that runs southwest into the Great Belt (**Figure 1.1**). The offshore wind farm is surrounded by a number of Natura 2000 sites in both Sweden and Denmark (see **Figure 1.2**.), designated for harbour porpoises, and in two cases also grey seals and harbour seals. On the Swedish side, the offshore wind farm borders *Lilla Middelgrund* to the north, and *Stora Middelgrund och Röde Bank* to the south. Continuing south is the large Nordvästra Skånes Havsområde that is directly connected with the Stora Middelgrund Natura 2000 site. On the Danish side, the closest Natura 2000 site is the Store Middelgrund. Three other Natura 2000 site have been appointed nearby in Danish Waters and are awaiting approval by the EU. All of these areas are designated for harbour porpoises. The borders of the potential windfarm is 1 km from the borders of any Natura 2000 site (**Table 1.1**).

Two other Windfarms are in the planning/application stages for southern Kattegat: One in the Swedish part of Stora Middelgrund and another near Hesselø in Danish Waters.

Table 1.1. Natura 2000 sites near the proposed wind farm area and range between the border of the Natura 2000 site and the windfarm area is given. * denotes newly appointed Natura 2000 sites awaiting approval by the EU.

Natura 2000 sites	Distance to OWF border	Appointed for
Fladen, SE	25 km	Harbour porpoise
Balgö, SE	25 km	Harbour porpoise, grey seal and harbour seal
Lilla Middelgrund, SE	1 km	Harbour porpoise
Stora Middelgrund and Röda Bank, SE	1 km	Harbour porpoise
Nordvästra Skånes havsområde, SE	14 km	Harbour porpoise, grey seal and harbour seal
Store Middelgrund, DK	11 km	Harbour porpoise
Gilleleje Flak and Tragten, DK	57 km	Harbour porpoise
Anholt and Sea to the North	14 km	Harbour porpoise*
Kims Top and the Chinese Wall	8 km	Harbour porpoise*

Figure 1.1. Map of the Kattegatt Syd offshore wind farm. From Vattenfall Vindkraft AB.

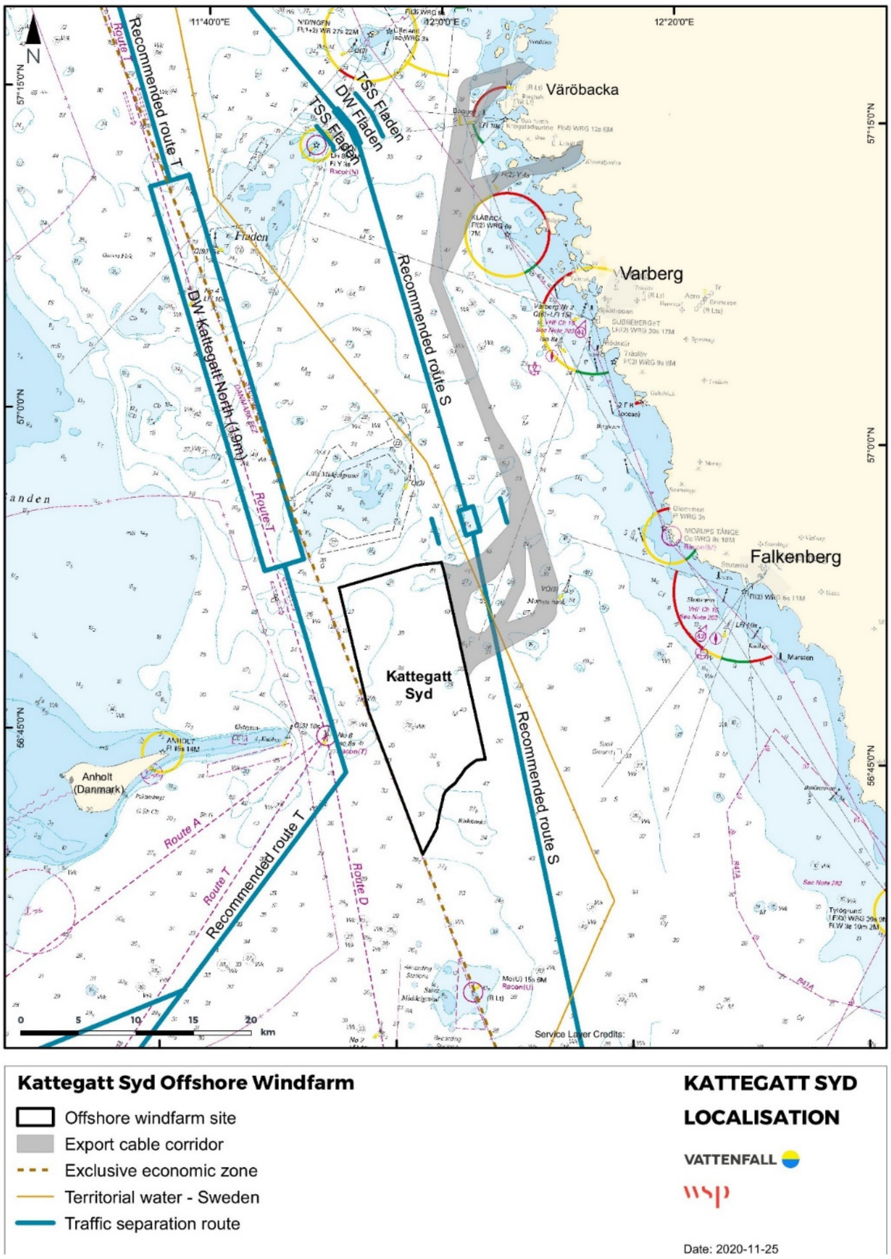
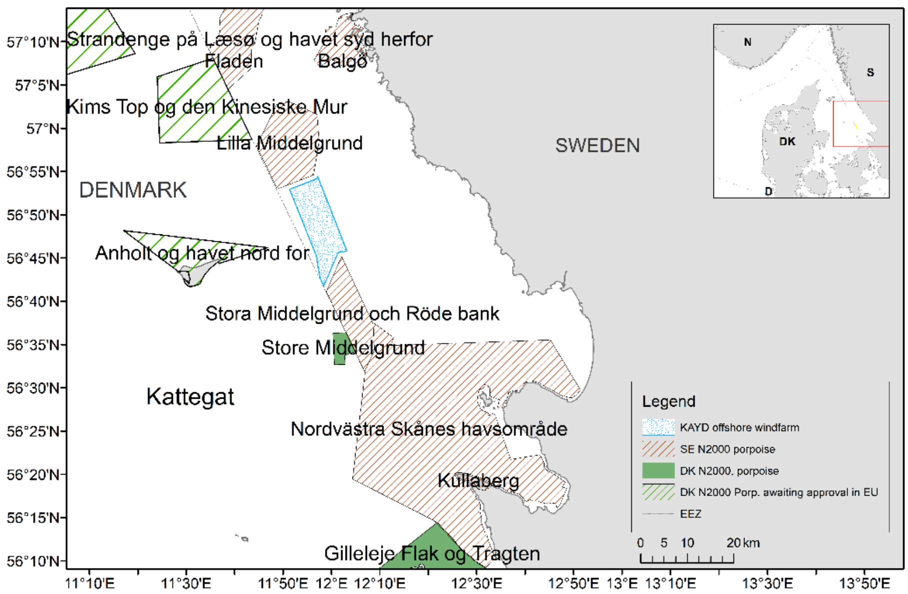


Figure 1.2. Map of the area relevant to the Kattegatt Syd OWF with Natura 2000 sites appointed for harbour porpoises shown.



1.1 Description of the planned geo-technical surveys

The purpose of the geo-technical surveys are to investigate the project area, as well as a buffer zone and corridors connecting the wind farm to land, in order to map the sea bottom with regards to bathymetry, geology, local deeps and troughs, sediment type and bottom habitat, as well as marine archaeological interests.

Such geo-technical surveys are usually conducted with a host of different survey systems and the exact methods by which these surveys will be conducted is not yet known. Assessment is therefore based on a generic survey, as outlined by Vattenfall (2019) and given in **Table 1.2**. The assessed survey equipment was decided in consultation with Vattenfall Vindkraft AB, and was at the time of writing considered to be best available knowledge for the intended job, expected to represent a realistic scenario for conduction of the surveys, and does not represent a worst case scenario. The sensitivity of the analysis and possible consequences of underestimating survey size is discussed together with the results.

Table 1.2. Potential equipment to be used during the pre-investigations. Supplied by Vattenfall Vindkraft AB. See text for explanation.

Type of survey	Equipment	Effort
	Site survey wind farm area (120-180 km^2)	
Geophysical survey	Multi-beam echosounder	70 days
	Side-scan sonar	
	Sub Bottom Profiler	
	2D seismic	
	Sparker	
	Magnetometri	
Geotechnical survey	Drill holes	90 days,
	Cone penetrometer test (CPT)	inclusive stops
	Seismic CPT	
	CPT in drill hole	
	Cable corridor survey (70 km length, 1 km wide)	
Geophysical survey	Multi-beam echosounder (MBES)	60 days
	Side-scan sonar (SSS)	
	Sub-bottom profiler (SBP)	
	Magnetometri	
Geotechnical survey	Cone penetrometer test (CPT)	20 days
	Vibrocorer	
	Coastal survey	
Geophysical survey following transects	Multi-beam echosounder (MBES)	15 days
	Side-scan sonar (SSS)	
	Sub-bottom profiler (SBP)	
	Magnetometri	

1.2 Potential sources of impacts from pre-investigations

A number of instruments are likely to be used in the survey, as listed in **Table 1.2**. These are listed below and for each is indicated whether they are likely to impact marine mammals to any noteworthy degree.

- Side scan sonar (**SSS**). Acoustic surveying of the seabed with sound of very high frequency, above 300 kHz (Rambøll, 2020). Not considered audible to marine mammals and therefore not assessed as an impact.

- Multi-beam echo-sounder (**MBES**). Acoustic survey of the seabed, comparable to side scan sonar in many respects. Frequency of signal (400 kHz) (Rambøll, 2020) outside hearing range of marine mammals and therefore not assessed as an impact.
- Magnetometry. Passive measurements of variations in the earth's geomagnetic field. As it is a passive technique, it is not assessed as an impact to marine mammals.
- **Sub-bottom profiling** (**SBP**). Acoustic surveying of the topmost layers of the seabed, down to depths of tens or hundreds of meters, depending on application. Audible to and capable of affecting marine mammals at considerable distances and therefore assessed in depth below. Equipment includes both parametric sub-bottom profiler and sparker.
- **2D Seismic surveys with single airgun**. Similar to sub-bottom profiling and audible to and capable of affecting marine mammals at considerable distances and therefore assessed in depth below.
- Seabed sampling. Mechanical sampling of the seabed, typically for biological surveys. Not assessed as an impact on marine mammals.
- Borehole. Sampling of the seabed from a drilled borehole. Noise from the drillship is assessed to be comparable to the noise from commercial cargo ships otherwise in the area (Kyhn et al., 2014) and therefore not assessed to constitute a significant additional source of disturbance to marine mammals.
- Cone penetration testing (CPT). Mechanical measurements of the properties of the sediment by insertion of measuring cone into sediment or borehole. The process does not rely on active sound emission and is therefore not assessed as an impact to marine mammals.
- Vibracorer. Sampling of the topmost meters of sediment by vibrating a core barrel into the sediment. Applies low-amplitude vibration to the core barrel, which does not radiate into the water to any significant degree (Reiser et al., 2011) and therefore not assessed as an impact to marine mammals.

1.3 Marine mammals in Kattegat

Three species of marine mammals are common in Kattegat; harbour seal (*Phoca vitulina*), grey seal (*Halichoerus gryphus*) and harbour porpoise (*Phocoena phocoena*). A few dolphin species are also observed regularly, but in very low numbers in Kattegat: Common dolphin (*Delphinus delphis*), whitebeaked dolphin (*Lagenorhynchus albirostris*) and bottlenosed dolphin (*Tursiops truncates);* and occasional single individuals of baleen whales can also be encountered: Fin whale (*Balaenoptera physalus*) and humpback whale (*Megaptera novaeanglia*). The occurrence of these species is unpredictable, however, and always as single individuals or very small groups. The likelihood that they would be encountered in the survey area during the actual surveys is assessed to be very low and therefore they have been excluded from further assessment.

1.3.1 Harbour porpoise (tumlare)

The harbour porpoise is the most common cetacean and is present throughout Kattegat.

Conservation status

Harbour porpoise is listed in Annex II and IV of the Habitats Directive (92/43/EEC), distribution and abundance must be evaluated according to descriptor 1 of the Marine Strategy Framework Directive, it is listed on Annex II of the Bern convention, Annex II of the Bonn convention and Annex II of the

Convention on the International Trade in Endangered Species (CITES). Furthermore, it is covered by the terms of the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS, a regional agreement under the Bonn Convention) and by HELCOM (The Helsinki Commission; protection of the marine environment of the Baltic Sea from all sources of pollution). The EU Habitats Directive is an important European legislative mechanism for addressing the conservation of wildlife and habitats. It requires site protection for a range of habitats and species listed in Annexes I and II respectively, and strict protection for a range of species listed in Annex IV. Since the harbour porpoise is listed in both Annex II and IV, it means that the harbour porpoise is protected throughout its range as well as that special areas of conservation must be appointed, which has been done in terms of Natura 2000 sites designated for harbour porpoises.

Sweden and Denmark encompass three different populations of harbour porpoises: The North Sea, Belt Sea and Baltic Proper population. Separate management units have been suggested for the three populations (Galatius et al., 2012; Sveegaard et al., 2015; Wiemann et al., 2010) and the porpoises in southern Kattegat belongs to the Belt Sea population. The management units of the Belt Sea population covers the Belt Sea, the Sound, southern Kattegat and the western Baltic Sea. The national red list status of the Belt Sea population of harbour porpoises is Least Concern (LC), both in Sweden and Denmark.

Distribution

The distribution of harbour porpoises is relatively well known in southern Kattegat, the Sound and Great Belt, as the Belt Sea population has been surveyed with multiple methods during the last four decades. The large scale SCANS surveys I-III covered this area with aerial and boat-based surveys three times (Hammond et al., 2002; Hammond et al., 2017; Hammond et al., 2013). A number of Danish studies from Aarhus University has led to the tracking of more than one hundred porpoises, by means of satellite transmitters to inform about their distribution over the last three decades (Edrén et al., 2010; Sveegaard et al., 2018; Sveegaard et al., 2011a). Kernel densities of the satellite-tracked porpoises from two time periods are shown in **Figure 1.3**. The location of the proposed wind farm is indicated with a red circle. The wind farm area appears important for harbour porpoises both summer and winter in later years (2007-2016) (green areas).

1.3.2 Yearly pattern of presence in Southern Kattegat

Harbour porpoises move around throughout the year and when and where there are peaks in presence, is important to consider in relation to establishment of an offshore Windfarm such as at Kattegatt Syd and application of Best Environmental Practise, i.e. performing the surveys when fewest animals will be affected. Newborn calves are entirely dependent on their mother during their first ten months of life, where they are nursed and slowly learn to forage independently (Lockyer, 2003; Teilmann et al., 2007). In Inner Danish Waters including Kattegat, porpoises give birth from April to October peaking in July, shown by necropsies of stranded and bycaught animals (Lockyer and Kinze, 2003). From small cetacean-dedicated cruises in 1987-89 (Kinze, 1990), and 1994 (Hammond et al., 1995) it was shown that percentage of new-born calves increased from May (9.1%) to June (6.9 - 10.6%) and reached a peak in July (11.5 - 23.8%) and August (18.2 - 23.5%) (Kinze, 1990). Because of the long nursing period, harbour porpoises are assessed vulnerable to disturbances all year.

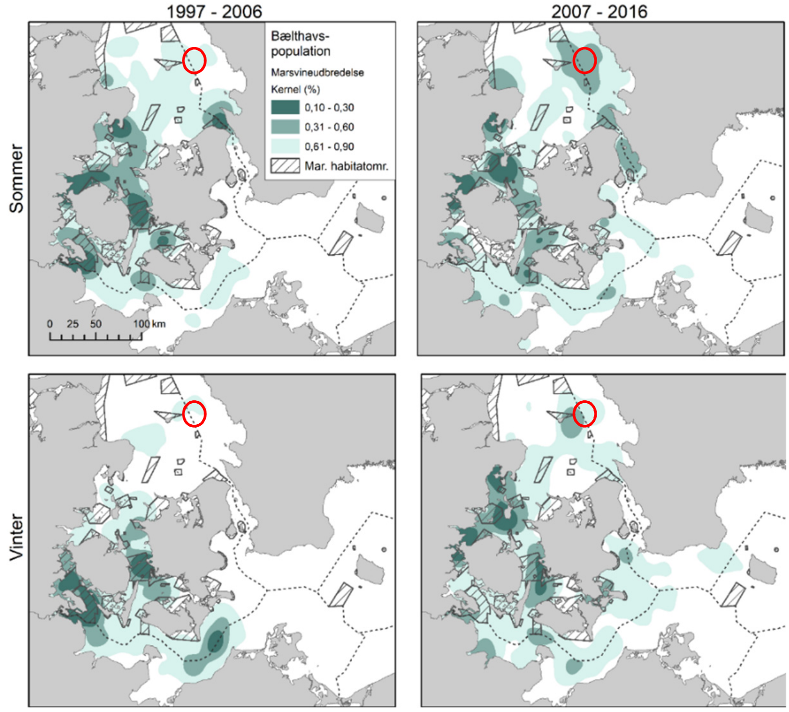


Figure 1.3. Distribution of satellite tracked porpoises in the Belt Sea management area analysed as kernel densities (the darker the colour, the higher the density) in two ten-year periods in summer (April-September) and winter (October-March). The Kernel categories are defined as high (contains 30% of all positions from porpoises in the smallest possible area), medium (31-60%) and low (61- 90%). The number of porpoises and positions per analysis: 1997-2006, summer: 39 animals/1958 pos., 1997-2006, winter: 18 animals/765 pos., 2007-2016, summer: 43 animals/1540 pos., 2007-2016, winter: 33 animals/1076 pos. The approximate position of the proposed wind farm Kattegatt Syd is shown as the red circle. Figure and figure text from Sveegaard et al. (2018).

There are four independent studies providing data on yearly presence of harbour porpoises near the Kattegatt Syd project area. The data are not quantitatively comparable to each other, as data was collected and quantified differently, and the data was collected in different years, which may cause variation. Nevertheless, the yearly peaks in porpoise presence are comparable.

1. In 2007 towed acoustic array data was collected close by the wind farm area every second month (Sveegaard et al., 2011b). The data showed several peaks in presence near the wind farm area: March-April, July-August and November-December.

2. Aarhus University has been equipping porpoises with satellite tags since 1997. These data has been compared to the towed acoustic data described above to show yearly patterns of presence (Sveegaard et al., 2018). The satellite tracks was used to make maps shown in **Figure 1.3**, where positions were mapped as Kernel densities, i.e. densities of positions from the tagged porpoises. These data show a yearly peak in May-June. Bear in mind that the resolution of the method is not very high, and it is therefore not possible to zoom in at the Kattegatt Syd project area to see exactly where the porpoises were.

3. The Danish Store Middelgrund is situated app. 9.5 km south of the project area. Aarhus University conducted a study at Store Middelgrund in 2015 with eleven PAM stations near and at Store Middelgrund (**Figure 1.4**). These data showed a peak in presence in June at all stations (Sveegaard et al., 2017) (**Figure 1.5**). Presence varied a lot over the year, but consistently among the eleven PAM stations, and the yearly pattern of presence therefore appears robust for the area in that year. Porpoise presence was also modelled against a suit of environmental variables to test which best described presence. The modelling was based on the PAM data and showed

that all variables were equally correlated to porpoise presence. Store Middelgrund is a shallow ground and may therefore be used differently by porpoises than the deeper and more flat site proposed for the wind farm.

4. The Natural History Museum of Sweden has conducted passive acoustic monitoring with CPODs for Havs- och Vattenmyndigheten since spring 2019 in the waters surrounding the Kattagatt Syd offshore windfarm site. This monitoring includes Swedish Stora Middelgrund and Röde Bank, and the Lilla Middelgrund Natura 2000 sites north of the proposed wind farm and Nordvästra Skånes Havsområde, south of the proposed wind farm (**Figure 1.4**). Here, presence of porpoises was lowest in June (**Figure 1.5**). The period of available data only covers May 2019 to October 2020.

5. In December 2020, passive acoustic monitoring was initiated by Vattenfall AB with five stations in the Kattegatt Syd offshore windfarm site. Data from the first few months are included in figure 1.5 top.

No information is available on what the porpoises use the different areas in southern Kattegat for, including whether the shallow grounds may be important for breeding. No specific areas has been identified in Kattegat or the Danish Straits, which could be characterized as a potential breeding site, in contrast to the case for the Baltic Proper, where this role is strongly suggested for the Midsjö Banks (Carlén et al., 2018). Passive acoustic monitoring within the offshore windfarm site began in December 2020 and continues to December 2021 to gain information on harbour porpoise presence in the area.

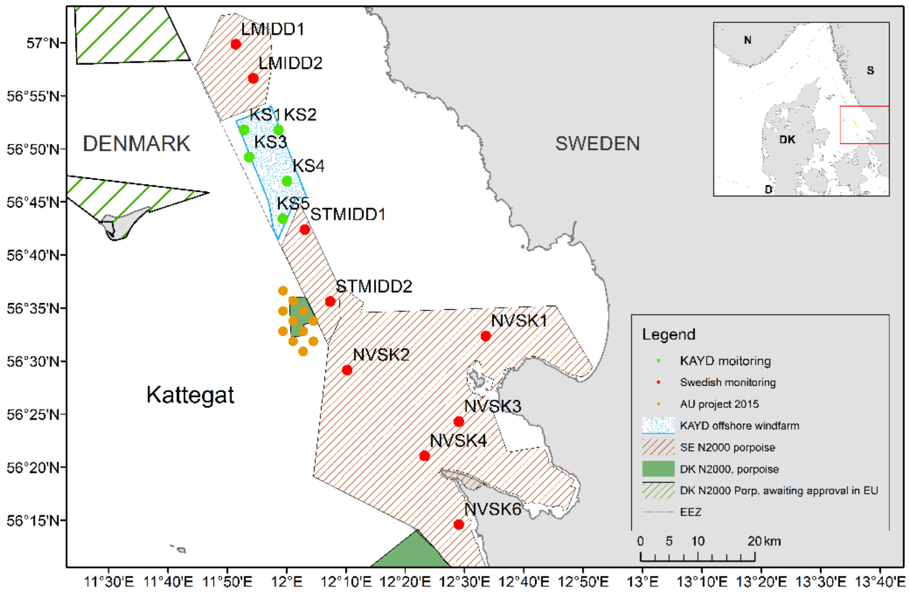
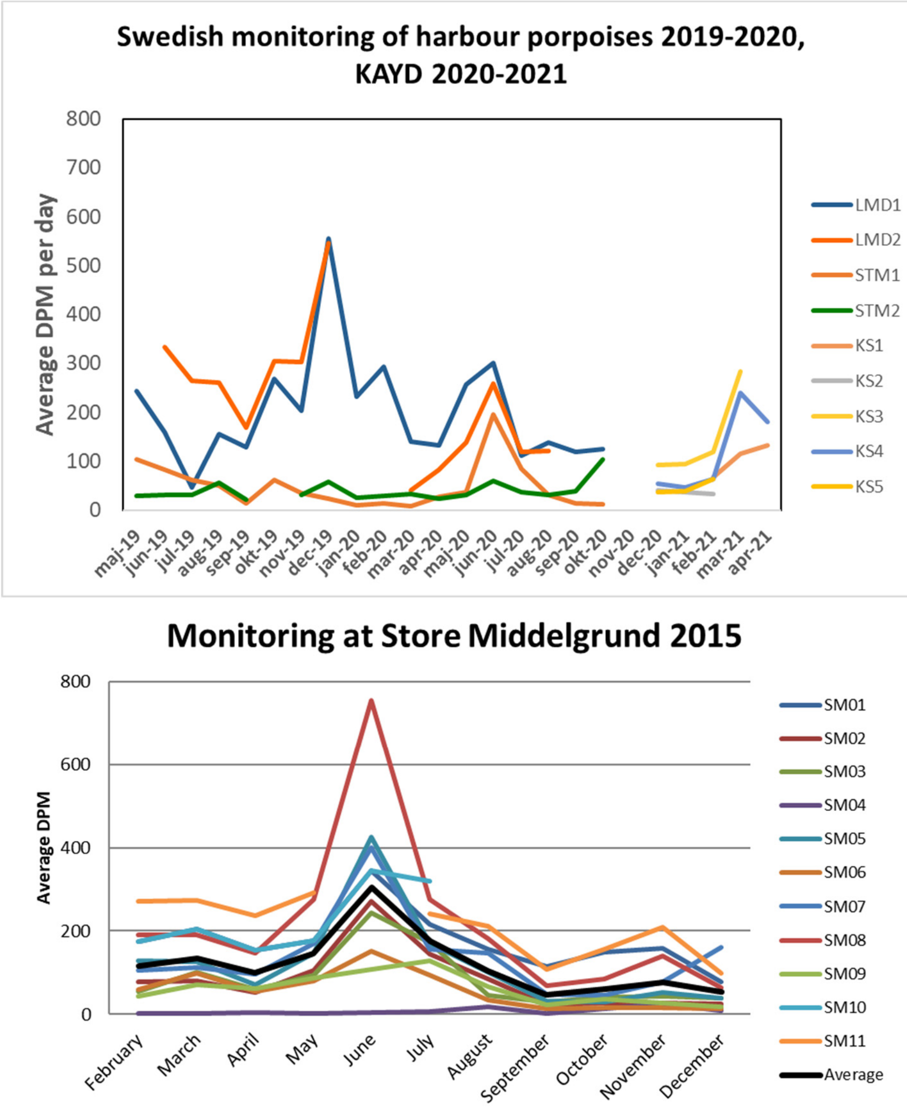


Figure 1.4. Location of Swedish monitoring stations from which data are available on porpoise presence near Kattegatt Syd windfarm site, as well as from a project conducted using same methodology during 2015 at Store Middelgrund by Aarhus University. Vattenfall has been collecting PAM data in the area since December 2020. Swedish monitoring data are freely available.

Figure 1.5. Top: Average Detection Positive Minutes (DPM) of porpoises at all Swedish monitoring stations relatively close to the Kattegatt Syd OWF as well as inside the KAYD offshore windfarm site. See station names on map in figure 1.4 above. Monitoring in Sweden began in spring 2019. Data made available from Havs- and Vattenmyndigheden. Monitoring in the offshore windfarm site began December 2020. Bottom: Average DPM of offshore wind farm porpoises at eleven PAM stations at Store Middelgrund during 2015. Data made available by Aarhus University. Note the different scales of the y-axis.



The Swedish monitoring is new and only a short dataset is available, however the exact same methodology was used by Aarhus University during 2015 to collect data on porpoise presence at Store Middelgrund south of the wind farm area, as described above. Here, porpoise activity was studied during a full year and showed highest presence during summer months (**Figure 1.5**), i.e. the opposite picture as the Swedish monitoring data shows. The monitoring by Vattenfall began December 2020 and data until April 2021 is included in figure 1.5. During this period, Sprig appear more important than Winter. The Danish study was conducted in 2015 and on the ground. The Swedish monitoring stations are for the most part placed off the Stora Middelgrund and Lilla Middelgrund, and the Vattenfall monitoring is conducted in the deeper area in between the grounds. It is possible that porpoises use these two types of areas; on and off the grounds, differently in general, as well as over the course of a year.

The presently available data is therefore not entirely consistent and cannot be used to conclude which period of the year may be most important for porpoises within the Kattegatt Syd project area and to conclude on the period best suited according to the principle of Best Environmental Practice.

1.4 Harbour seal (knubbsäl)

The harbour seal is the most common Danish and Swedish seal species and found throughout Danish and Swedish parts of Kattegat. Haul-outs sites are shown in **Figure 1.6** below.

1.4.1 Conservation status

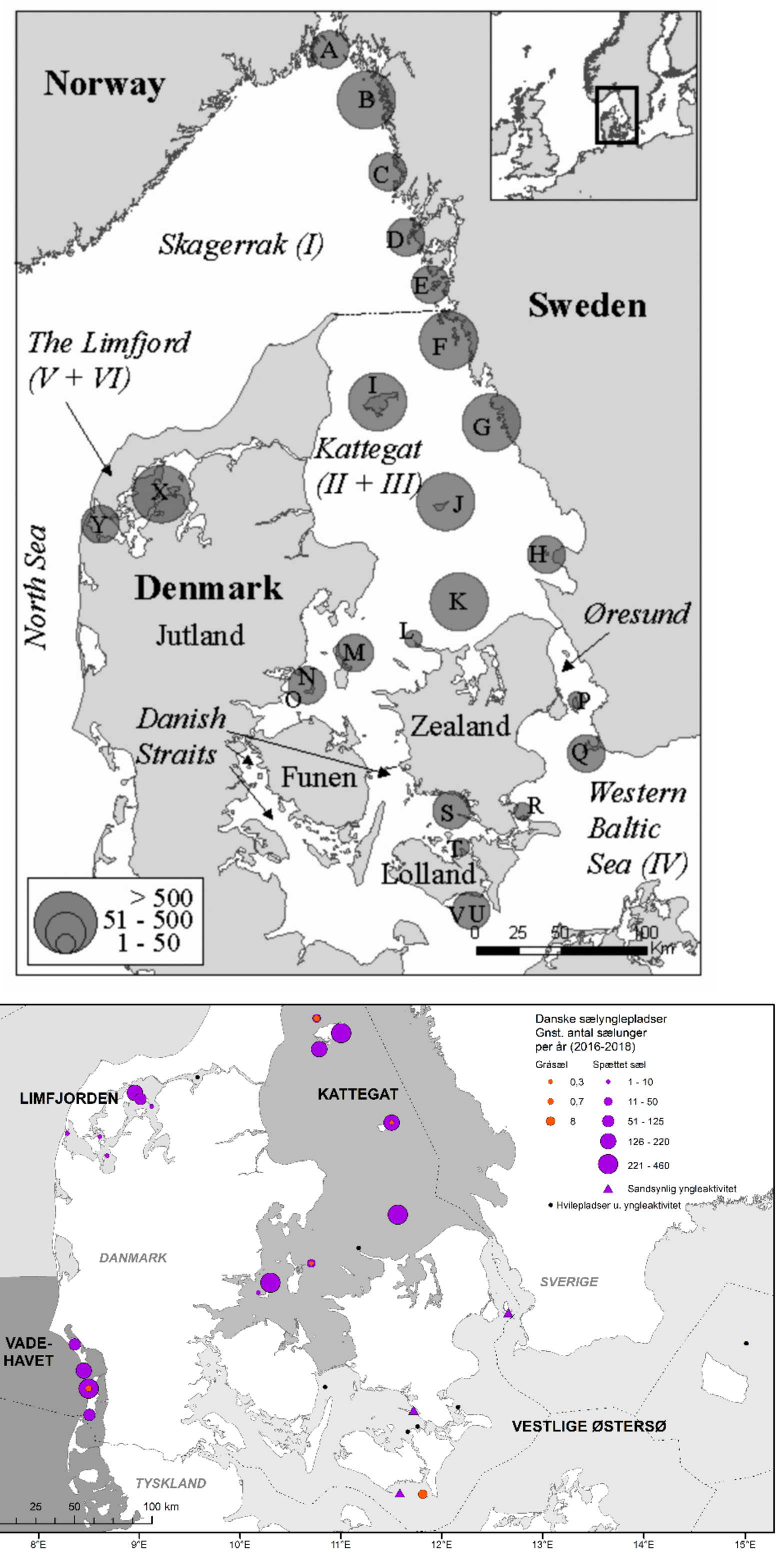
The harbour seal is not included on the Swedish Red List of 2020 (Artdatabanken, 2020), which means that it is assessed as Least Concern in Sweden; same as in Denmark (Moeslund et al., 2019). It is listed in annex II and V of the Habitats Directive (92/43/EEC), distribution and abundance must be evaluated according to descriptor 1 of the Marine Strategy Framework Directive, it is listed on annex II of the Bern convention (19th September 1979), annex II of the Bonn convention and annex II of the Convention on the international Trade in Endangered Species (CITES). Further, under the Convention on the Conservation of Migratory Species of Wild Animals, a trilateral agreement has been enforced to protect harbour seals of the Wadden Sea. Seal hunting is allowed in Sweden with permission from the Swedish Environmental Protection Agency (Naturvårdsverket). Denmark has amended HELCOMS recommendation (9th January 1988) to ban seal hunting throughout the Baltic Sea, although app. 40-50 harbour seals are shot with permission every year as a consequence of conflicts with fisheries. Special areas of conservation have been appointed for the protection of harbour seals in Sweden and Denmark. A number of Danish seal haul outs in Kattegat outside the Natura 2000 sites are further protected as wildlife reserves.

The harbour seal in Danish Waters is divided in four different management populations based on genetic studies and satellite tracking showing limited genetic exchange between the populations (Dietz et al., 2015; Dietz et al., 2013b; Olsen et al., 2014; Tougaard et al., 2008). The four populations are the Wadden Sea, the Limfjord, Kattegat and Western Baltic and they are managed separately. The Kattegat population is shared with Sweden and is the population of harbour seals present in the proposed site for Kattegatt Syd Offshore Wind Farm. In 2018, the Kattegat population was estimated to consist of 6300 individuals in the Danish part of Kattegat alone. The number is corrected for number of seals in the water at time of counting (Hansen and Høgslund, 2019).

1.4.2 Distribution

Harbour seals at Anholt has been tagged with Argos satellite transmitters in 2005, 2006 and 2008 (Dietz et al., 2013a) and in 2014 (not published). However, only yearlings and sub-adult seals were tagged, limiting the knowledge about where adult seals from Anholt forage. It is likely that also seals from the haul-outs on Hesselø and along the Swedish coast are found in the wind farm area.

Figure 1.6. Top: Harbour seal haul-outs in southern Scandinavia. Roman numbers refer to sub-populations, where II and III are relevant for Kattegat. Letters refer to place names. Haul-outs relevant for Kattegatt Syd are J= Anholt (DK), K = Hessel Ø (DK), H= Hallands Väderö (SE) and G = Varberg (SE). Copied from (Olsen et al., 2010).
Bottom: Map of pupping grounds in Danish Waters. Number of pups (average over three years, 2016-2018) is shown as purple circles. There are two relevant whelping grounds in Western Sweden: Varberg and Hallands Väderö. Very few grey seal pups are born annually in Kattegat (orange circles). The grey colours signify the four management areas for harbour seals. Maps courtesy of Signe Sveegaard.



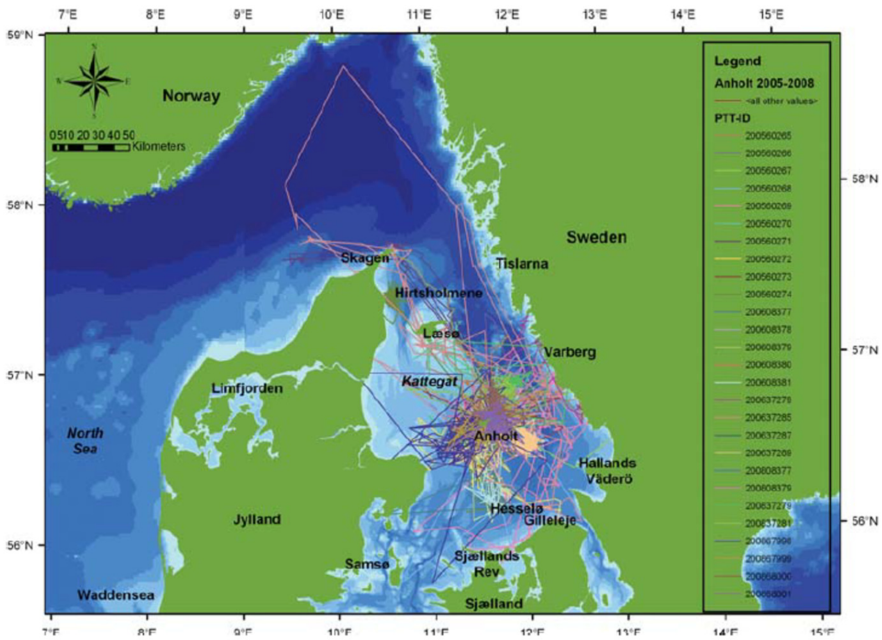


Figure 1.7. Tracks from 27 harbour seals tagged at Anholt with satellite transmitters. Figure from Dietz et al. (2013a).

To sum up the Kattegatt Syd wind farm area appears important for harbour seal yearlings and subadults, documented by satellite tagging of seals hauled out at Anholt. It is not known how important the area is for adults or in which periods.

1.4.3 Yearly pattern of presence in Southern Kattegat

Tagging of seals with satellite transmitters at Anholt were done in April and September and the tagging lasted from 42 to 268 days (Dietz et al., 2013a). The data shows that harbour seals use the area around the proposed Kattegatt Syd offshore wind farm (**Figure 1.7**) and it is likely that they spent significant time there. However, due to the time of tagging, it is not well known how important the project area is during the summer months. In general, harbour seals showed much higher site-fidelity during summer, than during winter, where they moved longer distances (Dietz et al., 2013a). Both Anholt and Hesselø are important haul-outs in the breeding and moulting season in May to August.

1.5 Grey seal (gråsäl)

The grey seal was exterminated from Danish and West Swedish waters in the beginning of the 20th century, but the species is re-occurring and the population is now increasing. Extremely few grey seal pups are born in Danish / West Swedish Waters, most of them in the Western Baltic (Hansen and Høgslund, 2019).

1.5.1 Conservation status

The grey seal population is listed as Vulnerable in the 2020 Danish Red List. The Swedish Red List 2020 considers only the Baltic population, which is listed as Least Concern (See https://artfakta.se/). The grey seal is listed in annex II and V of the Habitats Directive (92/43/EEC), distribution and abundance must be evaluated according to descriptor 1 of the Marine Strategy

Framework Directive, it is listed on annex II of the Bern convention (19th September 1979), annex II of the Bonn convention and annex II of the Convention on the international Trade in Endangered Species (CITES). Grey seal hunting is allowed in Sweden with permission from the Swedish Environmental Protection Agency (Naturvårdsverket) and several hundreds are shoot per year in the Baltic proper. Denmark has amended the HELCOM recommendation (9th January 1988) to ban seal hunting throughout the Baltic Sea, although dispensation is given to shoot grey seals that cause problems in the fisheries. In 2020 up to 40 grey seals may be shot in Denmark, primarily around Bornholm and in the Western Baltic. Special areas of conservation have been appointed for the protection of the grey seal in Sweden and Denmark, and some additional haul outs outside Natura 2000 sites are further protected in Denmark as wildlife reserves.

1.5.2 Distribution

No tracking data exists for grey seals in Kattegat, except for presence at the haul-out sites. In Kattegat the population is increasing and in 2018, 79 grey seals were observed in the Danish part of Kattegat during DCE's aerial seal counts for the NOVANA program. In the period 2010-2017, the maximum count in a single day was 127 grey seals at Læsø (Hansen and Høgslund, 2019). It is unknown whether grey seals use the proposed wind farm area to any significant degree, but as the population of grey seals in Kattegat is extremely small, it is unlikely grey seals will be encountered in the wind farm area during the surveys. Furthermore, the grey seals are likely to be protected by any mitigation measures taken to protect harbour seals.

1.5.1 Yearly pattern of presence in Southern Kattegat

There are no data on annual variation in presence of grey seals in Southern Kattegat. However, grey seals are observed during the annually conducted aerial harbour seal counts on Anholt and Hesselø during summer counts.

2 Assessment methodology

The aim of this impact assessment is to assess the potential negative impact of pre-investigations on marine mammals in the area. The pre-investigations are the first step towards establishment of an offshore wind farm at Kattegatt Syd. The primary receptors are marine mammals. The sensitivity of the receptor is variable depending on for example season, population status, age of the animal and type of impact. The primary impact is considered to be underwater noise from the various acoustic instruments that will be used to examine the seabed and top layers of sediment. The magnitude of the impact vary with instrument and use. The impact assessment is performed by combining the sensitivity of the receptor with the magnitude of the impact (**Table 2.1**).

Table 2.1. Table of methodology for evaluating negative significance of an impact. Based on Sveegard et al. (2017).

Impact significance		Impact magnitude			
		None or negligible	Minor	Medium	High
Sensitivity of receptor	Low	None or negligible	Minor	Minor	Moderate
	Medium	None or negligible	Minor	Moderate	Major
	High	None or negligible	Moderate	Moderate	Major

2.1 Impact magnitude

The assessment evaluates impacts both on individuals (injury) and at a population level (disturbance). At the level of individuals to individual animals, impact magnitude is divided into four categories: Negligible, Minor, Medium and High (**Error! Reference source not found.**). For individuals an impact classified as high indicates that the individual is affected to a degree, where it is unlikely to survive the injuries it suffers from the impact. This could be from clearing of WWII ammunition by explosion. A moderate impact indicates that the effect is temporary and that the individual most likely will survive, but that it will take time to recover, potentially affecting its nutritional or health status for a period. A minor impact may be a shorter duration disturbance effect of a limited area.

At population level, impact magnitude is divided into the same four categories: Negligible, Minor, Medium and High. The severity is based on assessment of energetic effect of impact on individuals from behavioural changes or loss of suitable habitat, with effects carrying over at a population level. This impact is through effects on vital parameters such as survival and fecundity. Only in very rare cases are survival affected directly, for example by a pregnancy terminated prematurely or separation of mother from calf/pub. In most cases the impact occurs as a cumulative loss of foraging opportunities, which leads to slightly, but cumulative loss of energy reserves, which in turn may lead to a slightly higher risk of mortality during winter (due to reduced thermal insulation) and slightly lower fecundity. Fecundity may be affected directly by the female simply skipping a year of reproduction in severe cases, but more likely indirectly through lower birth weight of the calf/pub, which again leads to decreased chance of survival through the first winter.

A common effect of exposure to underwater noise is that animals leave the impacted area. However, the effect is assumed to cease shortly after the acoustic instruments are turned off (within hours), and the animals begin to return.

How large impact such a displacement has at a population level will depend on whether the animals can move to other similarly suitable habitats with the same opportunities for foraging while the impact is ongoing, as well as on the duration of the impact.

At a population level, an impact classified as high indicates that the population is negatively affected to a degree where it could take years for the population to recover. This could for example be a permanent elimination of a seal haul-out used for reproduction, where there are no other similarly suitable haul-outs in the area. A moderate impact, in contrast, indicate that any effect on the population is temporary, i.e. could for example be restricted to the year, where the disturbance occurs. Minor impacts will affect individual animals, but not in a way that could propagate to any significant effect on the population. See **Table 2.2**.

Table 2.2. Criteria for assessing intensity of behavioural disturbance. The intensity is assessed at the level of the animals, number of animals and on the size of the affected area and does not pertain to Natura 2000 sites.

Impact magnitude	Criteria/conditions
Negligible	An insignificant number of animals is affected and/or disturbances are very short (such as startle responses), without any significant effect on the time budget of the affected animals. The total impact on the habitat is therefore insignificant.
Minor	Disturbance of small parts of the available habitat and/or over short periods, unlikely to affect the overall integrity of the available habitat and hence the energy budget of the animals significantly.
Moderate	Significant disturbance of considerable parts of the available habitat and/or over extended periods, effectively reducing the available habitat and hence the energy budget of a significant number of animals.
Major	Extensive disturbance of large areas and over long time, effectively reducing the available habitat and hence energy budget of a significant number of animals, sufficient to affect reproductive success and survival.

2.2 Sensitivity of marine mammals in Kattegatt Syd

For this sensitivity assessment of marine mammal populations and individuals in Kattegat towards impacts of the pre-investigations, we have combined factors in biology (physiological impact, behaviour and energy consumption), population status, vulnerable areas and periods (e.g. breeding or moulting) and distribution (their presence during the impact). The assessment methodology of marine mammal sensitivity is summarized in **Table 2.3** below.

Table 2.3. Assessment categories and methodology of **sensitivity** for marine mammal populations and individuals. All marine mammals in Sweden and Denmark are internationally and nationally protected and is therefore identical for all sensitivity categories.

Category	Criteria
Low	The population status is favourable The impacted area does not include nationally or regionally important areas used for breeding, feeding or migration Physiology and behaviour of the species is not, or only temporarily affected by the impact
Medium	The population status is favourable The impacted area include nationally or regionally important areas used for breeding, feeding or migration Physiology and behaviour of the species is moderately affected by the impact
High	The population status is not favourable and/or abundance is low The impacted area includes nationally or regionally important areas used for breeding, feeding or migration Physiology and behaviour of the species is severely and/or permanently affected by the impact

2.3 Harbour porpoise sensitivity

Harbour porpoise calving takes place from April to October, with the prime time being May-August. Calves of a few months of age follow their mother closely, and only when the mother dives to forage, is the calf left alone at the surface for short periods (Camphuysen and Kropp 2011). When the calf is about ten months old it still swims with its mother and have a correlated diurnal dive pattern, however it is not known if the dives themselves are synchronized (Teilmann et al. 2007). At eleven months of age the mother-calf dive pattern is less correlated, and it is likely around this age the calf now dives independently and eventually breaks away. Before this age, calves are unlikely to survive on their own. The period March-May is the period with the most bycatch in Kattegat, which is interpreted as the period where calves from the previous year begin to separate form their mother and, naïve as they are, therefore are especially prone to end as bycatch. In fact, yearlings are the most common age-class in bycatch from Kattegat (Berggren, 1994). Harbour porpoises are therefore assessed as having **high** sensitivity to disturbances from underwater noise all year (Table 2.4).

Table 2.4. Sensitivity of marine mammal populations in Kattegat to underwater noise from pre-investigations at Kattegatt Syd OWF.

Species	Jan Feb Mar Apr	May Jun Jul Aug	Sep Oct Nov Dec
Harbour porpoise	High	High	High
Harbour seal	Medium	Medium	Medium
Grey seal	Medium	Medium	Medium

2.4 Harbour seal sensitivity

Harbour seals are sensitive to disturbances from underwater noise. Harbour seals give birth to a single pup on haul-outs in the period May-June (Figure 1.6). The pup can immediately accompany its mother in the water, but the mother / pup pair is dependent on appropriate and undisturbed haul-outs during the first month for suckling. This pertains especially to disturbances on land and from noise in air. In southern Kattegat haul-outs relevant for the Kattegatt

Syd wind farm are Hesselø (DK) (closest distance 56 km), Anholt (DK) (closest distance 18 km) and Hallands Väderö (SE) (closest distance 40 km).

The pre-investigations at the Kattegatt Syd windfarm area are unlikely to disturb seals at the relevant haul-outs during the breeding and moulting period, and the pre-investigations are therefore not expected to negatively affect the harbour seal population in Southern Kattegat. The sensitivity of breeding and moulting seals on land are therefore assessed as **Low**. There may however be seals foraging in the water in the wind farm area during the pre-investigations. The sensitivity of harbour seals to underwater noise from the pre-investigations are assessed as **Medium** all year (**Table 2.4**).

2.5 Grey seal

Very little is known about sensitivity of grey seals to disturbances from underwater noise. Grey seals from the Baltic Population (including Kattegat) give birth to and nurse their pup in February-March. The pup is dependent on its mother for a few weeks from birth until weaning. As the pup is born in a white lanugo fur that is not water resistant, the pup has to remain on land to survive and is therefore very sensitive to disturbances during this period. Grey seals moult in May/June. During both the pupping and moulting period, grey seals depend on appropriate and undisturbed haul-outs on land. Pupping is, however, extremely rare in Kattegat. In Kattegat the closest haul-outs to the Kattegatt Syd windfarm area is the islands Hesselø and Anholt in Denmark and Hallands Väderö in Sweden. These sites are not expected to be disturbed by the pre-investigations in the Kattegatt Syd OWF, and the sensitivity of grey seals breeding or moulting on land is assessed as **Low**. The sensitivity of grey seals potentially foraging in the water in the project area during the pre-investigations are assessed as **Medium** all year. (**Table 2.4**).

2.6 Disturbance of Natura 2000 sites

There are presently no Swedish (or Danish) guidelines pertaining to regulation of noisy activities inside Natura 2000 sites appointed for harbour porpoises and/or seals. However, the British Joint Nature Conservation Committee (JNCC), were requested advice on exactly this issue and have provided guidance in a recent report (JNCC, 2020b) concerning noise between 10 Hz and 10 kHz, and we will therefore apply these guidelines to the use of the sparker and the small airgun array. The JNCC guidelines does not pertain to the multi-beam sonar as it is of much higher frequency, however, we have chosen to base this assessment on the approach by JNCC for higher frequency noise sources as well. The same concept by JNCC will therefore be used throughout this assessment. The key recommendations are summarized as:

A) The project must not disturb more than “20 % of the relevant area of the site in any given day”, and

B) The project must not cause disturbance above “An average of 10 % of the relevant area of the site over a season”.

The justification for the numbers can be found in the JNCC report (JNCC, 2020b) and the background report (JNCC, 2020a). Here we have assessed impacts on nearby Natura 2000 sites based on the below:

"Disturbance"

By disturbed area is understood the area where the sound pressure level, frequency weighted according to the most recent reviews (National Marine Fisheries Service, 2016; Southall et al., 2019) and expressed as a short-term rms-average (Tougaard and Beedholm, 2019; Tougaard et al., 2015), is predicted to exceed the threshold for behavioural reactions of porpoises. There is little consensus on the numerical value of this threshold. The sole review of the available data suggested a value approximately 50 dB above the hearing threshold for porpoises (Tougaard et al., 2015), which translates into a threshold of $L_{eq\text{-}125ms}$ 100 dB re. 1µPa, VHF-weighted (Southall et al., 2019), which has been used in other impact assessments, such as the Swedish Kriegers Flak Offshore Wind Farm (Tougaard and Mikaelsen, 2020; Tougaard and Mikaelsen, 2018).

"Relevant area"

In the context of Kattegatt Syd OWF the relevant area is interpreted as the Swedish Natura 2000 sites *Lilla Middelgrund* (178,4 km^2) and *Stora Middelgrund and Röde Bank* (114.1 km^2).

"20 % … in any given day"

In a precautionary way, this is interpreted such that the disturbed area should remain below 20 % of the Natura 2000 sites during the pre-investigations.

"An average of 10 % … over a season"

The disturbance must also be assessed across the season, which is defined by JNCC (JNCC, 2020b) as Summer from April to September inclusive, winter as October to March inclusive. During each season the disturbance may not exceed an average of more than 10 % disturbance of a Natura 2000 site.

2.6.2 Assessment of impact in Natura 2000 sites

In the lack of national guidelines, the impact will be evaluated according to the JNCC guidelines, which means that;

< 20 % disturbance = **acceptable** disturbance for single days

> 20 % disturbance = **unacceptable** for single days.

Across the construction phase, the disturbance is evaluated as average disturbance per day across the duration of the construction phase;

< 10 % = **acceptable**

> 10 % = **unacceptable**.

3 Primer on acoustics

It is beyond the scope of this report to give a full introduction to underwater acoustics and the impact of noise on marine mammals. However, some fundamental background is required to understand the modelling and assessment performed. This background is provided below. Further details can be found in previous assessment reports for similar projects (Tougaard and Mikaelsen, 2020).

3.1 Sound pressure and energy

Underwater acoustics differ from aerial acoustics in a number of important ways. The much higher density of water means that the speed of sound is higher (about 1500 m/s vs. about 340 m/s in air), which also means that the wavelength is about five times larger in water compared to air. However, more important is that the dissipative loss experienced as the sound waves propagate through water is much smaller in water than in air. Another important consequence of the high density of water is that it is easier to create high pressures in water than in air. For this reason, and others, it is difficult to compare measures of signal magnitude in air and water (i.e. to determine which of the two is the loudest). As a first rule of thumb, sound pressure levels measured on a dB scale therefore cannot be compared between air and water. Instead, one should compare to sound pressures of other underwater sounds, to get an impression of the intensity of an underwater sound. Some reference points for comparison are given in **Table 3.1**.

Table 3.1. Typical sound pressure levels of various biological and man-made sources.

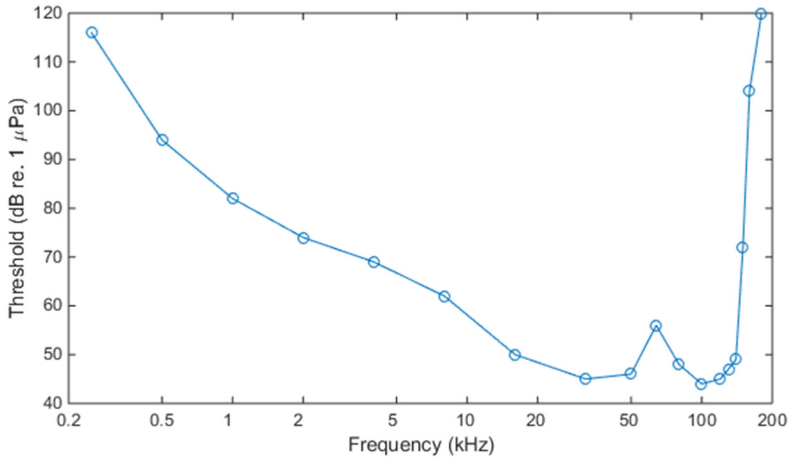
	Source level at 1 meters distance
Explosion of 100 g TNT	275 dB re. 1 µPa
Echolocation click of sperm whale	235 dB re. 1 µPa
Commercial echosounder	220 dB re. 1 µPa
Echolocation click of harbour porpoise	190 dB re. 1 µPa
Blue whale call	180 dB re. 1 µPa
Harbour seal mating call	145 dB re. 1 µPa
Natural background noise in shallow waters on a calm day	100 dB re. 1 µPa

The magnitude of underwater sounds can be quantified in two fundamentally different ways: either by the amplitude, which is a pressure and therefore measured in the unit of µPa, or by the energy (sound exposure level), which is the cumulated exposure over time. Energy is normally measured in the unit Joule, but in acoustics, the equivalent unit $\mu Pa^2 s$ is commonly used for reasons of simplicity. It is central to understand that the two units express two entirely different physical properties (pressure vs. energy). Thus, they cannot be compared. Note also that other references may occur in the literature as well.

3.2 Hearing in marine mammals

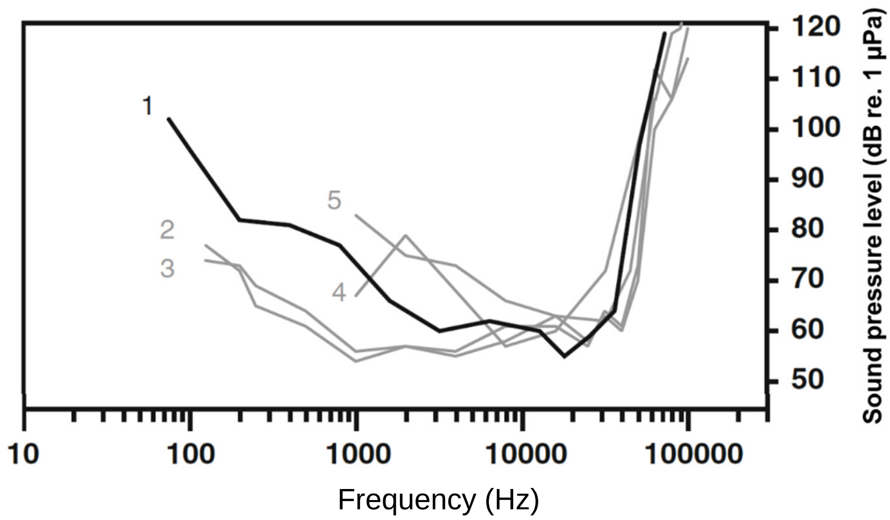
Marine mammals rely heavily on underwater hearing for orientation, prey capture and communication underwater. Consequently, they have very good underwater hearing and are sensitive to noise, as a disturbing factor and, if sufficiently loud, also by directly inflicting injury to the animals. The most fundamental description of hearing abilities of marine mammals is their audiograms, which express the hearing threshold at different frequencies. Harbour porpoise hearing is very sensitive and covers a broad frequency range (**Figure 3.1**). Best hearing is in the frequency range between about 10 kHz to around 160 kHz.

Figure 3.1. Audiogram for harbour porpoise, adapted from Kastelein et al. (2010). The audiogram shows the hearing threshold, i.e. the minimum audible level as a function of frequency. Best sensitivity (lowest threshold) is in the range 10-160 kHz.



The audiogram of harbour seals shows good underwater hearing in the range from a few hundred Hz to about 50 kHz (**Figure 3.2**). No audiogram is available for grey seals, but given their close taxonomic relationship and similar ear anatomy, it is a reasonable first assumption that their hearing is comparable to harbour seal hearing.

Figure 3.2. Audiograms for harbour seals. Numbers refer to different studies. 1: Reichmuth et al. (2013), 2+3: Kastelein et al. (2009), 4: Terhune (1988), and 5: Møhl (1968), From Reichmuth et al. (2013).



3.3 Impact of underwater noise

Underwater noise can impact marine mammals in different ways. In assessments as the present, it is customary to separate effects into different types, which are treated separately. The first split is between damage (injury) caused by loud sound and effects on behaviour of animals. It is useful to subdivide damage into severe effects (acoustic trauma, tissue damage) and effects entirely on the auditory system (noise inflicted hearing loss). It is also useful to divide behavioural effects into behaviours elicited by the noise (startle, deterrence etc.) and interference with the perception of sound itself (masking). The mechanisms through which the different effects manifests themselves differ as well. This has important implications for how exposure to the noise should be evaluated and in particular on the metrics used for exposure limits.

When discussing effects of noise it is important to make a distinction between the acute sound pressure level and the accumulated acoustic energy. A useful analogy comes from toxicology, where some substances are acutely toxic, in which case one is concerned only with the concentration of the toxin in the air breathed or food ingested. Other substances accumulate in the body, in which case the total dose accumulated over time becomes important. In acoustics, there are impacts, such as behavioural reactions, where the best predictor of a response is the short-time averaged sound pressure level, adequately frequency weighted (Tougaard et al., 2015); whereas other impacts, most notably hearing threshold shifts (TTS and PTS), are better predicted by the accumulated (time-integrated) acoustic energy (Southall et al., 2019; Tougaard et al., 2015).

This difference in how effects are best predicted, either based on the acute exposure (sound pressure level) or by cumulated dose (sound exposure level), means that it is not possible to define a single threshold, which can cover all effects. It is possible to have long-term sound exposure at low levels, which creates little behavioural effects, but which induce hearing threshold shifts (Kastelein et al., 2016) and equally possible to have short sounds, which induce behavioural reactions, but without any effects on hearing thresholds. The impact of pile driving on both behaviour and the risk of injury (hearing loss) must thus be treated separately.

3.4 Acoustic trauma

Very loud, impulsive sound (shock wave) is capable of inflicting direct damage to biological tissue (acoustic trauma). A recent review of blast injury on human divers (Lance et al., 2015) indicate a 10% risk of survivable injury at an exposure to 30 Pa· s, or a corresponding peak pressure of at least 226 dB re 1 µPa. Such high acoustic pressures are only encountered in connection to underwater explosions, not relevant for the geophysical surveys.

3.5 Noise induced hearing loss

The mammalian inner ear is adapted to be extremely sensitive to sound, and it is therefore a well-established assumption that injury from exposure to sound will manifest itself in the inner ear before any other tissue (Southall et al., 2007). Criteria and thresholds for noise-induced permanent hearing loss are given by National Marine Fisheries Service (2016) and Southall et al. (2019). These criteria and thresholds operate with two central principles: they are frequency weighted according to the hearing of target species and they are expressed as cumulated sound exposure level (SEL) over the duration of the exposure (up to a limit of 24 hours). The thresholds used in this assessment follows recommendations of National Marine Fisheries Service (2016) and Southall et al. (2019). For harbour porpoises, the threshold for permanent noise-induced hearing loss (PTS) is 155 dB re. 1 µPa^{2}s, frequency weighted with the VHF-cetacean weighting curve (Southall et al., 2019). For seals the corresponding PTS threshold is 185 dB re. 1 µPa^{2}s, frequency weighted with the Phocid seal weighting curve (Southall et al., 2019).

The modelling performed by Rambøll (appendix 1) was based on the thresholds for harbour porpoises shown in figure 3.3.

Table 3.1. Harbour porpoise impact thresholds as used by Rambøll (appendix 1) for the modelling of impact ranges.

Species	PTS, SELcum** VHF weighted dB re. 1μPa²s	PTS, SELcum** VHF weighted dB re. 1μPa²s	TTS, SELcum** VHF weighted dB re. 1μPa²s	TTS, SELcum** VHF weighted dB re. 1μPa²s	Behavior, SEL unweighted dB re. 1μPa²s	Behavior, rms*, VHF weighted dB re. 1μPa²s
	Non-impulsive	Impulsive	Non-impulsive	Impulsive		
Harbor Porpoise	173 dB	155 dB	153 dB	140 dB	145 dB	100 dB

*Tougaard, 2020, Includes animal fleeing at 1.5 m/s.
**Southall, 2019 Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects Includes animal fleeing at 1.5 m/s.

3.6 Disturbance of behaviour

Permanent or temporary damage to marine mammal hearing may not necessarily be the most detrimental effect of noise. Noise well below the level able to induce hearing loss may affect and alter the behaviour of animals, which can carry implications for the long-term survival and reproductive success of individual animals, and thereby ultimately on the population status (National Research Council, 2003). Effects can occur directly from severe reactions as for example panic or fleeing (negative phonotaxis), by which there is an increased risk of direct mortality due to for example bycatch in gill nets or separation of dependent calves from mothers. More common, however, is probably less severe effects where animals are displaced from habitats, or their foraging behaviour disrupted due to noise (as demonstrated for example by Wisniewska et al., 2018).

A review of results from behavioural reactions to noise in wild porpoises was performed by Tougaard et al. (2015). This review proposes a generic response threshold of a sound pressure level 40-50 dB above the hearing threshold (audiogram) of the porpoise, which corresponds to about 100 dB re. 1 μPa VHF-weighted (sensu Southall et al., 2019).

Not enough is known about responses of harbour seals to underwater noise for anyone to have proposed a generic threshold.

3.7 Masking

Masking is the phenomenon where noise can affect the ability of animals to detect and identify other sounds negatively. The masking noise must be audible, roughly coincide with (within tens of milliseconds), and have energy in roughly the same frequency band, as the masked sound. See Erbe et al. (2016) for a current review. The short, intermittent pulses used in the geophysical surveys means that they have little potential for masking. This effect is therefore not assessed.

4 Impacts from pre-survey

Three types of equipment have been assessed for impact and all were assessed for risk of injury (acoustic trauma) to marine mammals in the shape of permanent hearing loss (PTS) and extent of spatial and temporal loss of habitat due to behavioural changes. Modelling of impact ranges were performed by Rambøll (Rambøll, 2021) (report included as appendix 1). Modelling was performed for two positions inside the Kattegatt Syd offshore windfarm area, north and south for the month of November, which represents winter, which is the time of the year, where the transmission loss is lowest, which means that lower impact ranges is expected for the Summer season.

4.1 Sub-bottom Profiler

Sub-bottom profilers consists of a directional sound source towed on a float behind a vessel at slow speed. Based on Vattenfall (2019) and Rambøll (2020) the assessment was based on an Innomar SES2000 towed at a speed of 4 knots (2.1 m/s).

The Innomar SES2000 is a parametric sonar that emits two primary sounds at high frequencies, between 85 kHz and 115 kHz and measure on the low-frequency secondary sound around 10 Hz (Rambøll, 2020; Wunderlich, 2016). Impact is assessed on the primary sounds, due to their much higher audibility to porpoises. The primary sounds are inaudible to seals (see **Figure 3.2**) and impact therefore not assessed for these. Modelling of behavioural disturbance range and risk of inflicting permanent hearing loss (PTS) was modelled based on the below input parameters (Appendix 1 & Rambøll (2021)). Impact was modelled for two versions sub bottom Profiler signals, a) short 0.07 ms pulses and a SEL source level of 178 dB re. 1µPa^{2}s, and b) longer pulses of 1.3 ms pulses and a SEL source level of 186 dB re. 1µPa^{2}s.

Source level, rms	240 dB re. 1µPa
Source level, peak	198 dB re. 1µPa
Pulse duration, a.	0.07 ms
Single pulse SEL, a.	178 dB re. 1µPa^{2}s
Pulse duration, b.	1.3 ms
Single pulse SEL, b.	186 dB re. 1µPa^{2}s
Frequency	85-115 kHz
Pulse repetition rate	60 pulses/s
Survey ship speed	2.1 m/s
Porpoise flee speed	1.5 m/s (Otani et al., 2000).

4.1.1 Range of behavioural disturbance

The average and maximum ranges at which porpoises are expected to react to the sound from the two types of sub-bottom profiler signals were modelled by Rambøll (2021) as described in appendix 1 and the values are shown in Table 4.1. The maximum disturbance range was modelled for position 'south' in November and was 1899 m., which is thereby the estimated maximum impact range, under worst case assumptions of an omnidirectional sound source. In reality, the impact range will be smaller, because the sound source is directional. The maximum reaction threshold of 1.899 m translates into a affected area of 11.3 km^2 (9,3 km^2 for mean values) which can be considered the maximum temporary habitat loss during a survey, as porpoises inside this area are expected to react to the noise, with a gradient of lesser response further away from the source. As this area is very small relative to the entire windfarm area, and likely significantly overestimated, as the directionality of the sound source was ignored, the impact of the survey on individual porpoises in the during the survey is assessed as **minor,** and the impact at a population level is assessed as **negligible**.

4.1.2 Effect on Natura 2000 sites

The Sub Bottom Profiler has a disturbance effect within maximum 1,9 km or mean 1,7 km (Table 4.1). The border of the windfarm area is 1 km from the border of the nearby Natura 2000 sites, which means that even for the maximum values, porpoises will be disturbed in maximum 1,2 % of the Stora Middelgrund Natura 2000 site and maximum 0,7% of the Lilla Middelgrund Natura 2000 site, and only when the vessel is operating close to the windfarm border. This is well below the 20% JNCC threshold (see Table 4.1 and table 4.2). This means that the affected part of the Natura 2000 sites at any given day will be below the 20 % JNCC threshold and this impact is assessed as **acceptable** according to the JNCC guidelines.

Table 4.1. Model output with impact ranges for harbour porpoises. The harbour porpoise was assumed to be at distance zero at onset of soft start (see appendix 1 for details).

		Distance to threshold limit	Southall 2019/Tougaard 2020	
		Average maximum	**Average/ maximum**	**Average/maximum**
Area	**Activity**	**PTS Harbor Porpoise (1.5 m/s fleeing)**	**TTS Harbor Porpoise (1.5 m/s fleeing)**	**Behaviour Harbor Porpoise**
Site North	3D/2D Sparker (4 knots vessel speed) Impulsive	0 meters	400 meters	2828/3680 meters
Site North	Mini Airgun (4 knots vessel speed) Impulsive	0 meters	0 meters	600/913 meters
Site North	SBP/ Innomar SES 2000 (0.07 ms puls) (4 knot vessel speed)	0 meters	130 meters	1677/1845 meters
Site North	SBP/ Innomar SES 2000(1.3 ms puls) (4 knot vessel speed)	20 meters (45 second soft start**)	350 meters	1590/1757 meters
Site South	3D/2D Sparker (4 knots vessel speed) Impulsive	0 meters	450 meters	3130/3979 meters
Site South	Mini Airgun	0 meters	0 meters	640/909 meters
Site South	SBP/ Innomar SES 2000 (0.07 ms puls) (4 knot vessel speed)	0 meters	140 meters	1720/1899 meters
Site South	SBP/ Innomar SES 2000(1.3 ms puls) (4 knot vessel speed)	20 meters (45 second soft start**)	400 meters	1720/1899 meters

4.1.1 Risk of hearing loss - porpoises

Risk of hearing loss was assessed by modelling as outlined in appendix 1 (Rambøll, 2021). Energy of all pulses received by the fleeing animal is summed and compared to the threshold for inducing permanent hearing loss in VHF cetaceans by impulsive noise, taken from Southall et al. (2019) (155 dB re. 1 μPa^2s) (**Table 3.1**). Results are shown in **Table 4.1**.

From **Table 4.1** it can be seen that there is no risk of inflicting PTS in porpoises, as the animal can swim away before it reaches threshold level for both types of Sub Bottom Profiler signals. It is deemed unrealistic that any porpoise will be at a range of 20 m at the onset of soft start, as porpoises elsewhere have displayed negative phono taxis to vessel noise and move away at a range of app. 500 m from vessels (Bas et al., 2017).

As the exposure is almost certainly overestimated by ignoring the directivity of the sound source, the risk that any porpoise will suffer permanent hearing loss is virtually zero. The impact on the porpoise population in Kattegat by infliction of hearing loss is thereby assessed as **negligible**.

4.2 Sparker

Sparkers are used in a very similar way as the sub-bottom profiler. The main difference is in the sound source used. Sparkers use an array of many metal electrodes, onto which a high voltage is applied. As the sea water functions as an electrolyte a short spark will form, creating an air bubble, which quickly collapses. Formation of these air bubbles creates a very sharp and short acoustic pulse, which is used for the surveying.

As basis for the assessment, the characteristics of a Delta sparker was used (Rambøll, 2020; Vattenfall, 2019), with the following input parameters

Source level, rms	186 dB re. 1µPa (Rambøll, 2021)
Source level, zero-peak	208 dB re 1 µPa (Rambøll, 2021)
Pulse duration	2.2 ms (Rambøll, 2020)
Single pulse SEL	178 dB re. $1\mu Pa^2s$ (Rambøll, 2021)
Frequency	2-3 kHz (Rambøll, 2020)
Pulse repetition rate	3 pulses/s (Rambøll, 2020)
Survey ship speed	4 knots (Rambøll, 2020)
Porpoise flee speed	1.5 m/s (Otani et al., 2000)
Porpoise reaction threshold	141 dB re. 1µPa[1] (Tougaard et al., 2015)
Threshold PTS porpoises	155 dB re. $1\mu Pa^2s$[1] (Southall et al., 2019)
Threshold PTS seals	185 dB re. $1\mu Pa^2s$[2] (Southall et al., 2019)

4.2.1 Range of behavioural disturbance

The maximum range at which porpoises are expected to react to the sound from the sparker was estimated by modelling by Rambøll (Rambøll, 2021).

The behavioural reaction threshold is exceeded at a range of maximum 3680 m in December for position 'north', which for this assessment thereby is the estimated impact range.

Behavioural reactions in seals cannot be assessed quantitatively, as no generic threshold for behaviour is available. However, the few studies of reaction dis-

[1] Weighted with the VHF-weighting curve from Southall et al. (2019).

[2] Weighted with the PCW-weighting curve from Southall et al. (2019).

tances in wild seals to low frequency sounds, such as pile driving noise, indicate comparable reaction distances of seals and porpoises (Russell et al., 2016). It is therefore expected that reaction distances of seals to the sparker would be similar to the reaction distances of porpoises.

The maximum reaction threshold of 3,979 m translates into an affected area of 49.74 km², which can be considered the maximum temporary habitat loss during a survey, as animals inside this area are expected to be behaviourally affected by the survey when in progress, with a gradient of lesser response further away from the source. For the mean values the disturbed area is app. 31 km² (table 4.2). As this area is very small relative to the distribution of porpoises and seals in the southern Kattegat, the impact of the survey on individual porpoises and seals in the area during the survey is assessed as **minor**. The impact on the populations of marine mammals in Kattegatt is assessed as negligible.

4.2.2 Effect on Natura 2000 sites

In order to evaluate the effect of the survey on the nearby Natura 2000 sites, the disturbance range was calculated as the percent area disturbed above the threshold for behavioural changes for harbour porpoises within the Natura 2000 sites (table 4.2). Both mean values and maximum values as arrived via modelling by Rambøll (table 4.1) is included in the table. For both mean and maximum values, there is a risk that animals inside the Natura 2000 sites will be affected behaviourally. This risk is reduced with range to the survey vessel. Based on the maximum values, the disturbance translates into a maximum disturbance of the Stora Middelgrund & Röda Bank Natura 2000 site of about 12 %, i.e. well below the daily maximum disturbance limit of 20 % as determined by JNCC. For Lilla Middelgrund a maximum disturbance of 8 % is expected. As this is the worst case maximum impact and only expected when the vessel is operating the sparker close to the border of the windfarm site, where little survey effort is expected, the associated impact on the Natura 2000 sites will likely be less than the worst case estimated here. For mean values, the disturbance amounts to 6% of the Stora Middelgrund and 4% of the Lilla Middelgrund atura 2000 sites. The maximum impact of the sparker on the Natura 2000 sites is assessed as **acceptable for single days** with regards to the JNCC guidelines. The impact can be avoided entirely, if the sparker is kept at a distance of 3 km to the windfarm border, near the Natura 2000 sites, assuming maximum values.

Table 4.2. Based on the model out-puts from table 4.1 on behavioural disturbances, percent disturbance of the nearby Natura 2000 sites were calculated for maximum and mean model outputs. Note that the Natura 2000 sites are situated minimum 1 km from the border of the wind farm area. These calculations therefore apply to the closest range between Natura 2000 sites and the wind farm area.

Disturbance of Natura 2000 sites (Stora and Lilla Middelgrund) pr day					
		Range, km	**Area, km2**	**% Stora Middelgrund**	**% Lilla Middelgrund**
Maximum	Sparker	3,98	49,74	12,22	7,81
	SBP	1,90	11,34	1,12	0,71
	Mini airgun	0,91	2,62	0	0
Mean	Sparker	3,13	30,78	6,25	3,99
	SBP	1,72	9,29	0,71	0,46
	Mini airgun	0,60	1,13	0	0

The surveys are expected to last about 108 days within the windfarm area and about 137 days in the cable corridor (table 1.1). However, noise from the sparker will only affect the Natura 2000 sites when the survey vessel is close to the border of the windfarm borders where there is 2-3 km to the Natura 2000 border (mean and maximum values, respectively). This is likely to be only few of the survey days, as the Natura 2000 borders are in either end only, of the windfarm site. It is therefore unlikely that the 10% threshold across the season will be exceeded when using the sparker. The seasonal disturbance of the Natura 2000 sites by the sparker is assessed as **acceptable**.

4.2.3 Risk of hearing loss

Risk of inflicting hearing loss from exposure to the sparker was also estimated (Rambøll, 2021) (**Table 4.1**).

It assessed based on table 4.1 that there is no risk of inflicting permanent threshold shifts in harbour porpoises when using soft start. The risk of inflicting permanent hearing loss on individual porpoises from exposure to the sparker is thereby assessed as **negligible**. The impact on PTS on the porpoise population in Kattegat is assessed as **negligible**.

The risk of inflicting a temporary threshold shift (TTS) exists, if the porpoise is within maximum 450 m of the sparker (Rambøll, 2021), when the vessel passes. Because porpoises are likely scared off by the use of soft start as well as by the noise from the survey vessel itself, the risk that a porpoise will be this close to the sparker is assessed as very unlikely. The impact from temporary threshold shift on individual porpoises as well as the porpoise population in Kattegat is therefore assessed as **negligible.**

The threshold for infliction of PTS in seals is higher than for harbour porpoises. The risk of TTS and PTS in seals is therefore assessed as **negligible** for individuals. The effect of both TTS and PTS at a population level for both seal species in Kattegat is assessed as **negligible**.

4.3 2D seismic survey with single airgun

Small airguns, 100 cu-inch or less in volume, are commonly used as sources for sub-bottom profiling. The assessment below is based on a 40 cu-inch airgun, towed at a speed of 4 knots (2.1 m/s). Modelling of behavioural disturbance range and risk of inflicting permanent hearing loss (PTS) and temporary hearing loss (TTS) was modelled based on the following input parameters from appendix 1:

Source level, rms	193 dB re. 1µPa
Pulse duration	1.3 ms
Single pulse SEL	183 dB re. 1µPa^{2}s
Frequency	50-500 Hz (Hermannsen et al., 2015)
Pulse repetition rate	1 pulse every 4 sec
Survey ship speed	2.1 m/s
Porpoise flee speed	1.5 m/s (Otani et al., 2000)
Porpoise reaction threshold	100 dB re. 1µPa (rms),VHF-weighted
Threshold PTS porpoises	155 dB re. 1µPa^{2}s[3] (Southall et al., 2019)

[3] Weighted with the VHF-weighting curve from Southall et al. (2019).

Threshold PTS seals 173 dB re. $1\mu Pa^2s^5$

4.3.1 Range of behavioural disturbance

The maximum range at which porpoises are expected to react to the sound from the airgun was modelled by Rambøll (2021) in the same way as for the sparker (see table 4.1) (see appendix 1).

The behavioural reaction threshold is exceeded at a range of maximum 913 m in November at position 'north' (table 4.1), which for this assessment thereby is the estimated maximum impact range for the mini-airgun.

Behavioural reactions in seals cannot be assessed quantitatively, as no generic threshold for behaviour is available. However, the few studies of reaction distances in wild seals to low frequency sounds, such as pile driving noise, indicate comparable reaction distances of seals and porpoises (Russell et al., 2016). It is therefore expected that reaction distances of seals to the mini-airgun would be similar to the reaction distance of harbour porpoises.

The maximum reaction threshold of 913 m translates into an affected area of 2.6 km^2 (table 4.2), which can be considered the maximum temporary habitat loss during a survey, as animals inside this area are expected to be behaviourally affected by the survey when in progress. As this area is very small relative to the distribution of porpoises and seals in the southern Kattegat, the impact of the survey on individual porpoises and seals in the survey area during the survey is assessed as **minor**. At a population level the impact of behavioural changes is assessed as **negligible**.

4.3.2 Effect on Natura 2000 sites

Since there is a distance of 1 km between the windfarm area and the border of the closest Natura 2000 sites, no behavioural changes are expected within the Natura 2000 site. The disturbance of the Natura 2000 sites are therefore assessed as **acceptable**.

Over the season the impact on the nearby Natura 2000 sites is also expected to be below the JNCC threshold of maximum 10 % disturbed Natura 2000 area on average, since no disturbances are expected within the Natura 2000 sites on individual days. The assessed impact on the nearby Natura 2000 sites is **acceptable** according to the JNCC guidelines.

4.3.3 Risk of hearing loss

Risk of inflicting hearing loss from exposure to the airgun was modelled by Rambøll (2021) (see appendix 1). Results are given in table 4.1 above. The modelling shows, that when using soft start, PTS is not an expected effect for harbour porpoises from the mini-airgun. The likelihood that any porpoise will suffer permanent hearing loss due to exposure to the airgun is therefore assessed to be virtually zero. The impact on individual porpoises is assessed as **negligible**. The impact on the porpoise population by infliction of hearing loss is thereby assessed as **negligible**.

Since seals have a higher threshold for PTS than harbour porpoises (Southall et al., 2019), there is a lower risk of inflicting PTS in seals, and despite that this risk was not modelled (appendix 1), it is assessed that the likelihood that any seal will suffer permanent hearing loss due to exposure to the airgun virtually zero. The impact on individuals as well as at a population level by infliction of hearing loss is thereby assessed as **negligible** for both seal populations.

4.4 Mitigation measures

The estimates of impact made above are all under the assumption that the ship is moving and that animals therefore are warned well in advance of the approaching noise source and is scared away. The noise source in this way can therefore be said to be self-mitigating. Only when survey equipment is turned on is there a need for additional mitigation. The most appropriate way to do this would be in the form of a ramp up / soft start procedure, where the sound source is turned on gradually, i.e. starting at lowest possible source level, slowly ramping up, and / or similarly at lowest possible pulse repetition rate, slowly increasing to the rate used by the survey, or simply turning on / off. The duration of the soft start depends on the specifics of the equipment, but should be sufficient for animals close to the ship to escape to safe distance (could be outside risk of PTS, TTS or behavioural changes) before full output is reached. With a swim speed of 1.5 m / s it will take a porpoise 40 minutes to swim 3.9 km away from the ship, which is an indication of the time needed in case of the sparker to flee to an area where the received level is below the threshold for behavioural changes. For TTS the soft start would need to be 5 minutes, and for PTS even less. However, soft start is always recommended to reduce risk of panic reactions.

4.5 Effects from multiple activities

Several offshore windfarms are planned in the southern Kattegat area. It is therefore possible that several activities will be carried out simultaneously. This can be pre-investigations, the construction phase or a combination. There is therefore a potential for cumulative impact from simultaneous pre-investigations or construction of wind farms, should that occur. This is primarily relevant for wind farms potentially affecting the same Natura 2000 sites, as the contribution to disturbance from construction of all wind farms should be included in the comparison against the 10 % and 20 % thresholds to disturbed area as stipulated by JNCC.

The cumulative impact from simultaneous pre-investigations for several potential wind farms in the eastern Kattegat is assessed to be **minor**, given that the impact of pre-investigations or construction of the individual wind farms has been assessed to be minor or less. However, for Natura 2000 sites, all impacts need to be calculated according to the JNCC guidelines to evaluate overall impact across a season, as well as on a daily basis for several mutual or consecutive investigations and or constructions.

5 Conclusion and recommendation

Impacts of underwater noise from pre-investigations at the site of the potential windfarm at Kattegatt Syd has been assessed in the chapters above. At the time of writing the exact types of instruments to be used was unknown. The assessment has therefore been performed on assumptions of a typical survey with typical equipment used, and the maximum values for disturbances and TTS/PTS was used according to the precautionary principle. The actual effects are thus likely to be smaller. Of the equipment proposed, only three types were considered to have potential impact on marine mammals: a sparker, a parametric Sub Bottom Profiler and a small seismic airgun. The impacts were modelled by Rambøll (Rambøll, 2021).

The assessment shows that the risk of hearing loss in both seals and porpoises is **negligible** for all investigated equipment.

The behavioural reaction threshold of porpoises is exceeded at a maximum range of 1.9 km from the sub bottom profiler equivalent to a maximum impacted area of 11,3 km^2 (mean values give disturbance in 9,3 km^2). For the sparker the maximum impacted area is 49,7 km^2 (mean area of 30,1 km^2), and for the small airgun the maximum impacted area is 2,6 km^2 (mean of 1,1 km^2). For all three assessed equipment types with the stated parameters, the consequences of the behavioural disturbances on both seal populations and the harbour porpoise population in southern Kattegat was assessed as **negligible**.

As the survey vessel has to be within 1, 2 or 4 km based on maximum values (see table 4.1) of nearby Natura 2000 sites for impact to occur inside the protected sites from the assessed instruments, and the range between the border of the potential offshore windfarm site and the Natura 2000 site is 1 km, the impact on nearby Natura 2000 sites is well below the 20 % JNCC threshold, and the impact of survey activities with these instruments is therefore assessed as **acceptable** with regards to the JNCC guidelines. Based on the modelling by Rambøll for the winter period, impact inside Natura 2000 sites can be reduced to zero, if the vessel keeps a distance of 1 km or 3 km to the border of the windfarm site with the Sub Bottom Profiler and Sparker, respectively. This range may be lower in reality as suggested by the mean values, i.e. 0,7 or 2 km for the Sub Bottom Profiler and Sparker, respectively.

6 References

Bas, A.A., F. Christiansen, A.A. Öztürk, B. Öztürk, and C. McIntosh. 2017. The effects of marine traffic on the behaviour of Black Sea harbour porpoises (*Phocoena phocoena relicta*) within the Istanbul Strait, Turkey. *PLOS ONE*. 12:e0172970.

Berggren, P. 1994. Bycatches of the harbour porpoise (*Phocoena phocoena*) in the swedish Skagerrak, Kattegat and Baltic Seas; 1973-1993. *Rep.Int.Whal.Comm.* Special issue 15:211-215.

Carlén, I., L. Thomas, J. Carlström, M. Amundin, J. Teilmann, N. Tregenza, J. Tougaard, J.C. Koblitz, S. Sveegaard, D. Wennerberg, O. Loisa, M. Dähne, K. Brundiers, M. Kosecka, L.A. Kyhn, C.T. Ljungqvist, I. Pawliczka, R. Koza, B. Arciszewski, A. Galatius, M. Jabbusch, J. Laaksonlaita, J. Niemi, S. Lyytinen, A. Gallus, H. Benke, P. Blankett, K.E. Skóra, and A. Acevedo-Gutiérrez. 2018. Basin-scale distribution of harbour porpoises in the Baltic Sea provides basis for effective conservation actions. *Biological Conservation*. 226:42-53.

Dietz, R., A. Galatius, L. Mikkelsen, J. Nabe-Nielsen, F.F. Rigét, H. Schack, H. Skov, S. Sveegaard, J. Teilmann, and F. Thomsen. 2015. Marine mammals – Investigations and preparation of environmental impact assessment for Kriegers Flak. Report commissioned by EnergiNet.dk. Aarhus University, Roskilde. 184.

Dietz, R., J. Teilmann, S.M. Andersen, F. Rigét, and M.T. Olsen. 2013a. Movements and site fidelity of harbour seals (Phoca vitulina) in Kattegat, Denmark, with implications for the epidemiology of the phocine distemper virus. *ICES Journal of Marine Science*. 70:186-195.

Dietz, R., J. Teilmann, S.M. Andersen, R. Riget, and M.T. Olsen. 2013b. Movements and site fidelity of harbour seals (*Phoca vitulina*) in Kattegat, Denmark, with implications for the epidemiology of the phocine distemper virus. *ICES Journal of Marine Science*. 70:186–195.

Edrén, S.M.C., M.S. Wisz, J. Teilmann, R. Dietz, and J. Söderkvist. 2010. Modelling spatial patterns in harbour porpoise satellite telemetry data using maximum entropy. *Ecography*. 33:698-708.

Erbe, C., C. Reichmuth, K. Cunningham, K. Lucke, and R. Dooling. 2016. Communication masking in marine mammals: A review and research strategy. *Marine pollution bulletin*. 103:15-38.

Galatius, A., C.C. Kinze, and J. Teilmann. 2012. Population structure of harbour porpoises in the Baltic region: evidence of separation based on geometric morphometric comparisons. *Journal of the Marine Biological Association of the United Kingdom*. 92:1669-1676.

Hammond, P.S., H. Benke, P. Berggren, D.L. Borchers, S.T. Buckland, A. Collet, M.-P. Heide-Jørgensen, S. Heimlich-Boran, A.R. Hiby, M.F. Leopold, and N. Øien. 1995. Distribution and abundance of the harbour porpoise and other small cetaceans in the North Sea and adjacent waters. Final report Life 92-2/UK/027. 240.

Hammond, P.S., P. Berggren, H. Benke, D.L. Borchers, A. Collet, M.P. Heide-Jørgensen, S. Heimlich, A.R. Hiby, M.F. Leopold, and N. Øien. 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. *Journal of Applied Ecology*. 39:361-376.

Hammond, P.S., C. Lacey, A. Gilles, S. Viquerat, P. Börjesson, H. Herr, K. Macleod, V. Ridoux, M.B. Santos, M. Scheidat, J. Teilmann, J. Vingada, and N. Øien. 2017. Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys. SCANS III.

Hammond, P.S., K. Macleod, P. Berggren, D.L. Borchers, L. Burt, A. Cañadas, G. Desportes, G.P. Donovan, A. Gilles, D. Gillespie, J. Gordon, L. Hiby, I. Kuklik, R. Leaper, K. Lehnert, M. Leopold, P. Lovell, N. Øien, C.G.M. Paxton, V. Ridoux, E. Rogan, F. Samarra, M. Scheidat, M. Sequeira, U. Siebert, H. Skov, R. Swift, M.L. Tasker, J. Teilmann, O. Van Canneyt, and J.A. Vázquez. 2013. Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. *Biological Conservation*. 164:107-122.

Hansen, J.W., and S. Høgslund. 2019. Marine områder 2018. NOVANA. *In* Videnskabelig rapport fra DCE. Vol. 355. J.W. Hansen and S. Høgslund, editors. 156.

Hermannsen, L., J. Tougaard, K. Beedholm, J. Nabe-Nielsen, and P.T. Madsen. 2015. Characteristics and Propagation of Airgun Pulses in Shallow Water with Implications for Effects on Small Marine Mammals. *PLoS ONE*. 10:e0133436.

JNCC. 2020a. Background to the advice on noise management within harbour porpoise SACs in England, Wales and Northern Ireland.

JNCC. 2020b. Guidance for assessing the significance of noise disturbance against Conservation Objectives of harbour porpoise SACs. (England, Wales & Northern Ireland).

Kastelein, R.A., L. Helder-Hoek, J. Covi, and R. Gransier. 2016. Pile driving playback sounds and temporary threshold shift in harbor porpoises (Phocoena phocoena): Effect of exposure duration. *J Acoust Soc Am*. 139:2842.

Kastelein, R.A., L. Hoek, C.A.F. de Jong, and P.J. Wensveen. 2010. The effect of signal duration on the underwater detection thresholds of a harbor porpoise (*Phocoena phocoena*) for single frequency-modulated tonal signals between 0.25 and 160 kHz. *J. Acoust. Soc. Am*. 128:3211-3222.

Kastelein, R.A., P.J. Wensveen, L. Hoek, W.C. Verboom, and J.M. Terhune. 2009. Underwater detection of tonal signals between 0.125 and 100 kHz by harbor seals (*Phoca vitulina*). *J. Acoust. Soc. Am*. 125:1222-1229.

Kinze, C.C. 1990. The harbour porpoise (*Phocoena phocoena*, L., 1758) stock identification and migration patterns in Danish and adjacent waters. . Vol. Ph.D. University of Copenhagen.

Kyhn, L.A., S. Sveegaard, and J. Tougaard. 2014. Underwater noise emissions from a drillship in the Arctic. *Mar.Pollut.Bull.* 86:424-433.

Lance, R.M., B. Capehart, O. Kadro, and C.R. Bass. 2015. Human injury criteria for underwater blasts. *PLoS One*. 10:e0143485.

Lockyer, C. 2003. Harbour porpoises (Phocoena phocoena) in the North Atlantic: Biological parameters. *NAMMCO Sci. Publ.* :71-90.

Lockyer, C., and C. Kinze. 2003. Status, ecology and life history of harbour porpoise (*Phocoena phocoena),* in Danish waters. *NAMMCO Sci. Publ* . . 5:143-176.

Moeslund, J.E., B. Nygaard, R. Ejrnæs, N. Bell, L.D. Bruun, R. Bygebjerg, H. Carl, J. Damgaard, E. Dylmer, M. Elmeros, K. Flensted, K. Fog, I. Goldberg, H. Gønget, F. Helsing, M. Holmen, P. Jørum, J. Lissner, T. Læssøe, H.B. Madsen, J. Misser, P.R. Møller, O.F. Nielsen, K. Olsen, J. Sterup, U. Søchting, P. Wiberg-Larsen, and P. Wind. 2019. Den Danske Rødliste 2019. Aarhus Universitet, DCE - Nationalt Center for Miljø og Energi., Aarhus.

Møhl, B. 1968. Auditory sensitivity of the common seal in air and water. *J.Aud.Res.* 8:27-38.

National Marine Fisheries Service. 2016. Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing underwater acoustic thresholds for onset of permanent and temporary threshold shifts. NOAA Technical Memorandum NMFS-OPR-55, Silver Spring, MD. 178.

National Research Council. 2003. Ocean noise and marine mammals. The National Academies Press, Washington, D.C.

Olsen, M.T., L.W. Andersen, R. Dietz, J. Teilmann, T. Härkönen, and H.R. Siegismund. 2014. Integrating genetic data and population viability analyses for the identification of harbour seal (Phoca vitulina) populations and management units. *Molecular Ecology*. 23:815-831.

Olsen, M.T., S.M. Andersen, J. Teilmann, R. Dietz, S.M.C. Edrén, A. Linnet, and T. Härkönen. 2010. Status of the harbour seal (*Phoca vitulina*) in Southern Scandinavia. *NAMMCOSci. Publ.* 8:77-94.

Otani, S., Y. Naito, and A. Kato. 2000. Diving behaviour and swimming speed of a free-ranging harbor porpoise, *Phocoena phocoena. Mar. Mamm. Sci.* 16:811-814.

Rambøll. 2020. Konsekvenser av geofysiska och geotekniska undersökningar. Beskrivning av planerad verksamhet och redovisning av verksamheten i förhållande till hänsynsreglerna i 2 kap miljöbalken, Göteborg.

Rambøll. 2021. Vattenfall KAYD Survey permit underwater noise calculations. Vol. v 1. Rambøll, København. 10.

Reichmuth, C., M. Holt, J. Mulsow, J. Sills, and B. Southall. 2013. Comparative assessment of amphibious hearing in pinnipeds. *Journal of Comparative Physiology A*. 199:491-507.

Reiser, C.M., D.W. Funk, R. Rodrigues, and D. Hannay. 2011. Marine mammal monitoring and mitigation during marine geophysical surveys by Shell Offshore, Inc. in the Alaskan Chukchi and Beaufort seas, July–October 2010: 90-day report. LGL Rep. P1171E–1. , Anchorage.

Russell, D.J.F., G.D. Hastie, D. Thompson, V.M. Janik, P.S. Hammond, L.A.S. Scott-Hayward, J. Matthiopoulos, E.L. Jones, and B.J. McConnell. 2016. Avoidance of wind farms by harbour seals is limited to pile driving activities. *J. Appl. Ecol.*:1-11.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine Mammal Noise Exposure Criteria. *Aquat. Mamm*. 33:411-414.

Southall, B.L., J.J. Finneran, C. Reichmuth, P.E. Nachtigall, D.R. Ketten, A.E. Bowles, W.T. Ellison, D.P. Nowacek, and P.L. Tyack. 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. *Aquatic Mammals*. 45:125-232.

Sveegard, S., A. Galatius, and J. Tougaard. 2017. Marine mammals in Finnish Russian and Estonian Waters in relation to the Nord Stream 2 project. Expert Assessment. *In* Scientific Report from DCE - Danish Centre for Environment and Energy, Aarhus Unversity. Vol. 238. DCE - Danish Centre for Environment and Energy, Aarhus Unversity, Roskilde. 80.

Sveegaard, S., J.D. Balle, L.A. Kyhn, J. Larsen, C. Mohn, J. Teilmann, and J. Nabe-Nielsen. 2017. Monthly variation in fine-scale distribution of harbour porpoises at St. Middelgrund reef. . *In* Technical Report from DCE - Danish Centre for Environment and Energy D.-D.C.f.E.a.E. Aarhus University, editor. Aarhus University, DCE - Danish Centre for Environment and Energy, Roskilde. 34.

Sveegaard, S., A. Galatius, R. Dietz, L. Kyhn, J.C. Koblitz, M. Amundin, J. Nabe-Nielsen, M.-H.S. Sinding, L.W. Andersen, and J. Teilmann. 2015. Defining management units for cetaceans by combining genetics, morphology, acoustics and satellite tracking. *Global Ecology and Conservation*. 3:839-850.

Sveegaard, S., J. Nabe-Nielsen, and J. Teilmann. 2018. Marsvins udbredelse og status for de marine habitatområder i danske farvande. *In* Videnskabelig rapport. Vol. 284. Aarhus Universitet, DCE - Nationalt Center for Miljø og Energi. 36.

Sveegaard, S., J. Teilmann, P. Berggren, K.M. Mouritzen, D. Gillespie, and J. Tougaard. 2011a. Acoustic surveys confirm the high-density areas of harbour porpoises found by satellite tracking. *ICES Journal of Marine Science*. 68.

Sveegaard, S., J. Teilmann, J. Tougaard, R. Dietz, K. Mouritsen, G. Desportes, and U. Siebert. 2011b. High-density areas for harbor porpoises (*Phocoena phocoena*) identified by satellite tracking. *Marine Mammal Science*. 27:230-246.

Teilmann, J., F. Larsen, and G. Desportes. 2007. Time allocation and diving behaviour of harbour porpoises (*Phocoena phocoena*) in Danish and adjacent waters. *J.Cet.Res.Managem*. 9:201-210.

Terhune, J.M. 1988. Detection thresholds of a harbor seal to repeated underwater high-frequency, short duration sinusoidal pulses. *Can. J. Zool.* 66:1578-1582.

Tougaard, J., and K. Beedholm. 2019. Practical implementation of auditory time and frequency weighting in marine bioacoustics. *Appl. Acoust.* 145:137-143.

Tougaard, J., and M. Mikaelsen. 2020. Effects of larger turbines for the offshore wind farm at Krieger's Flak, Sweden. Addendum with revised and extended assessment of impact on marine mammals. Aarhus University, DCE – Danish Centre for Environment and Energy, 32 pp. Scientific Report No. 366.

Tougaard, J., and M.A. Mikaelsen. 2018. Effects of larger turbines for the offshore wind farm at Krieger's Flak, Sweden. Assessment of impact on marine mammals. Aarhus University, DCE – Danish Centre for Environment and Energy, 112 pp. Scientific Report No. 286. .

Tougaard, J., J. Teilmann, and S. Tougaard. 2008. Harbour seal spatial distribution estimated from Argos satellite telemetry: overcoming positioning errors. *Endangered Species Research.* 4:113-122.

Tougaard, J., A.J. Wright, and P.T. Madsen. 2015. Cetacean noise criteria revisited in the light of proposed exposure limits for harbour porpoises. *Mar.Pollut.Bull.* 90:196-208.

Vattenfall. 2019. Underlag för avgränsningssamråd. Ansökan om undersökningstillstånd- Kattegatt Syd. Letter to Länsstyrelsen Hallands Län.

Wiemann, A., L.W. Andersen, P. Berggren, U. Siebert, H. Benke, J. Teilmann, C. Lockyer, I. Pawliczka, K. Skora, A. Roos, T. Lyrholm, K.B. Paulus, V. Ketmaier, and R. Tiedemann. 2010. Mitochondrial Control Region and microsatellite analyses on harbour porpoise (*Phocoena phocoena*) unravel population differentiation in the Baltic Sea and adjacent waters. *Conserv. Genet.* . 11:195–211.

Wisniewska, D.M., M. Johnson, J. Teilmann, U. Siebert, A. Galatius, R. Dietz, and P.T. Madsen. 2018. High rates of vessel noise disrupt foraging in wild harbour porpoises (*Phocoena phocoena*). *Proc. R. Soc. B.* 285.

Wunderlich, J. 2016. Innomar's SES-2000 Parametric SBPs and Marine Mammals Technical Note TN-01 (Rev. D, June 2016).

TECHNICAL NOTE

Vattenfall KAYD Survey permit underwater noise calculations, Ramboll/15-11-2021 Version 3.0

Date November 15, 2021

1 Introduction

This study is an underwater noise propagation performed for the geotechnical survey equipment to be used in the survey package according to Vattenfall's application for survey permit for the OWF site. The purpose of this study is to provide the expected distances from the potential geotechnical survey activities to the applicable harbor porpoise underwater sound impact threshold limits.

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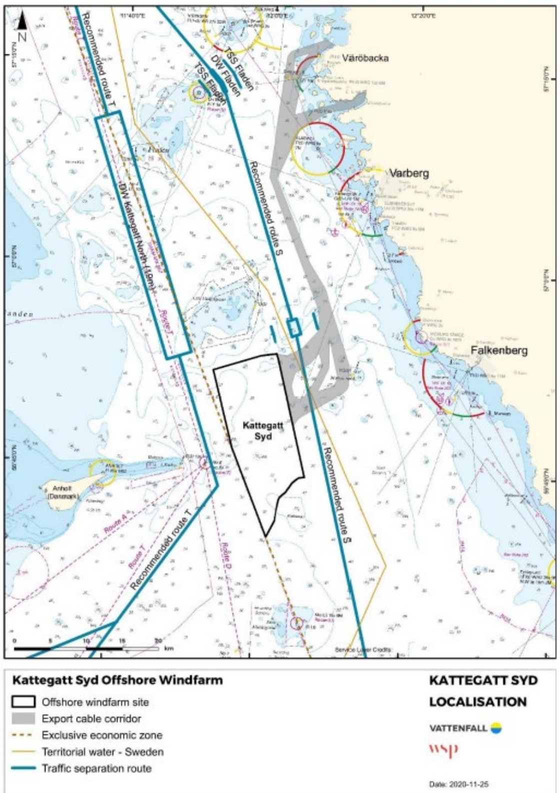

Figure 1-1. KAYD OWF Site

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Underwater sound, like sound in the air, is disturbances from a source in a medium – here water – travelling in a 3-dimensional manner as the disturbance propagate with the speed of sound.

Sound travels at different speed in different media. The speed of sound is determined by the density and compressibility of the medium. Density is the amount of material in a given volume, and compressibility is a measure of how much a substance could be compacted for a given pressure. The denser and the more compressible, the slower the sound waves would travel. Water is much denser than air, but since it is nearly incompressible the speed of sound is about four times faster in water than in air. The speed of sound can also be affected by temperature. Sound waves tend to travel faster at higher temperatures.

Underwater sound can be measured as a change in pressure and is described as sound pressure and can be measured with a pressure sensitive device (hydrophone).

Because of the large range pressure amplitudes of sound, it is convenient to use a decibel (dB) logarithmic scale to quantify pressure levels. The underwater sound pressure level in decibels (dB) is defined in the following equation:

Sound Pressure Level (SPL) = $20\log_{10}(P/P_0)$

P is the pressure and P_0 is the reference pressure. The reference pressure is 1 micropascal (μPa) for underwater sound which is different for sound pressure levels in the air. For this reason, sound pressure levels in the water and air cannot be directly compared.

Underwater sound levels vary in accordance to the sound source's time signature and acoustic environmental conditions and can be future defined in terms of exposure, average and/or maximum levels. The following acoustic parameters are commonly used to assess the noise impact from underwater noise sources for the identified local marine life.

1.1 Applicable acoustic parameters

The following key terms are used in this document:

Sound Pressure Level (SPL) – this quantifies the magnitude of a sound at a given point, i.e. how loud it is, and is measured in decibels (dB). As a relative unit, dB are quoted relative to 1 micropascal in underwater studies (so, dB re 1 μPa).

Sound Exposure Level (SEL) – this is a decibel measure for describing how much sound energy a receptor (e.g. a marine mammal) has received from an event and is normalized to an interval of one second (quoted in dB re. 1 $\mu Pa^2 s$). It can be thought of as a logarithmic measure of Sound Exposure and hence a 3 dB increase in SEL equates to a doubling of sound energy; dB re. 1 $\mu Pa^2 s$.

Cumulative Sound Exposure (SEL(cum)) – this is the time integral of the squared pressures over the duration of a sound or series of sounds. It enables sounds of differing duration and level to be characterized in terms of total sound energy normalized to an interval of one second (quoted in dB re. $Pa^2 s$).

Peak pressure level (PEAK) – the zero-to-peak sound pressure at a given point in time.

Root mean square (RMS) – the sound pressure averaged over a given time; The RMS SPL is commonly used to evaluate the effects of continuous noise sources. The RMS sound pressure level or SPL is the mean square pressure level.

Pulsed/impulsive sound – a discontinuous sound source comprising one or more instantaneous sounds as during munitions clearance.

Continuous sound – sound source, like a vessel engine, or humming as in drilling operation.

2 Underwater sound propagation model

The underwater sound propagation model calculates estimates of the sound field generated from underwater sound sources. The modelling results are used to determine the potential impacts distances from the identified significant underwater noise sources for the various identified marine life for the area. Based on source location and underwater source sound level, the acoustic field at any range from the source is estimated using dBSEA's acoustic propagation model (Parabolic equation method (≤500 Hz), Jensen 2011 and ray tracing (>500 Hz)). The sound propagation modelling uses acoustic parameters appropriate for the specific geographic region of interest, including the expected water column sound speed profile, the bathymetry, and the bottom geo-acoustic properties, to produce site-specific estimates of the radiated noise field as a function of range and depth. The acoustic model is used to predict the directional transmission loss from source locations corresponding to receiver locations. The received level at any 3-dimensional location away from the source is calculated by combining the source level and transmission loss, both of which are direction dependent. Underwater acoustic transmission loss and received underwater sound levels are a function of depth, range, bearing, and environmental properties. The output values can be used to compute or estimate specific noise metrics relevant to safety criteria filtering for frequency-dependent marine mammal hearing capabilities.

Underwater sound source levels are used as input for the underwater sound propagation program, which computes the sound field as a function of range, depth, and bearing relative to the source location.

Bathymetry data is provided from EMODNET (The European Marine Observation and Data Network).

Water column data (Salinity, Temperature, Speed of underwater sound/depth) is provided from ICES (International Council for the Exploration of the Sea) HELCOM specific measurement stations positioned close to the selected modelling positions. The salinity was set at 34 PSU to calculate the underwater sound absorption coefficient (Ainslie and McColm, 1998)

Table 2-1 Speed of sound profile data

Depth (m)	Winter/spring Speed of sound m/s	Summer/Autum Speed of sound m/s
0	1432	1495
10	1435	1498
20	1438	1496
30	1466	1488
40	1472	1478
50	1466	1475

Seabed Conditions (Sand, Clay /depth) are provided from general geological survey data for areas close to the modelling area.

Table 2-2 Overview of seabed geoacoustic profile used for the modelling for position West (C_p = compressed wave speed, α = compressional attenuation).

Seabed layer (m)	Material	Geoacoustic property
0 – 20 meters	Sand	C_p = 1900 m/s α = 0,8 dB/λ
20 – 30 meters	Clay with coarse sediment	C_p = 1500 m/s α = 0,2 dB/λ
30 – meters	Bedrock	C_p = 5250 m/s α = 0.1 dB/λ

Predictions have been performed for summer/autumn (assumed survey period and worst case) water column conditions which have different underwater sound propagation characteristics and will give the maximum underwater noise level of the whole sea depth.

3 Sound sources

Table 3-1 Sound sources

Activity	Dominant frequency range	Reference	dBSEA sound propagation Calculation method	Sound source level @ 1 meter
3D/2D Sparker (4 knots vessel speed) OMNI	2-3 kHZ (3 puls per sec.)	Crocker, Franatonio 2016, Delta sparker, Alpine Data 800J, 2017	Ray tracing	186 dB rms 208 dB Peak 178 dB SEL(sec)
Mini Airgun (40 cu in) Omni directional Impulsive	Frekvens: 50 – 500 Hz shotrate: 1 puls/ 4 sec	Wyatt 2008	Parabolic equation/ Ray tracing	193 dB rms 202 dB Peak 183 dB SEL(ss, sec)
SBP/ Innomar SES 2000 (4 knot vessel speed) Beam-non impulsive	85-115 kHz (0.07 ms puls) 60 pulse/sec.	Innomar data and tech, note. SubAcoustech 2018 Data	Ray tracing	240 dB SPL (vertical) 187 dB rms 198 dB peak 178 dB SEL(sec) (Horizontal)*
SBP/ Innomar SES 2000 (4 knot vessel speed) Beam-non impulsive	85-115 kHz (1.3 ms puls) 60 pulse/sec.	Innomar data and tech. note. SubAcoustech 2018 data	Ray tracing	240 dB SPL (vertical) 187 dB rms 198 dB peak 186 dB SEL(sec) (Horizontal)*

*The SBP is highly directional focusing vertically toward the sea floor and so the Horizontal directivity based on Innomar technical note is included.

The underwater survey noise sources that have a dominant frequency range of 20-500 Hz (lower frequency sources) have a sound source spectrum in the model op to 8000 Hz. The higher frequencies are included but are not that significant because the majority of the sound energy is in the lower frequencies and dominate the overall VHF (Harbor Porpoise) weighted levels. The table showing the dominate frequency range is just showing the frequency range where most of the sound energy is.

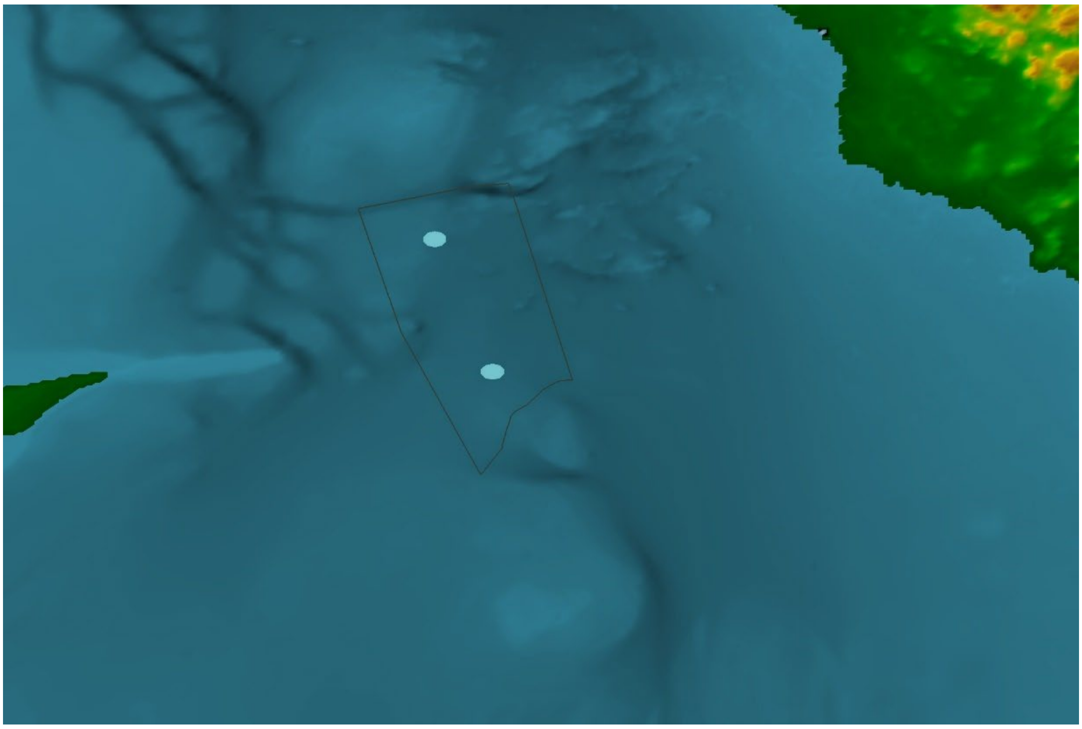

Figure 3-1. Sound source positions

4 Baseline for underwater noise impact assessment

The source sound pressure levels and associated impact zones can be viewed as indicative precautionary ranges. It is important to note that it is highly unlikely that any marine mammal would stay at a stationary location or within a fixed radius of a vessel (or any other noise source). The behavior of receivers (animals) is included in a model of exposure. A worst-case assumption of a stationary animal can be made, but this is likely to overestimate the extent of especially the impact threshold zones considerably and therefore included is a simple model for animal escape, including a threshold for reaction followed by movement away from the source, either in a straight line perpendicular to the track line or radially away from the sound source. Receiver (animal) movement is modelled as a movement with a speed of 1.5 m/s, beginning at a received single pulse SEL of 145 dB re. 1 µPa2s. Moving survey vessels travel along a line with constant speed (4 knots). The receiver swims with a speed of 1.5 m/s and starts reacting when the ship is a distance from the point where the animal is a-beam (perpendicular to the line) and the animal is at the perpendicular distance from the line.

The sound sources can be said to have a self-mitigating effect, in that they deter animals from the source at much lower levels than the levels required to exceed impact threshold limits. Exposure during start-up will be different, however, as animals could be much closer to the source at start-up of the survey and it is thus the beginning of that carries the highest risk of inducing.

4.1 Marine Mammals

Generally, the effect of noise on marine mammals can be divided into four broad categories that largely depend on the individual's proximity to the sound source:

- Detection
- Masking
- Behavioral changes
- Physical damages

The limits of each zone of impact are not sharp, and there is a large overlap between the zones. The four categories are described below.

Detection ranges depend on background noise levels as well as hearing thresholds for the animals in question.

Masking occurs when noise interferes with an animal's ability to perceive (detect, interpret, and/or discriminate) a sound. There are still many uncertainties regarding how masking affects marine mammals.

The occurrence and significance of a behavioral change varies by individual, species, and circumstances. Some sounds may not cause any response, while others may result in minor to significant changes in a variety of behaviors, such as diving, surfacing, vocalizing, feeding, and/or mating.

Physical damage to marine mammals relates to damage to the hearing apparatus. Physical damages to the hearing apparatus may lead to permanent changes in the animals' detection threshold (permanent threshold shift, PTS). This can be caused by the destruction of sensory cells in the inner ear, or by metabolic exhaustion of sensory cells, support cells or even auditory nerve cells. Hearing loss is usually only temporary (temporary threshold shift, TTS) and the animal will regain its original detection abilities after a recovery period. For PTS and TTS, the sound intensity is an important factor for the degree of hearing loss, as is the frequency, the exposure duration, and the length of the recovery time.

The proposed criteria for PTS, TTS and behavioral response in this report are based on results presented in scientific literature and/or commonly and currently used in environmental impact assessments of underwater sound. The behavior of receivers (animals) is essential to include in a model of exposure. A worst case assumption of a stationary animal can be made, but this is likely to overestimate the extent of especially the TTS/PTS zones considerably and a simple model for animal escape is utilized, including a threshold for reaction followed by movement radially away (1.5 m/s) from the sound source.

4.2 Marine Mammal Auditory Weighting Function

The ability to hear sounds varies across a species' hearing range. Most mammal audiograms have a typical "U-shape," with frequencies at the bottom of the "U" being those to which the animal is more sensitive, in terms of hearing. Auditory weighting functions best reflect an animal's ability to hear a sound (and do not necessarily reflect how an animal will perceive and behaviorally react to that sound). To reflect higher hearing sensitivity at particular frequencies, sounds are often weighted. Auditory weighting functions have been proposed for marine mammals, specifically associated with PTS/TTS acoustic thresholds expressed in the SELcum metric, which take into account what is known about marine mammal hearing (Southall, 2019). Very High Frequency (VHF) weighted impact threshold limits are applicable to Harbor Porpoises.

4.3 Harbor Porpoise Criteria

Table 4-1 summarizes criteria for assessing impacts for marine mammal (Harbor Porpoise) and Table 4-2 for marine mammal (Seals). The criteria are associated with different impacts and limits. These threshold values for impact have been determined by an assessment of available values from the most recent scientific literature and accepted limits. (Tougaard, 2020, Southall 2019).

When analyzing the auditory effects of noise exposure, it is often helpful to broadly categorize noise as either impulse noise — noise with high peak sound pressure, short duration, fast rise-time, and broad frequency content — or non-impulsive (i.e., steady-state) noise. When considering auditory effects, sonars, other coherent active sources, and vibratory pile driving are considered to be non-impulsive sources, while explosives, impact pile driving, and air guns are treated as impulsive sources. Note that the terms non-impulsive or steady-state do not necessarily imply long duration signals, only that the acoustic signal has sufficient duration to overcome starting transients and reach a steady-state condition. For harmonic signals, sounds with duration greater than approximately 5 to 10 cycles are generally considered to be steady-state. The sparker and the mini air gun are considered impulsive. The SBP is considered non-impulsive.

Table 4-1 Threshold values for harbor porpoise

Species	PTS, SELcum** VHF weighted dB re. 1μPa²s	PTS, SELcum** VHF weighted dB re. 1μPa²s	TTS, SELcum** VHF weighted dB re. 1μPa²s	TTS, SELcum** VHF weighted dB re. 1μPa²s	Behavior, SEL unweighted dB re. 1μPa²s	Behavior, rms*, VHF weighted dB re. 1μPa²s
	Non-impulsive	Impulsive	Non-impulsive	Impulsive		
Harbor Porpoise	173 dB	155 dB	153 dB	140 dB	145 dB	100 dB

*Tougaard, 2020, Includes animal fleeing at 1.5 m/s.
**Southall, 2019 Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects Includes animal fleeing at 1.5 m/s.

5 Results:

The sound propagation model was run with the source levels, and environmental parameterization described in previous sections. The distances predicted to the various threshold limits are the maximum at any depth down to the bottom. The following table summarize the results of the acoustic modelling in terms of the maximum and average radial distances from the investigation activities to the applicable assessment underwater noise threshold levels specified.

The exposure time and exposure levels take into consideration:

- the survey vessel speed,
- survey equipment pulse rate,
- the underwater sound propagation (level reduction per distance from source from the model)
- and the behavior of receivers (animals), fleeing 1.5 m/s.

A model for animal escape, including a threshold for reaction followed by movement away from the source, either in a straight line perpendicular to the vessel moving direction or away from a stationary sound source is included in the time exposure calculations. A receiver (animal) movement is modelled as a movement with a speed of 1.5 m/s. A moving survey vessels travel along a line with constant speed (4 knots). The receiver swims with a speed of 1.5 m/s and starts swimming away when the survey equipment is started. As the survey vessel approaches the Harbor Porpoise, and as the Harbor Porpoise swims away (perpendicularly) resulting in a specific distance for each pulse from the survey activity and summation of these pulses is the cumulative exposure. The calculation of cumulative exposure level (SELcum) stops when the distance to the Harbor Porpoise is large enough so that the noise levels from the survey activity are low enough to not significantly contribute to the overall cumulative exposure level. This method is also described in; Tougaard, J. 2016. Input to revision of guidelines regarding underwater noise from oil and gas activities - effects on marine mammals and mitigation measures. Aarhus University, DCE – Danish Centre for Environment and Energy, 52 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 202.

Due to the varied sea floor bathymetry, the underwater sound does not propagate equally in all directions. In order to give a better representation of the range of the radial distance from the activities to the impact threshold limits, the average and maximum distances are given.

5.1 Harbor Porpoise

As shown in Table 5-1 (winter/spring) and 5-2 (summer/fall) the equipment will have the potential to cause behavioral impact on harbour porpoise. With a soft start on the sub bottom profiler (SBP) and the Sparker the harbor porpoise will swim away at distances perpendicular to the source (shown in Table 5-1) and no PTS are expected. It is common practice in many seismic regulations to ask for a gradual increase of sound emissions from seismic sources when beginning or after a stop in transmissions for whatever reason (technical, navigational or due to a shutdown because of a marine mammal sighting).The rationale behind a soft start is to provide a gradually increasing sound level, alerting any nearby marine mammals and giving them opportunity to move to safe distances before the array starts transmitting at full power and in this way protect them from developing PTS or sustaining other injuries.

Table 5-1 Investigation activity (including survey vessel) modelling results – distance to Harbor Porpoise threshold limits (VHF weighted) Winter/Spring

		Distance to threshold limit	Southall 2019/Tougaard 2020	
		Average maximum	Average/ maximum	Average/maximum
Area	**Activity**	**PTS Harbor Porpoise (1.5 m/s fleeing)**	**TTS Harbor Porpoise (1.5 m/s fleeing)**	**Behaviour Harbor Porpiose**
Site North	3D/2D Sparker (4 knots vessel speed) Impulsive	0 meters	400 meters	2828/3680 meters
Site North	Mini Airgun (4 knots vessel speed) Impulsive	0 meters	0 meters	600/913 meters
Site North	SBP/ Innomar SES 2000 (0.07 ms puls) (4 knot vessel speed)	0 meters	130 meters	1677/1845 meters
Site North	SBP/ Innomar SES 2000(1.3 ms puls) (4 knot vessel speed)	20 meters (45 second soft start**)	350 meters	1590/1757 meters
Site South	3D/2D Sparker (4 knots vessel speed) Impulsive	0 meters	450 meters	3130/3979 meters
Site South	Mini Airgun	0 meters	0 meters	640/909 meters
Site South	SBP/ Innomar SES 2000 (0.07 ms puls) (4 knot vessel speed)	0 meters	140 meters	1720/1899 meters
Site South	SBP/ Innomar SES 2000(1.3 ms puls) (4 knot vessel speed)	20 meters (45 second soft start**)	400 meters	1720/1899 meters

**Amount of time needed for a soft start (lower levels) for the animal to flee out of the PTS impact zone before full power profiling.

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Table 5-2 Investigation activity (including survey vessel) modelling results – distance to Harbor Porpoise threshold limits (VHF weighted) Summer/autumn

		Distance to threshold limit	Southall 2019/Tougaard 2020	
		Average maximum	Average/ maximum	Average/maximum
Area	Activity	PTS Harbor Porpoise (1.5 m/s fleeing)	TTS Harbor Porpoise (1.5 m/s fleeing)	Behaviour Harbor Porpiose
Site North	3D/2D Sparker (4 knots vessel speed) Impulsive	0 meters	300 meters	1257/1878 meters
Site North	Mini Airgun (4 knots vessel speed) Impulsive	0 meters	0 meters	537/818 meters
Site North	SBP/ Innomar SES 2000 (0.07 ms puls) (4 knot vessel speed)	0 meters	110 meters	1472/1690 meters
Site North	SBP/ Innomar SES 2000(1.3 ms puls) (4 knot vessel speed)	20 meters (45 second soft start**)	300 meters	1472/1690 meters
Site South	3D/2D Sparker (4 knots vessel speed) Impulsive	0 meters	350 meters	1620/2041 meters
Site South	Mini Airgun	0 meters	0 meters	594/858 meters
Site South	SBP/ Innomar SES 2000 (0.07 ms puls) (4 knot vessel speed)	0 meters	130 meters	1700/1870 meters
Site South	SBP/ Innomar SES 2000(1.3 ms puls) (4 knot vessel speed)	20 meters (45 second soft start**)	380 meters	1700/1870 meters

**Amount of time needed for a soft start (lower levels) for the animal to flee out of the PTS impact zone before full power profiling.

The sound thus can be said to have a self-mitigating effect, in that they deter animals from the ship at much lower levels than the levels required to induce PTS. Exposure during ramp up will be different, however, as animals could be much closer to the ship at start-up of the survey and it is thus the beginning of each line that carries the highest risk of inducing PTS in porpoises.

6 References

NOAA, NMFS 2018 Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0)

Innomar's SES-2000 Parametric SBPs and Marine Mammals, Technical Note (Rev. D, June 2016)Dr.-Ing. Jens Wunderlich, Innomar Technologie GmbH

Innomar Data Sheet: SES-2000 medium -100, Parametric Sub-bottom Profiler

Crocker, Frantantonio, NUWC-NPT Technical Report 12,203, 24 March 2016, Characteristics of Sounds Emitted During High-Resolution Marine Geophysical Surveys.

A framework for regulating underwater noise during pile driving, Swedish Defence Research Agency (FOI). SWEDISH ENVIRONMENTAL PROTECTION AGENCY 2017.

Ainslie M. A., McColm J. G., "A simplified formula for viscous and chemical absorption in sea water", Journal of the Acoustical Society of America, 103(3), 1671-1672, 1998.

Southall, Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing. *Aquatic Mammals* 2019, *45*(2), 125-232, DOI 10.1578/AM.45.2.2019.125 2019

Tougaard, INPUT TO REVISION OF GUIDELINES REGARDING UNDERWATER NOISE FROM OIL AND GAS ACTIVITIES - EFFECTS ON MARINE MAMMALS AND MITIGATION MEASURES, DCE – Danish Centre for Environment and Energy, 2016

Review and Assessment of Underwater Sound Produced from Oil and Gas Sound Activities and Potential Reporting Requirements under the Marine Strategy Framework Directive. 2011. Genesis Oil and Gas Consultants report for the Department of Energy and Climate Change.

Waytt, Joint Industry Programme on Sound and Marine Life, Review of Existing Data on Underwater Sounds Produced by the Oil and Gas Industry, Seiche Measurements Limited Ref – S186

Willis, Noise Associated with Small Scale Drilling Operations Marine Energy Research Group Swansea University, Wales UK, 3rd International Conference on Ocean Energy, 6 October, Bilbao

Reiser, C.M, D.W. Funk, R. Rodrigues, and D. Hannay. (eds.) 2011. Marine mammal monitoring and mitigation during marine geophysical surveys by Shell Offshore, Inc. in the Alaskan Chukchi and Beaufort seas, July–October 2010: 90-day report. LGL Rep. P1171E–1. Rep. from LGL Alaska Research Associates Inc., Anchorage, AK, and JASCO Applied Sciences, Victoria, BC for Shell Offshore Inc, Houston, TX, Nat. Mar. Fish. Serv., Silver Spring, MD, and U.S. Fish and Wild. Serv., Anchorage, AK. 240 pp, plus appendices.

Jensen, F.B., Kuperman, W.A., Porter, M., B.,, Schmidt, H., 2011. Computational Ocean Acoustics, Second Edition Springer, New York, Dordrecht, Heidelberg, London.

Nedwell and Edwards. 2004. A review of measurements of underwater man-made noise carried out by Subacoustech Ltd, 1993 – 2003. Subacoustech Report ref: 534R0109

Maxon, Skellerup, Taougaard, Working Group 2014, Marine mammals and underwater noise in relation to pile driving, Energinet.dk Underwater noise and marine mammals Rev2 – 4. Marts 2015, Energinet.dk

Wyatt, R. (2008). Joint Industry Programme on Sound and Marine Life - Review of Existing Data on Underwater Sounds Produced by the Oil and Gas Industry.

Tougaard, J., Carstensen, J., Teilmann, J., Skov, H., and Rasmussen, P., 2009. Pile driving zone of responsiveness extends beyond 20 km for harbour porpoises (Phocoena phocoena, (L.)). J.Acoust.Soc.Am. 126, 11-14.

Tougaard, J., Wright, A.J., and Madsen, P.T., 2015. Cetacean noise criteria revisited in the light of proposed exposure limits for harbour porpoises. Marine Pollution Bulletin, 90(1-2): p. 196-208.

KATTEGATT SYD OFFSHORE WIND FARM

Assessment of impact from pre-project surveys

An offshore windfarm is planned for Kattegatt Syd by Vattenfall Vindkraft AB. This report assesses impacts on marine mammals of proposed pre-investigations from use of a sparker, a parametric Sub Bottom Profiler and a small seismic airgun. The assessment found that negligible to minor impacts are expected on harbour seals, grey seals and harbour porpoises. The bordering Natura 2000 site could potentially be affected if the survey vessel is closer than 3 km from the border of the area. The impact on the Natura 2000 site is of short duration and assessed as acceptable with regards to the JNCC guidelines.

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