HEARD BUT NOT SEEN

Sea-scale passive acoustic Survey Reveals a Remnant Baltic Sea Harbour Porpoise Population that Needs Urgent Protection

SAMBAH

Non-technical report

Static Acoustic Monitoring of the BAltic Harbour porpoise

LIFE08 NAT/S/000261

Content

Why this report?

This report targets managers, stakeholders and policymakers and focus on the interpretation of the SAMBAH project results in the context of population status assessments and the implementation of necessary conservation measures such as the designation of protected areas and by-catch mitigation. To give a background for this we have included information on harbour porpoise ecology, the most severe threats to them and the most important international agreements that need to be taken into account.

Summary of aims of and achievements in SAMBAH

The Baltic Sea is home for the harbour porpoise (*Phocoena phocoena*), the only year-round resident whale species in this brackish eco system. The population in the Baltic Proper is small and has been drastically reduced during the last several decades, and it is now listed as critically endangered by the IUCN (Hammond et al., 2008) and by HELCOM (HELCOM, 2013a). These classifications, however, are based on very uncertain abundance estimates. This, in combination with a complex of threats and problems which are still poorly understood, especially with reference to potential cumulative effects, called for improved methodologies for collecting data on population size as well as spatial and temporal distribution. The overall objective of the SAMBAH project (www.sambah.org) was to develop and assess a best practice methodology for this purpose, and thereby to make possible the designation of appropriate SCIs/SACs for the species within the Natura 2000 network as well as the identification of other relevant mitigation and conservation measures.

SAMBAH objective 1*:* Estimate densities and abundance of and produce distribution maps for harbour porpoises in the depth range of 5-80 meters within the project area in the Baltic Sea (see fig. 1). Data on abundance is necessary to assess the conservation status of this subpopulation as well as the potentially negative impact of anthropogenic activities such as by-catch. The results will also serve as a baseline for future surveys to follow up the effects of conservation measurements taken.

SAMBAH objective 2*:* Identify possible hotspots, habitat preferences, and areas with higher risk of conflicts with anthropogenic activities for the Baltic Sea harbour porpoise. This information is necessary for the designation of appropriate protected areas for the harbour porpoises.

SAMBAH objective 3: Increase the knowledge and awareness of the Baltic Sea harbour porpoise among policymakers, managers, stakeholders, users of the marine environment and the general public, in the nations bordering the Baltic Sea and within the European Community. This is necessary to reach the ultimate aim of the project, a favourable conservation status of the Baltic Sea harbour porpoise.

SAMBAH objective 4*:* Implement best practice methods for cost efficient, large scale survey of echolocating toothed whales in general and the harbour porpoises in a low population density area like the Baltic Sea in particular. The implementation of coherent methods throughout the distribution range of the Baltic Sea harbour porpoise will facilitate future monitoring actions to follow up the effects of conservations measurements taken on a local, regional, national or transnational scale.

What did we do? The SAMBAH consortium deployed click train detectors, so called C-PODs (www.chelonia.co.uk), in 304 stations distributed over a major part of the Baltic Sea (Fig. 1), in the depth interval 5m to 80m, and kept them in operation for two years (May 2011-April 2013). This static Acoustic Monitoring (SAM) approach was based on the fact that the harbour porpoise generates species-specific echolocation click trains that can be logged and used as a proxy for presence. The detectability of porpoise click trains may be affected by hydrological phenomena such as pycnoclines, and were therefore measured by playing artificial porpoise click trains in connection with visiting the C-POD stations for battery and SD card replacements. The probability of C-PODs detecting free-swimming porpoises was measured in an experiment using a sophisticated hydrophone array system, by which the underwater swimming tracks of the porpoises could be reconstructed in high resolution. These tracks were then correlated to the loggings of a grid of C-PODs deployed in the experiment area. Since this was outside the SAMBAH area playback of artificial porpoise click trains was done here as well and used as a conversion factor between the two areas. The click rate of porpoises was measured by providing five wild porpoises with sound recording instruments, in combination with depth gauges and GPS transmitters.

The main advantage of this method, compared to visual surveys, is that it gives information on harbour porpoise occurrence over time, instead of the snapshot image given by visual surveys. It can also be carried out irrespective of weather conditions and at night, and it requires comparatively little manpower compared to the effort achieved.

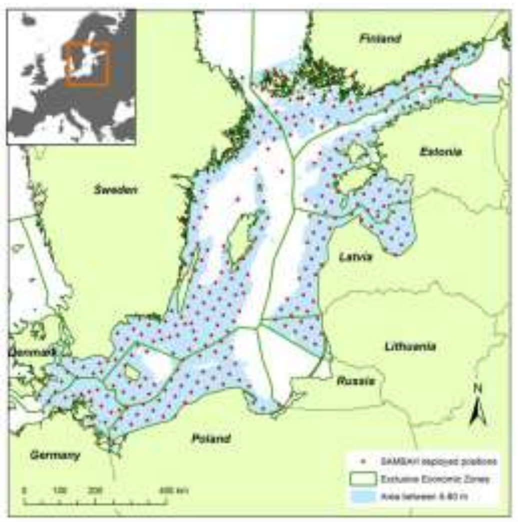


Figure 1. Map over the SAMBAH study area. Blue marks the surveyed area, with the red dots showing the C-POD stations. White parts within this area indicate water depths <5m and >80m, and Russian waters, *which were not monitored*. Green lines mark EEZ borders.

What did we achieve? An average 478 days of logging were collected per station, which constituted 64% of the theoretically possible. It corresponds to a total of 398 logging years. Data were obtained from 298 of the 304 stations, and click trains were detected at 144 stations (Fig. 2). There were more data losses along the eastern coast, mainly because many C-PODs were lost due to intensive trawling, e.g. in the Bay of Riga, and because foul weather and severe ice conditions interfered with servicing of the C-PODs for battery and memory card replacement. Also data were lost due to malfunctioning acoustic releasers that did not allow the C-PODs to float to the surface to be retrieved.

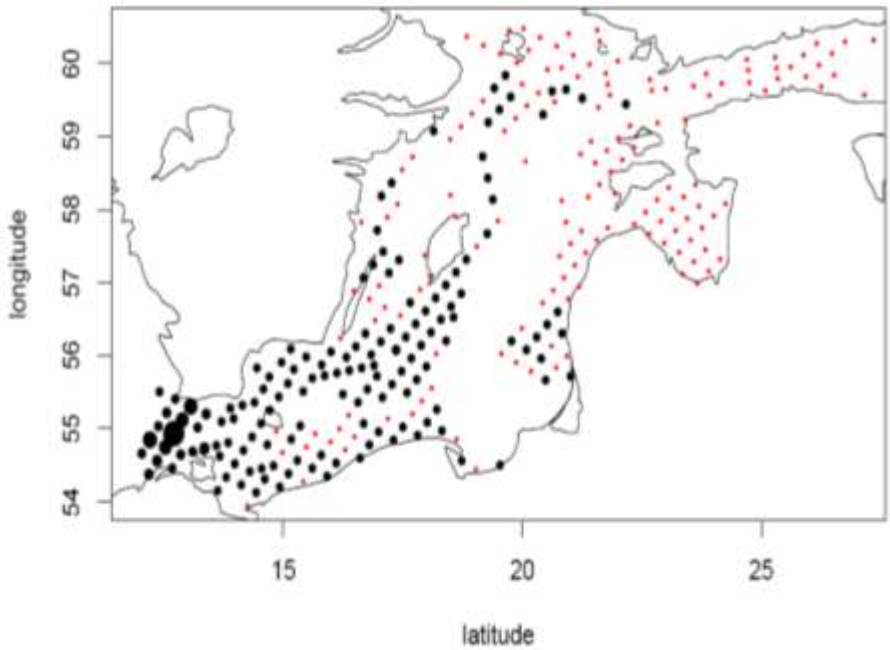
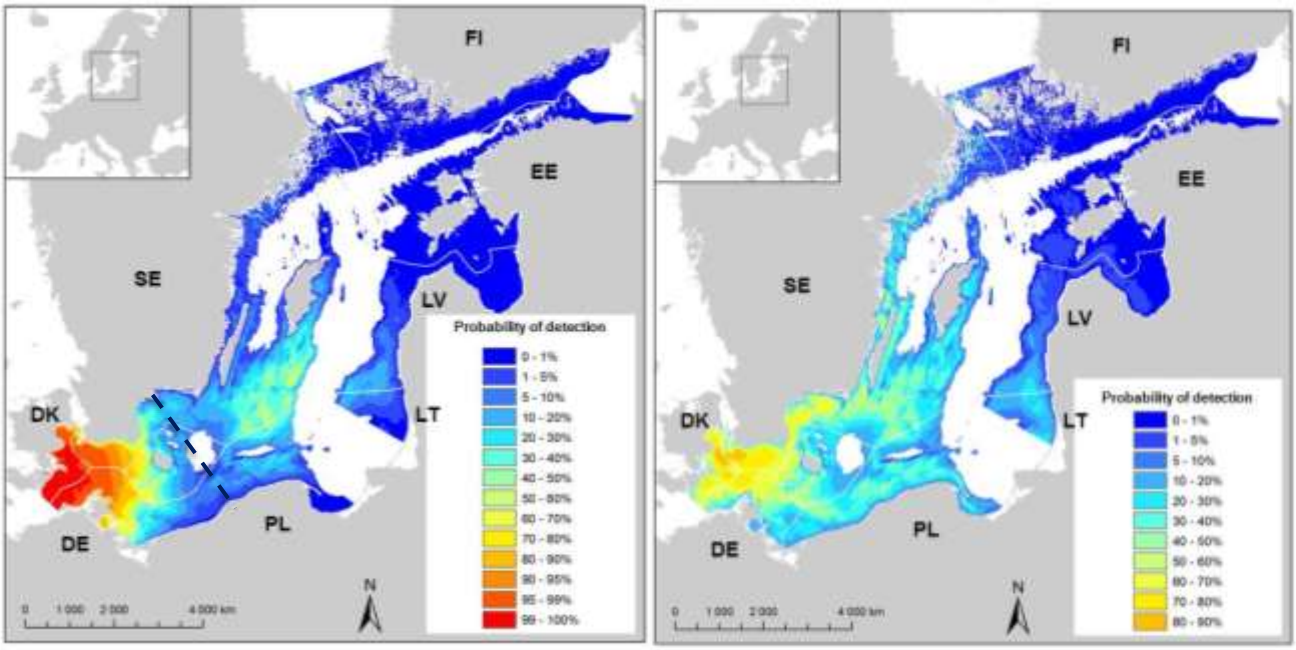


Figure 2. Encounter rate, measured as proportion of click positive seconds per second monitored, averaged over two years. The size of the black dots is proportional to encounter rate. Red dots indicate positions with zero encounter rate.

What were the results? – The distribution maps showed a clear separation of two population clusters during the summer (Fig. 3a). An approximate delimitation line east of Bornholm was drawn through a rather large area with very low probability of detecting porpoises (Fig. 3a).

East of the delimitation line the porpoises, the majority of which were found on the shallow offshore banks south-west of the island of Gotland, were estimated at ca. 500 animals (95% CI 80-1,091). Since this concentration coincided with calving (May-June) and more importantly mating (July-August; cf. Fig. 5), it is evident that this population is genetically separated from the porpoises in the south-western part of the Baltic Sea. Hence it is suggested that these banks are very important for the survival of this population.

In the south-west the porpoise density was very high, with an estimated total abundance of more than twenty thousand porpoises (95% CI 13,461-38,024). These porpoises most likely belonged to the Belt Sea population.



a) August b) February

Figure 3a-b. Porpoise distribution modelled as the probability of detecting click trains for (a) August and (b) February . Dashed line in (a) indicates the proposed delimitation border between the two summer clusters.

Even though the abundance estimate for the offshore banks found by SAMBAH is similar to the earlier population estimates for the Baltic Sea harbour porpoise population arrived at by SCANS I and the survey in 2002 (ca. 600 pods and ca. 100 pods, respectively (Hiby and Lovell, 1996; Berggren et al., 2004), our estimate cannot be directly compared with them, since they mainly surveyed the south-western part of the Baltic Sea and only covered part of one of the offshore banks, the South Mid-Sea Bank. Hence previous estimates should instead be compared with the abundance found by SAMBAH for the area west of the delimitation line (fig. 3a), and thus indicates a substantial increase in this area during the last decade.

During winter the porpoises were more dispersed, still with the highest density in the southwest, albeit much lower than during summer and still with a considerable number of porpoises on the offshore banks (fig. 3b). Apparently many of the Belt Sea porpoises in the southwest migrated back into the Inner Danish waters (Sveegaard et al., 2015a). The Polish coast appears to be an important wintering area for the Baltic Proper porpoises, together with the eastern coast of Sweden all the way up to the Åland Sea. The total winter abundance in the whole surveyed area was estimated at around 11,000 animals (95% CI 5,535-23,910).

Laws and regulations

The Habitats Directive (Council Directive 1992/43/EEC on the Conservation of natural habitats and of wild fauna and flora; (EU Council, 1992)) aims at protecting, at different levels, some 220 habitats and approx. 1000 species listed in the Annexes. Of importance for the harbour porpoise is Annex II, in which it is listed. This Annex covers species requiring the designation of Special Areas of Conservation (SAC), which are part of the Natura 2000 network. They must be chosen by the member states from the Sites of Community Importance (SCI). An SCI is a site which contributes significantly to the maintenance or restoration at a favourable conservation status of a natural habitat type or a species and/or of the biodiversity in the region. SCIs are proposed to the Commission by the member states and once approved they can be designated as SACs by the member state.

The harbour porpoise is also listed in Annex IV, which includes species that need strict protection. This implies that member states, in addition to designating SACs for the harbour porpoise, must also ensure that it is appropriately protected in the rest of its distribution, e.g. against by-catch in commercial fishery. If necessary, action plans must be set up for the management of the species, and laws and regulations implemented that ensure that the ecological needs of the species are met. The size and number of SACs in the waters of each member state depend on the distribution of the harbour porpoise, presence of hotspots such as important breeding grounds, and areas important for the gene flow between separated sub-populations.

The conservation action plans should include measures to prevent degradation of the habitat and detrimental effects of anthropogenic disturbances, such as underwater noise from shipping, from air-guns used for gas and oil prospecting and from pile driving during the construction of offshore windmill parks.

The conservation status of the harbour porpoise should be monitored over its whole distribution, i.e. not only within the SACs. Every 6th year the member states must report on measures taken according to the Directive. This report should include:

- A description of the necessary measures that were implemented in the SACs and of the strict protection system introduced in the whole distribution area.
- An assessment of the effects of these measures on the conservation status of the porpoise
- The most important findings from the monitoring of the porpoise population and of incidental catch of the harbour porpoise

The Directive also requires the member states to exchange information and make sure that transnational activities are well coordinated.

The Marine Strategy Framework Directive (MSFD; Council Directive 2008/56/EC; (EU Parliament and Council, 2008)) aims at

- protecting and preserving the marine environment, preventing its deterioration or, where practicable, restoring marine ecosystems in areas where they have been adversely affected
- preventing and reducing inputs into the marine environment, with a view to phasing out pollution, so as to ensure that there are no significant negative impacts on or risks to marine biodiversity, marine ecosystems, human health or legitimate uses of the sea

To achieve this, eleven qualitative descriptors for the determining of good environmental status have been defined; of these the harbour porpoise is affected by descriptors 1, 4 and 11.

1. Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions
4. All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity
11. Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment

A task group for descriptor 11 produced practical tools for monitoring noise and recommended the following indicators (Tasker et al., 2010; Van der Graaf et al., 2012):

11.1 Low and mid-frequency impulsive sounds – e.g. from air-guns, pile driving and underwater explosions. The indicator proposed to be measured is the proportion of days within a calendar year in which such impulsive sounds inside a rectangle of 15’N x 15’E/W exceed 185 dB re 1µPa^{2}s (SEL) or 224 dB re. 1µPa peak, measured over the frequency band 10Hz to 10kHz. A baseline for this needs to be established before maximum values can be determined.

11.2 Low frequency continuous sounds – mainly generated by shipping. The indicator to be measured should be the ambient noise level at a set of representative observation stations within the 1/3 octave bands of 63 and 125 Hz. This level should not exceed baseline values of year 2012 or 100dB re 1µPa RMS, averaged over a year.

The MSFD requires the member states to carry out coordinated monitoring programs in order to evaluate the state of the marine environment. These programs include:

- actions to specify the cause of changes and identify possible correction measures that can restore good environmental status
- actions that confirm that the correction measures result in the intended improvements
- the development of technical specifications and standardized methods for EU-level monitoring ensuring comparable information

Finally the MSFD requires the member states to design and implement action programs necessary to achieve good environment status in their territorial waters. These programs should include spatial measures that will ensure a cohesive and representative network of marine protected areas according to the Habitats Directive and other international agreements.

ASCOBANS (Agreement for the protections of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas; http://www.ascobans.org/) has been ratified by six of the countries surrounding the Baltic Sea. This agreement is part of the Bonn Convention or the Convention on Migratory Species (CMS). It is of special interest for the harbour porpoise, since it is the most common and widespread small cetacean species in this region. Three action plans have been produced by ASCOBANS, a recovery plan for the Baltic Sea called the Jastarnia Plan (ASCOBANS, 2009)), and conservation plans for the Western Baltic, Belt Seas and Kattegat and for the North Sea. These plans follow the recent findings on the population structure of the harbour porpoise in the region. They list recommendations and mitigation actions concerning threats to the species and its habitats and state the need for monitoring population trends.

HELCOM (the Baltic Marine Environment Protection Commission or Helsinki Commission; http://www.helcom.fi/) is a regional, intergovernmental organisation. All countries surrounding the Baltic Sea have ratified it, together with the European Union. The agreement aims at protecting the marine environment of the Baltic region from all sources of pollution through intergovernmental cooperation.

HELCOM's Baltic Sea Action Plan (BSAP) (HELCOM, 2010) includes recommendations for actions aiming at improved conservation status of the Baltic harbour porpoise. One of its goals is a significant reduction, towards zero, of harbour porpoise by-catch rates (HELCOM, 2013b). In co-operation with ASCOBANS, a coordinated reporting system and a database on Baltic harbour porpoise sightings and strandings and on by-catches, originally developed and run by the Baltic Sea Porpoise and Jastarnia Project, is now in operation and can be accessed via the HELCOM website (http://helcom.fi/baltic-sea-trends/data-maps/biodiversity/harbour-porpoise/). The BSAP also includes a red list (HELCOM, 2013a), similar to that of the IUCN, where the Baltic harbour porpoise is listed as critically endangered (CR). There are also recommendations on research that should be carried out to monitor population status and trends.

The ecology of the harbour porpoise

Population structure - All harbour porpoises in the Baltic Sea are presumed to belong to one population (Hammond et al., 2008), although the population structure in the Baltic region is not entirely clear (Andersen, 1993; Tiedemann et al., 1996; Wang and Berggren, 1997; Andersen et al., 2001; Berggren and Wang, 2008; Palmé et al., 2008; Wiemann et al., 2010). A recent study, combining genetic, morphometric, satellite telemetry and SAM data suggests that there are three populations or management units in the Baltic region (fig. 4), one in the North Sea, Skagerrak and northern Kattegat, down to LAT ~57°N, one south of this line in the southern part of Kattegat and in the Belt Seas, extending into the Baltic Sea eastward to LON 13.5°E, and one in the Baltic Proper, east of this delimitation line (Sveegaard et al., 2015b).

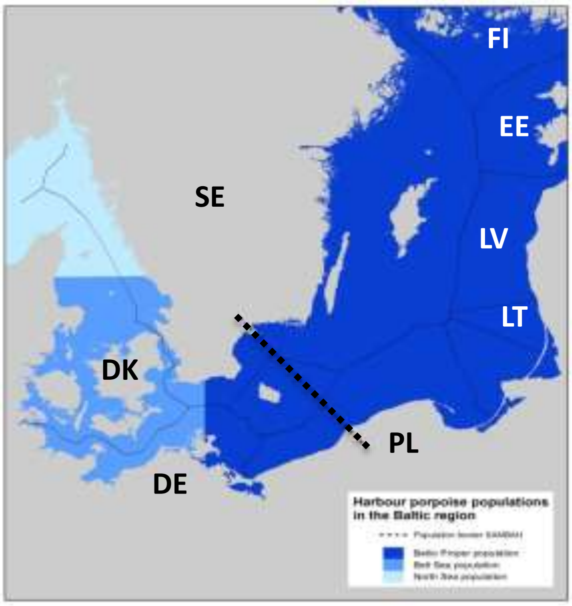


Figure 4. Three populations have been identified in the Baltic region with a delimitation line in northern Kattegat at LAT ~57°N *and another one in south-western Baltic at approx. LON 13.5° E (Sveegaard et al., 2015a). The dashed line indicates the proposed delimitation between two summer clusters identified by SAMBAH.*

Life cycle and reproduction - Harbour porpoises are sexually mature when they are 3-4 years of age and thereafter the females usually give birth to a calf every or every second year, even though few females get pregnant the first year of maturity (Read, 1990; Read and Hohn, 1995; Lockyer and Kinze, 2003). Reproduction is seasonal, with calving taking place in May-June and mating in July-August (fig. 5) (Börjesson and Read, 2003; Lockyer and Kinze, 2003).

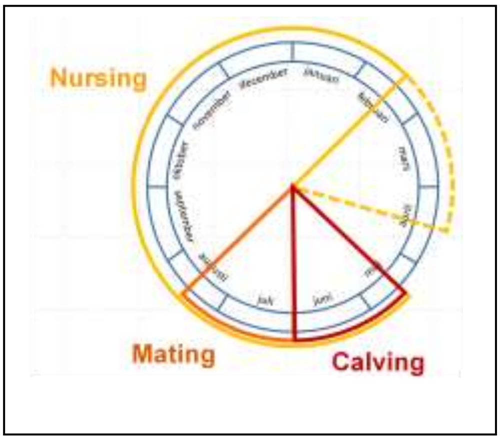


Figure 5. Annual life cycle for the Harbour porpoise in the Baltic region.

The pregnancy lasts ca. 10.5 months and the female nurse the calf for up to nine months (Börjesson and Read, 2003; Lockyer and Kinze, 2003). A harbour porpoise seldom lives longer than 12 years (Read and Hohn, 1995; Lockyer and Kinze, 2003), which limits the average life-time calf production per female to 4-6 (Lockyer and Kinze, 2003). Maximum recorded longevity is 23 years (Lockyer and Kinze, 2003).

Echolocation - In murky waters, at night and at great depths the porpoise relies completely on its echolocation or sonar. It generates high-frequency click sounds and listens for the echo from prey fish and obstacles in the environment (fig. 6). The sonar of porpoises is called "narrow-band high frequency", referring to the frequency composition of the clicks. Basically a click is a ~100µs long pulse containing 10-15 cycles of a pure sinus tone at ~130kZ, rendering it a very narrow frequency spectrum (Amundin, 1991; Villadsgaard et al., 2007). This makes it easy to distinguish it from broadband sonar species, e.g. like the bottlenose dolphin, *Tursiops truncatus* (Au, 1993).

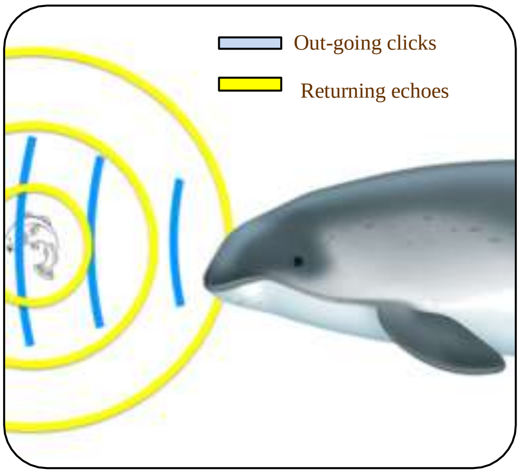


Figure 6. The porpoise generates click trains and listens for the returning echoes from obstacles and fish.

The sound is focused into a forward-directed narrow beam (Koblitz et al., 2012); to increase the search sector when exploring the surroundings, the porpoise scans with the beam from side to side. The clicks are transmitted in trains with varying inter-click interval (ICI). The ICI in orientation click trains ranges between 40 and 60ms. When the porpoise has locked on a target, the ICI depends on the distance: before producing a new click in a train, the porpoise waits for the echo to return and then processes it for some 20ms (Verfuss et al., 1999; Verfuß et al., 2005). These click sounds are also used in communication, and click trains with context-specific ICI patterns have been identified (Amundin, 1991; Clausen et al., 2010).

Feeding - Harbour porpoises can dive to at least 220 meters depth, although most dives are shallower than 30 meters and last less than a minute (Westgate et al., 1995; Otani et al., 1998; Björge and Tolley, 2009). During the deeper dives they are presumed to search for prey in the vicinity of the bottom or at a specific depth. Although small schooling fish like herring, *Clupea harengus,* and sprat, *Sprattus sprattus*, are important prey, demersal foraging is characteristic in many areas. In the Baltic Sea region, herring, sprat and small specimens of cod (*Gadus morhua*) are the main prey items (Read, 1999;

Börjesson and Read, 2003; Lockyer and Kinze, 2003). In the Belt Seas, herring and cod are the most important prey, measured as consumed weight, whereas gobies were the most frequently found prey, but since they are so small, the consumed weight was only 5% of the total intake (Sveegaard et al., 2012).

In the Baltic Sea the dramatic reduction of the piscivorous cod (*Gadus morhua*) since the 1980-ies has directly benefitted its main prey, the sprat (*Sprattus sprattus*), which currently occurs in historically high abundance levels (Casini et al., 2008a), even though the quotas for the Baltic Proper, decided by the EU Commission, have been slightly reduced during the last five year. The herring stocks decreased steadily since the 1970-ies, but this trend changed at the turn of the century and they are now increasing (Casini et al., 2008b); during the last five years the Baltic herring stock quotas for the Baltic Proper have increased by over 100% (http://ec.europa.eu/fisheries/cfp/fishing_rules/tacs/index_en.htm). This suggests that prey should not be a limiting factor for the harbor porpoise in the Baltic Sea.

Distribution in the Baltic Sea – Based on the SAMBAH results, an important summer area for the Baltic harbour porpoise were identified (Fig. 3a). One possible explanation for this aggregation is natal philopatry, believed to be the case in the harbour porpoise females (Huggenberger et al., 2002). The SAMBAH results also show that the contact between these porpoises and those in the high density area in the south-western part of the Baltic is very limited during the reproduction period (Sveegaard et al., 2015a). This indicates that the summer offshore banks aggregation is an important and genetically isolated reproduction unit and may be considered to be what remains of the Baltic Proper harbour porpoise population.

Threat status of the harbour porpoise in the Baltic region

As shown in Table 1, the Baltic harbour porpoise is listed as critically endangered by the IUCN (Hammond et al., 2008) and Helcom (HELCOM, 2013a). These classifications were based on rather uncertain data from only the south-western part of the Baltic Sea. SAMBAH now for the first time provides good abundance estimates and distribution maps for the entire Baltic Sea and for the whole year, which partly change the picture. The summer cluster on the offshore banks in central Baltic only counted ca. 500 individuals, and they must be considered critically endangered. Applying the Possible Biological Removal (PBR) concept again (cf.(Wade, 1998; Berggren et al., 2002)) showed that this population cannot tolerate even a single by-caught animal per year, if the aim is to meet ASCOBANS' objective to restoring the population to 80% of its carrying capacity. Hence this calls for immediate and resolute conservation measures. Additionally, since they also are genetically isolated from the porpoises in the south-west, and hence may be what is left of the original Baltic Proper population, makes them even more important to protect.

The SAMBAH abundance estimate for the south-western part of the Baltic, however, which can be directly compared to the earlier abundance estimates by SCANS I (Hiby and Lovell, 1996; Berggren et al., 2004) and the 2002 survey by (Berggren et al., 2004), indicates a remarkable increase here in porpoise numbers in the last decade. This is most likely due to a substantial population growth in the Belt Seas.

***Table 1**. Threat status of the harbour porpoise in the Baltic region.*

Sea area	Organisation	Status	Reference
Baltic Sea	IUCN	Critically endangered (CR)	(Hammond et al., 2002)
Baltic Sea	HELCOM	Critically endangered (CR)	(HELCOM, 2013a)
Kattegat (”Western Baltic”)	HELCOM	Vulnerable (VU)	HELCOM 2007

Contributing factors to today’s dire situation in the Baltic Proper

Severe winters and historic commercial hunt - It has been suggested that it was to avoid the ice that Baltic Sea porpoises migrated through the Belt Seas (Andersen, 1982), where they were subject to commercial hunting, in particular in the Little Belt in Denmark, until the end of the 19th century. This hunt was resumed during the two world wars, albeit at a smaller scale (Lockyer and Kinze, 2003).

In Danish waters, the total estimated catch for the 18th and 19th century is estimated to be over 180,000 animals (Lockyer and Kinze, 2003). During the first and second world war, approximately 2,600 harbour porpoises were taken in the Little Belt (Kinze, 1995). Whether or not these porpoises actually were from the Baltic Proper population or were Belt Sea porpoises that migrated between the south-western part of the Baltic and the Belt Seas as we know it today (Verfuß et al., 2007; Gallus et al., 2012; Benke et al., 2014; Sveegaard et al., 2015a), must be considered uncertain. In Polish waters more than 700 harbour porpoises were taken primarily in salmon drift nets between 1922 and 1933, when a bounty was being paid (Skóra et al., 1988).

During the first half of the 20th century there were several severe winters, and e.g. in 1929 several hundred porpoises drowned under the ice and were subsequently found on the beaches of Bornholm (Johansen, 1929). Also during the severe winter in 1942 a substantial number of porpoises drowned under the ice east of the island of Als in the southern entrance of Little Belt in Denmark (Lockyer and Kinze, 2003).

Even though harbour porpoises are no longer actively hunted in the Baltic region, the historic hunt and the severe ice winters, followed by the considerable by-catch caused by the introduction of nylon gill nets in 1950-60, and the introduction of several types of environmental contaminants, may be the major causes to the presently low number of porpoises in the Baltic Sea.

Current negative anthropogenic impacts on Baltic porpoises – how can they be reduced?

In order to assess what anthropogenic activities might be in conflict with harbour porpoises, spatiotemporal data on potential impact factors are needed together with spatiotemporal data on the Baltic harbour porpoise. As a first step, spatial overlap analysis can be done, followed by analysis of possible temporal overlap. This can then be used in order to minimize negative impacts on the porpoises, while still, maybe, be able to allow the anthropogenic activities to continue. Here we show examples from Swedish waters – it may serve as a model for other nations. In Sweden the main source of information on different anthropogenic impact factors has been the County Administrations and national agencies.

By-catch in fisheries - Today, the most significant threat to the harbour porpoise throughout its distribution range is incidental catches in fishing gear, primarily in bottom-set, large mesh gillnets targeting cod, turbot, plaice or lumpfish (Clausen, 1983; Clausen and Andersen, 1988; Vinther and Larsen, 2004b). In the Baltic Sea, only minimum data on by-catches are available from collection or observer schemes. The low animal density and the fact that the majority of the fishing effort is carried out by small vessels prevent observer schemes with sufficient coverage to yield independent and reliable estimates to be carried out at a reasonable cost. A cheaper alternative is to use on-board CCTV, through which not only porpoise by-catch can be monitored, but also by-catch of seals, birds and fish. This method has been tested and evaluated on six Danish fishing vessels, primarily to assess fish by-catch (Kindt-Larsen et al., 2011). Using observers would be almost 5-7 times more expensive than using CCTV, depending on what categories of analysing staff is engaged (Kindt-Larsen et al., 2012). Also CCTV allows monitoring by-catch on small boats that cannot accommodate an observer.

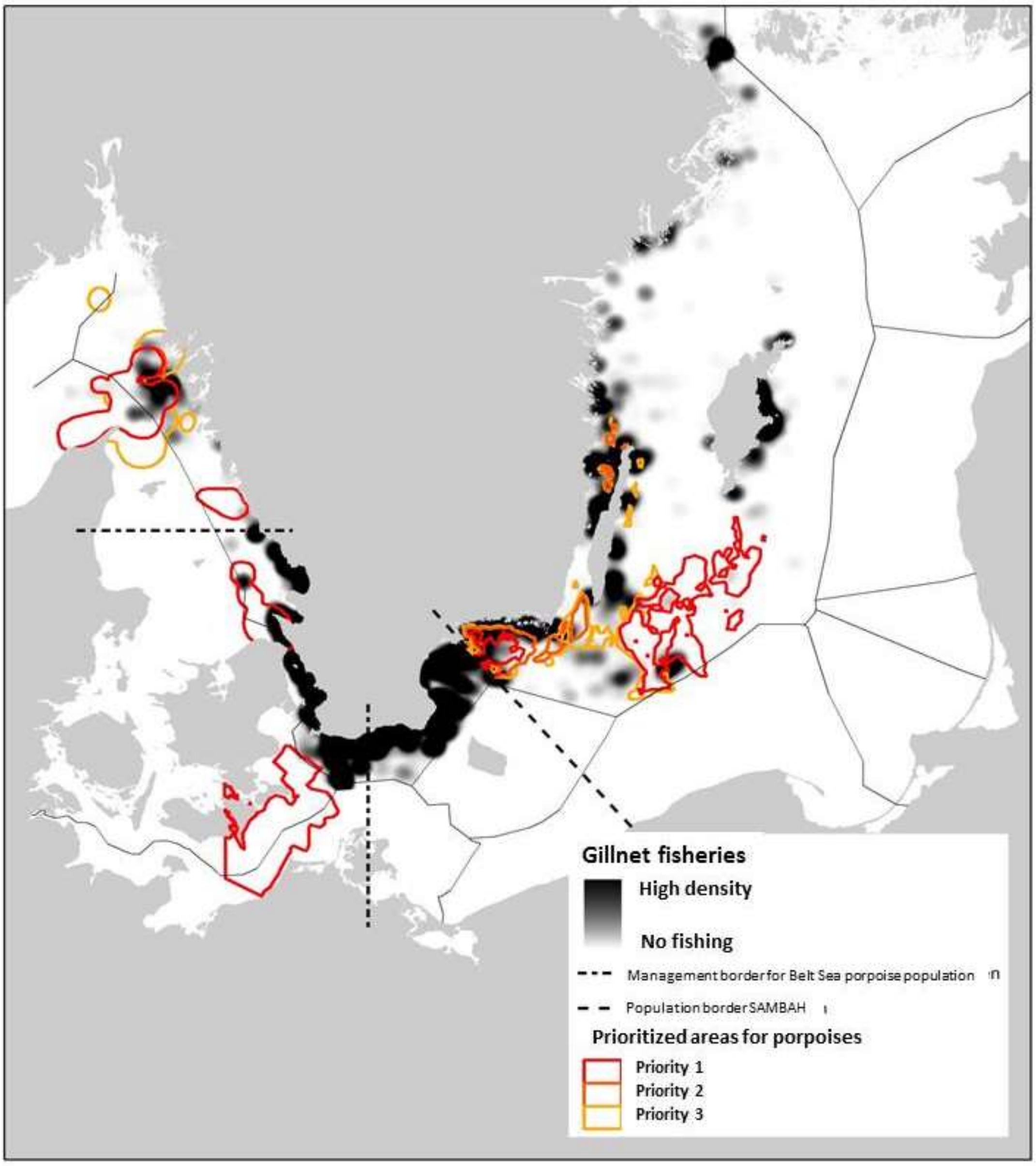
In Swedish and Polish waters, a large proportion of the by-catches has occurred in drift nets or semi-drift nets for salmon (Berggren, 1994; Skóra and Kuklik, 2003). The drift net fishery is now prohibited (Regulation 812/04 (EC)), but the semi-drift nets used by Polish fishermen are still allowed and in use. The present by-catch rate in this fishery is not known.

In addition to by-catches in professional fishing gear, an unknown number of harbour porpoises are believed to be taken in the recreational fisheries but no published records of this have been found.

Without real data on where and when by-catch occurs, a risk analysis can be carried out in order to identify in which areas by-catch mitigation may give the best effects. In this kind of analysis GIS layers with fishing effort for the gillnet types that are responsible for most of the by-catch are multiplied by

GIS layers with porpoise distribution. The analysis should separate seasons, since both fishing effort and porpoise distribution varies over the year.

For the Swedish fisheries data from the Swedish Agency for Marine and Water Management (SwAM 2014) were used for the preparation of Action C5. These data consist of fishing log positions for 2011-13, with information on type of fishing and species caught. Focus was on the large-mesh bottom-set gillnets, which have the highest by-catch rates (Vinther, 1999; Vinther and Larsen, 2004a). As a proxy for real effort, which was not included in this dataset, the number of logging points within a radius of 10km, separated per season, was used. This resulted in a GIS raster file showing relative fishing effort (Fig. 7).



***Figur 7**. Core area density of large-mesh bottom-set gillnets, used for cod, turbot, plaice or lumpfish during 2011-2013, in relation to important areas for the Baltic harbour porpoise, proposed by SAMBAH to the Swedish Agency for Marine and Water management (Action C5). Dashed lines indicate the management borders for the Belt Sea population (Sveegaard et al., 2015a), and the proposed delimitation border between two summer concentrations of porpoises found by SAMBAH.*

When it comes to reducing porpoise by-catch there are three main approaches: reduced fishing effort, use of acoustic deterrents, so called pingers and use of alternative fishing gear.

Fishing effort has indeed been reduced over the last several decades, but not in order to reduce by-catch, but as an effect of a variety of factors, such as reduced catches and reduced profitability, mainly due to low prices on fish and seal depredation (Sara Königson, Swedish University of Agriculture, pers. comm. 2016). Based on the reports from licensed Swedish fishermen to the EU logbook, there has been an 80% reduction in gillnet fishing effort in southern Baltic Sea between 1997 and 2012 (Sara Königson, Swedish University of Agriculture; pers. comm. 2016).

Pingers have been tested in a large number of studies all over the world. The overall conclusion from 14 controlled pinger experiments in North America and Europe is that pingers almost entirely eliminate by-catch (Dawson et al., 2013; Larsen and Eigaard, 2014). Whether or not porpoises habituate to pingers is unclear; in some studies the results indicate so (Gearin, 2000; Cox, 2001; Carlström et al., 2009), whereas in two long-term studies in a commercial fishery this has not been observed, in spite of the fact that the studied pingers were transmitting the same sound, a 300ms long 10kHz tone, every 4 seconds (Palka, 2008). Other pinger marks transmit several different sounds at varying intervals, and it has been shown that this reduces habituation (Kyhn et al., 2015).

In the Jastarnia Plan (ASCOBANS, 2009), ASCOBANS has recommended the use of pingers in the Baltic Sea only as a temporary, short term measure, until alternative, porpoise-safe fishing gear, such as cod traps, have been developed and fully implemented. However, because the EU pinger regulation 812/2004 only makes it mandatory to use pingers by fishing vessels more than 12 m long, only a very small portion of the fishing fleet in the Baltic is affected by this regulation. Even among those fishermen that are obliged to use pingers, it has been difficult to reach full compliance. This is coupled to problems with functionality and the pingers being considered too expensive. It is also difficult and expensive to supervise compliance and functionality.

An additional problem is that pingers have been shown to act as “dinner bells” for seals (Stridh, 2008), which would further aggravate the seal depredation. This is already a grave problem in the Baltic Sea (Fjälling, 2006), and therefore Baltic fishermen are very reluctant to use pingers. In Sweden the development of a “seal safe” pinger is in progress (Amundin, pers. comm. 2016). The sounds of this pinger has been adjusted so that the frequency components within the seals’ hearing range have been attenuated and those above, up to 150 kHz which is the upper hearing limit of the harbour porpoise, have been boosted. Field tests with porpoises are planned to be carried out during 2016.

In Sweden the development of traps as substitute for gillnets has mainly been driven by a need to reduce seal damages on catch and gear ((Westerberg et al., 2006; Königson et al., 2015b). In Barents Sea cod traps with two chambers, suspended above the seabed, have been used successfully to reduce by-catch of king crab (*Paralithodes camtschaticus*) (Furevik, 2008). As a positive side-effect, these traps have no by-catch of porpoises, seals or sea birds (Königson et al., 2015a). Further development of fish traps for the commercial fisheries has been on-going since 2009 and have shown that cod pots can be an economically viable alternative to gillnets (Königson et al., 2015b). Experiments with two-chamber cod pots, also suspended above the seabed, in the Baltic Sea have shown that escape windows improve size selectivity of cod (Ovegård et al., 2011) and that green lamps increase both catch per effort and weight of cod above 38cm (Bryhn et al., 2014).

In addition to mitigating by-catch in active fishing gear it is also highly recommended to set up programs for collecting lost gear, so called ghost nets, which may continue to catch porpoises, seals, birds and fish for a very long time. Conclusions from such programs in Poland and Lithuania point at the importance of expanding the actions to cover the whole Baltic, to make sure that the already gained experiences are utilized and that the commercial fishermen are actively involved. Furthermore it was stressed that it is important to find ways to re-use these retrieved nets (Szulc, 2013). A first important step would be to collect information in order to assess the spatial distribution and volume of ghost nets, in order to identify where actions may be of greatest benefit. This estimate should preferably be based on experiences from Swedish initiatives and methods developed in Poland and Lithuania.

Underwater noise - Marine installations may generate loud noise levels at different stages of their construction and operation. Such noise may have different effects on harbour porpoises, depending on its sound pressure level, duration and frequency content. A background to this is given in Appendix I.

One of the noisiest human activities in the marine environment and also most extended in time is pile-driving of the wind power foundations (fig. 8) (Nedwell et al., 2007; Tougaard et al., 2009; Bailey et al., 2010). On the other hand the reported noise levels from wind turbines during normal operation are low (Nedwell et al., 2007; Andersson, 2011) and unlikely to have any significant negative impact on marine mammals (Madsen, 2006).

High noise levels are also caused by so called airguns. These are used during seismic surveys, in particular in connection with search for oil and gas deposits in the sediments under the sea floor. They emit very strong low frequency pulses directed into the sea floor; however, strong side-lobes are also generated that are expected to be audible to harbour porpoises at a distance of at least eight kilometres (Goold and Fish, 1998). Hermansen et al. (2015) concluded that even though the risk of hearing damage is small, the potential for behavioural responses is substantial for distances of several kilometres from the airgun.

Underwater blasting is being carried out for underwater constructions, e.g. it was done during the deployment of the Nord Stream gas pipeline (NordStream, 2009). It is also done by the military when clearing WW II mines and during military exercises (see below). Compared to explosions in air the impact zone of underwater explosions is much greater. If close to the explosion, marine mammals are physically damaged, in worst case lethally, and suffer primarily bleedings in and in the vicinity of the lungs, in the ear and nasal cavities and in the intestines (Yelverton, 1973; Goertner, 1982; Landsberg, 2000). At longer distances permanent hearing damage can be inflicted (Ketten, 1995). Whether or not this may lead to a porpoises losing the ability to use echolocation for navigation and finding food is unclear. The major temporal threshold shift (TTS) in a captive porpoises exposed to airgun pulses, which have the main energy below 500Hz, were in the lower frequency ranges, and was measured at 4kHz, whereas no TTS was found at 32kHz or 100kHz (Lucke et al., 2009). Considering their lower frequency hearing (Nedwell et al., 2004), seals are expected to be more and more severely affected by all low frequency impulsive noise (Thompson et al., 2013).

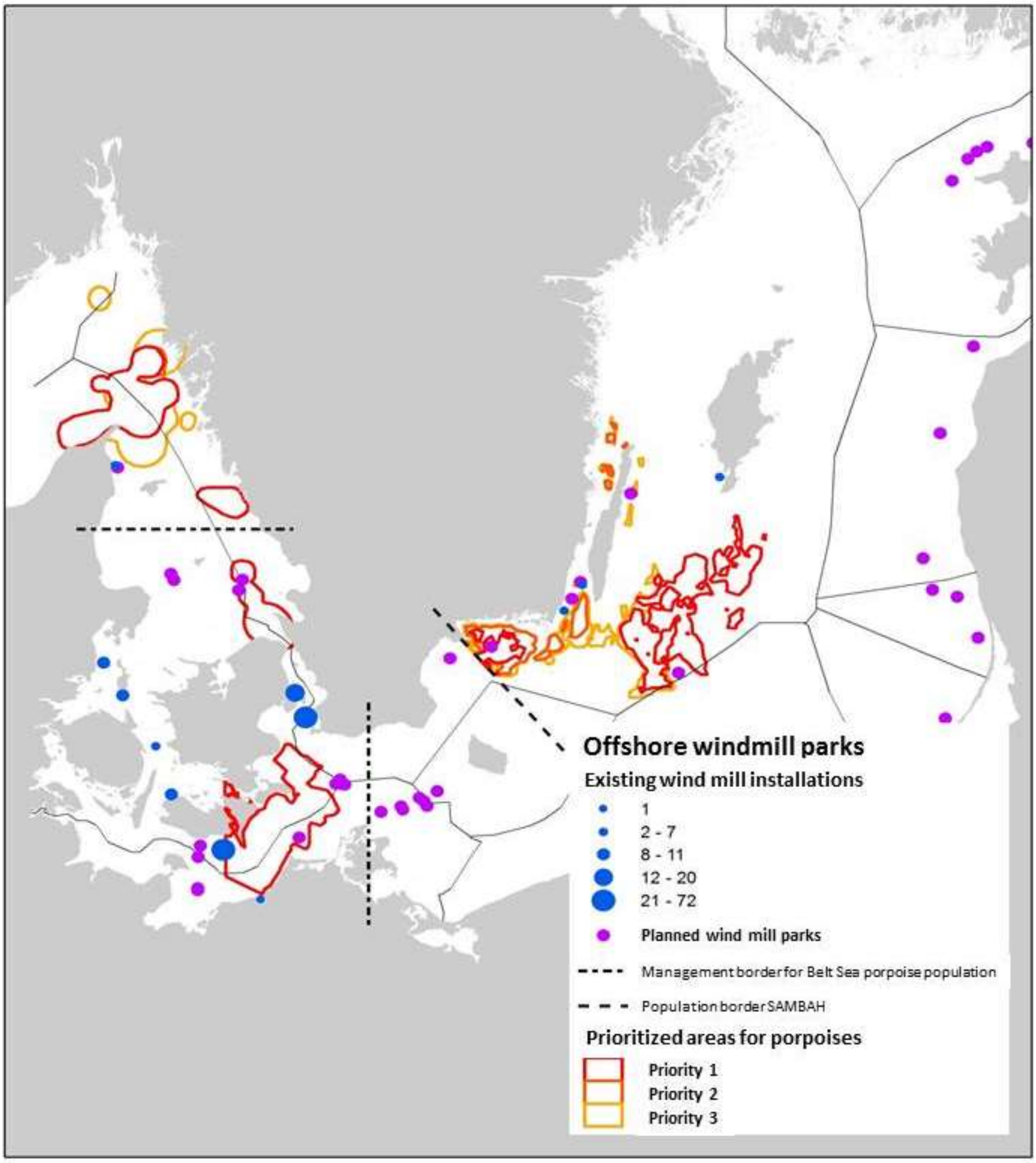


Figure 8*. Existing and planned wind mill parks in relation to the important areas for the harbour porpoise proposed by SAMBAH (cf Action C5). Dashed lines indicate the management borders for the Belt Sea population (Sveegaard et al., 2015a), and the proposed delimitation border between two summer concentrations of porpoises found by SAMBAH.*

Besides inflicting physical damage, underwater noise may also affect porpoises directly by behavioural disturbances or indirectly by disturbance of their prey. Lucke et al. (2009) found that the porpoise they exposed to airgun sound pulses showed aversive behaviour reactions at sound pressure levels 20-25dB below the levels that caused TTS. Pile driving and other activities that generate intense impulse sounds are likely to disrupt the behaviour of marine mammals at ranges of many kilometres, and these activities have the potential to induce hearing impairment at close range (Madsen, 2006). During pile-driving during the construction of two offshore wind farms in the Danish North Sea the echolocation activity by harbour porpoises was drastically reduced (Carstensen, 2006) and at one of the farm sites these effects remained two years after the wind mills had been taken in use (Teilmann and Carstensen, 2012), in spite of the fact that the noise from wild mills in operation is low in amplitude as well as frequency (Andersson, 2011).

The impact of underwater construction activities on harbour porpoises in the Baltic Sea is likely to increase with increasing demands for renewable energy sources and increased prices on fossil fuels. However, the extent of the impact of e.g. construction of wind farms is highly dependent on what technique is used for the foundations (e.g. pile, gravity or "suction bucket" foundations; see (OSPAR, 2014)). Furthermore, the negative impact of pile driving, seismic surveys and underwater blasting can be significantly reduced if appropriate precautionary or mitigation measures are taken (Koschinski and Kock, 2009; Koschinski, 2011b; OSPAR, 2014). Examples of such measures are to time the activities or the noisiest phases of them during low-density seasons for harbour porpoises, and/or the use of acoustic deterrence devices (pingers) or ramping up the pile driving blows, in order to cause harbour porpoises to leave the area before the activity or the noisiest phase is carried out. There are also noise mitigation techniques, such as bubble curtains or containing the wind mill foundation inside a caisson, either air-filled or sound insulated, that can be employed.

In Germany and the UK advices and guidelines have been developed for how to deal with underwater noise. In Germany there are detailed guidelines for noise to be considered in environment impact assessment (EIA) in connection with the construction of offshore windmill parks (Bundesamt für Seeschiffahrt und Hydrographie (BSH), 2013). They include maximum noise levels that must not be exceeded.

In the UK there are guidelines on intentional impact, including catch, injury, killing or disturbance, on species that are protected within the Habitats Directive (JNCC, 2010a). They are so far only used as best practice, targeting stakeholders, authorities and courts. They give information on when the national implementation of the Habitats Directive may be at risk of being violated, how such risks can be reduced and if not, under what conditions permits may still be issued. These guidelines also include specifics on the reduction of negative impacts from seismic explorations, underwater blasting works and pile driving on marine mammals (JNCC, 2010b, 2010d, 2010c). Corresponding guidelines have been developed for Scotch waters (Marine Scotland, 2014) and Irish waters (NPWS, 2012).

As a general rule, it should be required by offshore operations that generate noise to measure the noise and how it is propagated in the surrounding waters, and also the effects – or lack thereof - of mitigation measures in order to add to the collective knowledge and to make it possible to improve methodology. It should be done in a standardized format so data from different countries can be compared. Hence all nations are urged to coordinate these monitoring activities. For an extensive summary, including a threshold values and noise weighing curve for marine mammals, readers are referred to (Southall, 2007) and (Tougaard et al., 2015).

Shipping - Shipping also generates noise, but since it is an almost continuous and very widespread activity, it is treated separately. It can be divided into two major categories: big ships and leisure boats. All big ships have AIS (Automatic Identification System) transponders allowing their movements to be followed with high resolution in time and space. In figure 9 we have used a GIS layer with all AIS traffic during 2011, showing the relative density of ship traffic overlaid our proposed important areas for porpoises in the Baltic Proper. As can be seen there are major ship lanes where most of the traffic is concentrated, but there is still a lot of traffic outside these lanes. The main ship lanes pass inside the most important areas for porpoises in southern and central Baltic Sea.

It may be considered unlikely that the main ship lanes, going along the north-western border of the proposed core reproductive area in central Baltic (fig. 9), can be moved in order to reduce possible impact on porpoises. However, in figure 9 can also be seen another ship lane with lower traffic intensity that goes right through the middle of this area, between the North and South Mid-Sea banks and east of the Hoburg bank. Provided that this traffic also occurs during the summer, it may be desirable and possible to re-direct this traffic during this sensitive period for the porpoises. On the other hand, it is not proven that this kind of traffic is really disturbing to porpoises; the ships can be detected by the porpoises at large distances and their “behaviour” is easy to predict. In the Great Belt in Denmark, where the shipping is intense, the porpoise abundance is very high (Hammond et al., 2013). Hence porpoises may be able to adjust their own behaviour to avoid being put at risk and to minimize its negative impact. However, when it comes to very fast ships, like high-speed ferries, drastic behaviour responses may be seen: a porpoise, provided with satellite tag and a depth gauge, made a long dive and stayed near the sea floor during the entire passage of the ship (Teilmann et al., 2015). This may put a heavy physiological burden on the animal (Linnenschmidt et al., 2013). It is highly recommended that research is initiated to clarify this.

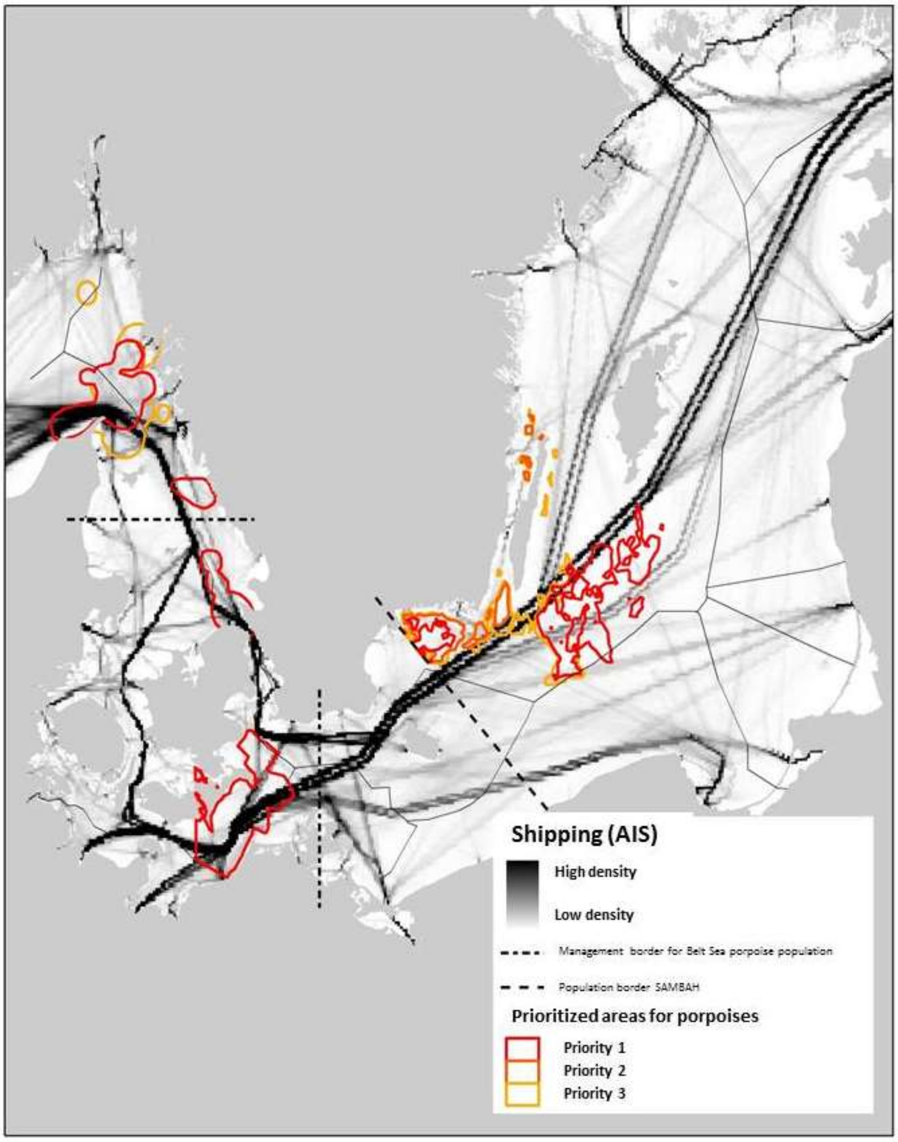


Figure 9. *Monthly average of relative density of commercial shipping traffic based on AIS data for 2011, in relation to proposed important areas for the harbour porpoise (Action C5). Dashed lines indicate the management borders for the Belt Sea population (Sveegaard et al., 2015a), and the proposed delimitation border between two summer concentrations of porpoises found by SAMBAH.*

There is no corresponding data on the spatial distribution or density of leisure boat traffic. There are however two gross differences with relevance to the harbour porpoise compared to commercial shipping: (1) the leisure boats are mainly used very close to the coast and (2) they are almost entirely used during daytime and in the summer, in Sweden roughly from April-May until September. On the other hand this is when most animals reproduce and thus are extra sensitive to disturbance. An additional potential risk factor is that leisure boats are often very fast, and powered by outboard engines that generate very loud and more high frequency noise than freighters, even if noise from the latter also extend over the whole hearing range of porpoises (Hermannsen et al., 2014). Yet another difference relative to big ships is that leisure boats are less predictable, which is an additional potential stressor.

Maybe an indirect way to measure the intensity of leisure boat traffic would be to use satellite photos, covering the coastal areas. It should be possible to determine boat type, e.g. differentiating between slow and fast motor boats and sailing vessels. Also SAMBAH data at selected positions may be analysed for speed boat specific noise.

Military activities - Gun exercises, mine clearances and sonar exercises take place more or less in all Swedish waters, but with higher concentration in defined military shooting and exercise areas (see fig. 10). Since the military exercise areas and the world war mine fields are spatially settled (see fig. 10), reducing possible negative impact can only be done on a temporal scale, supplemented with mitigation measures like bubble curtains around detonations and using pingers to make porpoises leave the area before the activity is started. Koschinski (2011b) presented current state of knowledge on mitigation methods for underwater explosions. One option, mentioned in Koschinski and Kock (2009), for the disposal of dumped military munitions instead of detonating it, is to freeze it and then remove it for safe disposal on land.

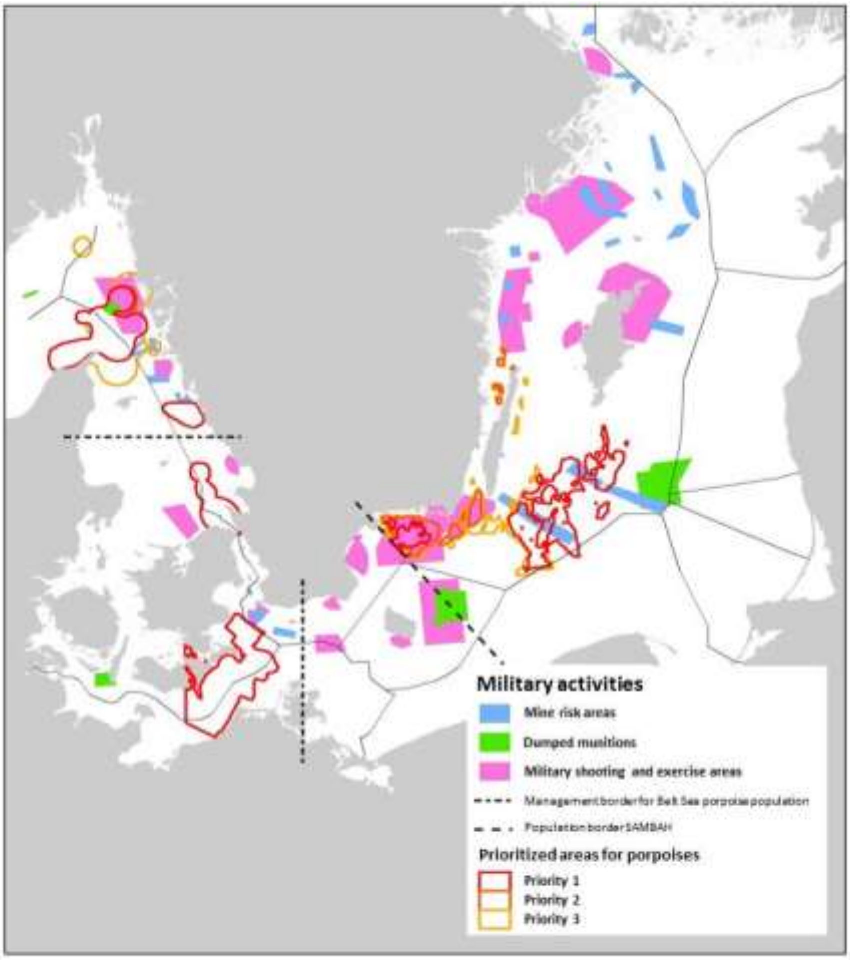


***Figure 10**. Areas with mines, dumped munitions and for military exercises, in relation to proposed important areas for harbour porpoises in the Baltic Proper. Dashed lines indicate the management borders for the Belt Sea population (Sveegaard et al., 2015a), and the proposed delimitation border between two summer concentrations of porpoises found by SAMBAH.*

The Swedish armed forces have acknowledged the hazards of these activities for the marine life and have developed a GIS-based planning tool, called the Marine Biological Calendar, to be used in order to minimize the negative impacts on porpoises, seals, birds and fish. In this software spatial information on military exercise areas, protected areas such as Natura 2000 areas and Helcom Marine Protected Areas and hydrographical conditions can be combined with dynamic biological data such as seasonal protected areas for birds or seals and spatial and temporal distribution for the harbour porpoise. This tool can be downloaded on http://www.forsvarsmakten.se/sv/om-myndigheten/vart-arbetssatt/vart-miljoarbete/marinbiologisk-kalender/ (in Swedish). It makes it possible for the armed forces to time their exercises in a particular exercise area or targeting the clearing of a selected war mine field to a period where sensitive animal species are affected the least. Figure 11 shows a screen dump from this tool, presenting a map with layers showing military exercise areas, Natura 2000 areas, HELCOM Marine Protected Areas, and sea haul-out sites for a few summer months, which can be selected for the time period in question.

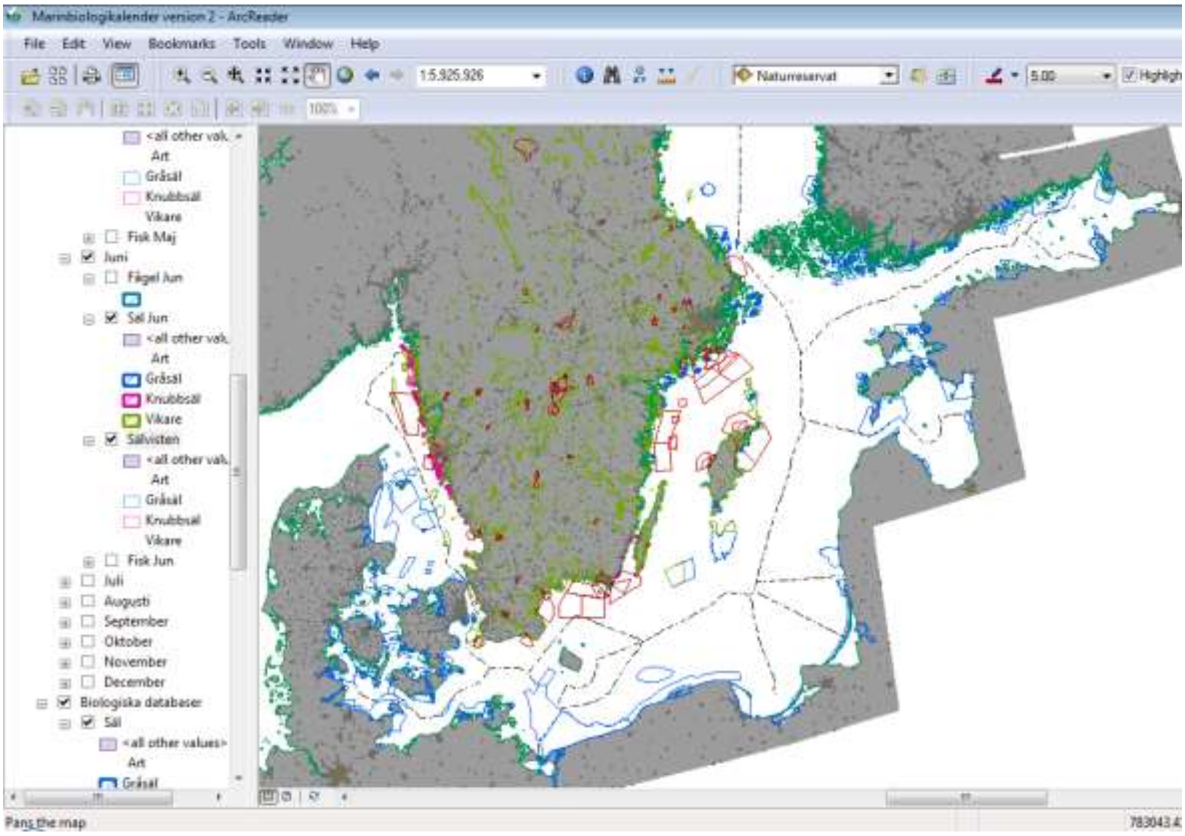


Figure 11. *A screen dump of the Swedish Armed Forces' planning tool, the Marine Biological Calendar, which make it possible for the Navy to time its activities in order to minimize their negative impact on the marine life. Red polygons: Swedish military exercise areas; blue polygons: Natura 2000 and Helcom Marine Protected Areas; purple dots: harbour seal haul-out sites; blue dots: grey seal haul-out sites. The maps showing the probability of detecting porpoises as well as the prioritized areas proposed by SAMBAH will be incorporated.*

Future surveys and follow-up of the harbour porpoises in the Baltic Sea

One of the main reasons for launching SAMBAH was the difficulties in producing good abundance estimates using traditional survey methods, and the complete lack of knowledge on spatial distribution of the Baltic harbour porpoise. In the rest of the porpoise distribution range, aerial and ship-based visual line-transect surveys work well, as proven by SCANS and SCANS II. A third SCANS is planned to be carried out in these areas in 2016.

SAMBAH has shown that it is possible also to survey areas with very low population densities. The scale of this survey should be compared to that of the SCANS surveys, and it can be argued that like them, a SAMBAH-type survey needs not be repeated e.g. every 10 years. However, there is still a need for more frequent monitoring, since the Baltic Proper harbour porpoise population is so small and hence very sensitive to negative impacts. Therefore smaller-scale Static Acoustic Monitoring (SAM) studies in selected areas in the Baltic are highly recommended, preferably in areas shown in SAMBAH to be of great importance for the population, e.g. the shallow offshore banks south of Gotland with their summer aggregations of porpoises.

Several countries in the Baltic region are already carrying out censuses of porpoises in their Natura 2000 areas. In the German waters in southern Baltic the relative density of porpoises has been monitored since 2002 using SAM (Benke et al. 2014). Poland has carried out regional SAM in Puck Bay (I. Pawliczka, Hel Marine Station, pers. comm. 2015) although not with the aim of estimating abundance. Denmark is planning to measure porpoise densities using SAM methodology in low density areas. These national initiatives should preferably be coordinated internationally, and expanded to countries in the region, as recommended in the Habitats Directive and the Marine Strategy Framework Directive, so the results can be used to assess the status of the whole population.

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Appendix I. Impact of underwater noise and other disturbances on the harbour porpoise

SAMBAH

Static Acoustic Monitoring of the BAltic Harbour porpoise

LIFE08 NAT/S/000261

Adapted from Action C5: "Protected areas for the Harbour Porpoises in Swedish waters" (in Swedish) by Julia Carlström and Ida Carlén, Aqua Biota Water Research, Sweden.

Sources to and distribution of underwater noise

In the sea there are both natural and anthropogenic sources to noise. Sound propagation in the sea is very complex, but in general low frequencies reaches farther than high frequencies. At low frequencies (10-500Hz) noise from commercial shipping, seismic exploration with airguns and piling of wind mill foundations dominate. This kind of noise propagates across oceans.

At mid-frequencies (500Hz – 25kHz) natural noise from breaking waves and rain and anthropogenic noise from e.g. some military sonar systems, fast leisure boats and high speed ferries and the upper part of piling noise spectrum are the main sources. This kind of noise propagates up to tens of kilometres.

Higher frequencies (>25kHz) have shorter range and are generated by dolphins and porpoises, several types of military sonar systems and commercial echosounders and the higher portions of anthropogenic noise also goes above 25kHz (Nedwell et al., 2007; Hildebrand, 2009; Bailey et al., 2010; Andersson, 2013; Johansson et al., 2013). Note that the harbour porpoise are very sensitive to a much broader frequency range than that of their own echolocation click sounds which are centred in a narrow frequency band at 130kHz. Their best hearing is between 10 and 150 kHz, but they can hear strong sounds down to a few hundred Hz (see figure 1) (Andersen, 1970; Kastelein et al., 2002). Other delphinids have similar audiograms, but generates broad band echolocation clicks with frequencies from a few kHz up to above 100kHz (Au, 1993).

Underwater noise measurements in north-eastern Pacific have shown that in the period 1950 – 2007 the level of anthropogenic noise has increase with an average of 3.3 dB per year. This can mainly be explained by the increase in commercial shipping, which in turn is correlated with the global economic growth (Frisk, 2012).

In the Marine Strategy Framework Directive underwater noise is dealt with by the Descriptor 11. So far two indicators have been defined:

1. Spatio-temporal distribution of strong, low to mid-frequency impulsive noise
2. Continuous low frequency noise.
3. The first indicator includes the noise from the piling of wind mill foundations, from seismic exploration with airguns and from underwater explosions, e.g. for clearing of world war mines and dumped munitions. The other indicator includes noise from shipping, from underwater car and train tunnels and bridges and from operational noise from offshore wind mill parks and oil rigs.

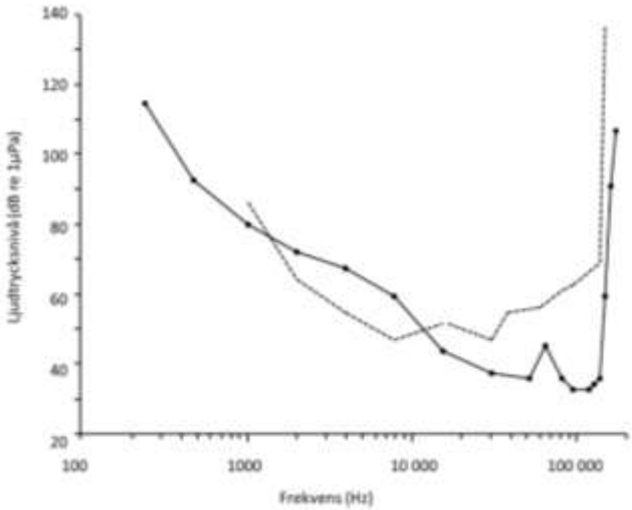

***Figure1**. Audiograms for the harbour porpoise, obtained from conditioned behavioural response experiments in captivity (solid line: (Kastelein et al., 2002); dashed line: (Andersen, 1970). The porpoise can hear the sound pressure levels above the curves.*

In addition to these two indicators the task group also suggested a third indicator dealing with high frequency pulsed sounds, mainly from echosounders and sonars (Tasker et al., 2010). This indicator was rejected by the EU Commission, and therefore the task group recommended in its final report that, in order to develop such an indicator, the use of echosounders and sonar systems should be monitored and their possible negative impact on whales and dolphins should be assessed (Van der Graaf et al., 2012).

Today the knowledge on underwater noise propagation in space and time is rather limited. For low to mid-frequency impulsive noise (indicator 11.1) HELCOM will therefore establish a regional database for the Baltic region. Focusing on continuous, low frequency noise (indicator 11.2), the EU funded BIAS (Baltic Sea Information on the Acoustic Soundscape (www.bias-project.eu)) project runs from September 2012 until August 2016. During 2014 BIAS carried out ship noise measurements at 36 stations in the waters of all EU countries in the Baltic Sea except Latvia and Lithuania. Based on these measurements, supplemented by AIS data on the ship traffic, modelled noise maps for the entire Baltic

Sea will be produced. Corresponding data collection was done in Kattegat and Skagerrak by Sweden and Denmark at an additional five stations.

Zones of impact for underwater noise and threshold values

Figure 2 shows a theoretical model for how underwater noise may affect marine mammals at different distances (Richardson et al., 1995). “Detection” means that the animals can hear the sounds, but without being affected, whereas “masking” means that acoustic information, such as the sonar echoes generated by porpoises or communication signals generated by porpoises and seals are ”drowned” in the noise. At even higher noise levels the behaviour of the animals’ behaviour is affected and then their physiology and eventually they may be killed.

Figure 2. *Theoretical zones of noise influence on marine mammals (Richardson et al., 1995)*

Behavioural effects may be considered to be milder than physiological effects, but depending on the extent of the effects, also behaviour changes may lead to effects on a population level. The behaviour effects increase with increasing noise levels. Southall (2007) give some examples for dolphins and porpoises:

- Small effects: small changes in movement patterns, breathing frequency or sonar behaviour
- Inter-mediate effects: moderate changes in the above, small, initial fright reactions, temporary separations between mother and dependent calf or temporary reduction of reproduction behaviour.
- Strong effects: from moderate to extended and substantial separation of mother and depending calf, with interrupted acoustic contact between them; from moderate to extended reduction of reproduction behaviour, extended avoidance of the area or panic escape.

Since the harbour porpoise is a small whale living in cold temperate waters it has a high energy turn-over rate (metabolism) (Lockyer et al., 2003; Lockyer and Kinze, 2003; Lockyer, 2007; Koopman, 2008). This means that its distribution is tightly coupled to high productive areas (e.g. (Embling et al., 2010; Gilles, 2011; Sveegaard et al., 2012). A porpoise needs to eat several times per day and if it is starved for a couple of days in the winter, there is a big risk that it gets hypothermic and dies. Females may be pregnant and lactating at the same time (Lockyer and Kinze, 2003) and for the main part of the year are accompanied by a calf with limited diving and swimming capabilities; this makes the dependence on productive areas is even bigger. A calf has less energy storage than an adult, and cannot survive more than a couple of days without milk from its mother. This means that areas occupied by adult females are especially sensitive to disturbances that affect their behaviour.

Physiological effects can be divided into two categories: temporary hearing impairment (temporary threshold shift, TTS) and permanent hearing impairment (permanent threshold shift, PTS). Frequent TTS may proceed to PTS and the risk for this increases with increasing noise levels, the duration of the exposure and the number of times the exposure is repeated (Ahroon et al., 1996). The risk for TTS also varies with frequency. The threshold value for TTS is used as threshold value for physiological effects in general.

There are no generally accepted threshold values for behavioural or physiological effects on the harbour porpoise. An extensive and comprehensive summary, including proposed threshold values and a weighing curve for the assessment of the effect of underwater noise on marine mammals have been presented by Southall (2007). Since then many new findings have been published and a recent paper compares data from eleven different studies, where porpoises have responded negatively when exposed to measured received noise levels (Tougaard et al., 2015). When this was compared with the hearing sensitivity of the porpoises, it was found that they reacted negatively to sounds that were 40-50dB stronger than their hearing threshold, irrespective of frequency. For TTS there are only five studies on the level of impact and they have been done using two different methods which makes comparisons difficult. Anyhow they indicate that TTS occurs when the porpoises are exposed to sound that are 100dB stronger than threshold, irrespective of frequency. Therefore Tougaard and his colleagues proposed to use the inverted audiogram with different margins as threshold values for behavioural and physiological impacts (Tougaard, 2015).

For practical applications in connection with the construction of offshore wind mill parks in southern North Sea, the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUP) has developed a concept in order to protect the harbour porpoise from harmful physiological impacts caused by underwater noise (BMUB, 2014). Based on a summary of the scientific literature on how porpoises are affected by piling noise, BMUB has defined a double threshold value, expressed as sound exposure level (SEL), which may not exceed 160 dB re 1 µPa^2 s and sound pressure level ($SPL_{peak-peak}$), which may not exceed 190 dB re 1 µPa at a distance of 750 m from the piling source. The threshold value that is reached first shall be used.

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Appendix II: Reduction of underwater noise and other disturbances

SAMBAH

Static Acoustic Monitoring of the BAltic Harbour porpoise

LIFE08 NAT/S/000261

Adapted from Action C5: “Protected areas for the Harbour Porpoises in Swedish waters” (in Swedish) by Julia Carlström and Ida Carlén, Aqua Biota Water Research, Sweden.

Reduction of negative impact of underwater noise

There are three main methods to reduce the negative impact of underwater noise:

1. Reduction of the noise that is generated
2. Reduction of noise propagation
3. Reduction of noise exposure

From an ecological point of view, reduction at the source is the best and the reduction of the noise exposure the worst. This report gives examples of methods addressing these approaches.

Reduction of generated noise

Below is given a broad summary of how the generation of noise can be reduced in different operations:

- Commercial shipping
- Seismic exploration using airguns
- Underwater explosions
- Military active sonar system
- Construction of offshore wind mill parks
- Leisure boats and tourism

For the **commercial shipping** the international maritime organization (IMO) has produced guidelines for the voluntary reduction of underwater noise in order to reduce negative impact on the marine life. The guidelines includes methods to theoretically calculate underwater noise from a vessel in connection with the design of new ships, i.e. how to design propellers, hulls and engines in order to minimize noise. Also there are guidelines for how maintenance and the way the ship is operated may affect the generated noise. The latter includes recommendations to choose the speed that minimizes noise and also on speed limits in sensitive areas and re-direction of ship lanes to avoid disturbing sensitive marine habitats or migration routes for marine life (IMO, 2014).

In order to reduce underwater noise generated by **seismic explorations** (Weilgart, 2010) describe different technical solutions for airguns and the hydrophones that are part of this detection system. These include optimizing the hardware and also the data analysis. The former may be to better match the output of the airguns with the hydrophones, and thereby improve the signal to noise ratio. With such optimization it may be possible to reduce the number and source level of the sound pulses, eliminate the part of the frequency spectrum that is not used in the analysis (>200 Hz) and eliminate the sound energy that is leaked to the surrounding areas. There are also technical solutions available for using silencers or alternative sound sources based on oscillators or vibrators, but these have to be further developed before they can be commercially useful. Vibrators have a more directional sound beam and may be towed closer to the bottom, which means that less sound is leaked to the surroundings. Also vibrators make it possible to transmit the same sound energy over a longer period of time, which allows the source level to be reduced. Using sound sources with a more controlled spectrum it is possible to optimize the frequency content and match it to the hydrophone and also to use frequency modulated sounds which improves the extraction of the echoes from the oil or gas deposits.

Several researchers have described different methods to reduce the areas of impact in connection with **underwater explosions** (Karlsson, 2004; Koschinski and Kock, 2009; JNCC, 2010a; Koschinski, 2011a). They include minimizing the weight of the explosive charges, the use of rod-formed charges instead of point-formed in order to minimizing the source level of the impulse, but still maintain the seismic pulse, to place the charge in a drilled hole with filling material to maximize the transmission of the energy to demolitions, and dividing the charges into smaller, which are delayed with some milliseconds to obtain several smaller explosions instead of one big.

Andersson and Johansson (2013) give an overview of national guidelines from a number of countries on how to use **military sonar systems**. The also describe the main parts of relevant international conventions and agreements. Based on this and on Swedish conditions, they then give a summary of possible preventive measures that can be employed by the armed forces. Among the planning measures they recommend that the topography of the exercise areas should be studied in order to make sure that animals are not trapped in bays and bottom ravines during an exercise. Also the Swedish armed forces have taken an initiative of their own, and have produced the so called “marine biological calendar" (http://www.forsvarsmakten.se/sv/om-myndigheten/vart-arbetssatt/vart-miljoarbete/marinbiologisk-kalender/; in Swedish), which is a GIS-based planning tool that can help the military to plan their exercises and other activities in space and time in order to minimize negative impacts on marine life.

During the **construction of offshore wind power plants**, the strongest noise is generated when pile-driving the foundations into the sediment. Alternative ways of establishing the foundations are vibration or drilling or using completely different types of foundations, such as gravitation and "suction bucket" foundations. OSPAR (2014) gives an overview of different methods to reduce noise in connection with building wind power plants. It includes technical descriptions of the methods, the practical experiences, the achieved dampening of the noise and the developmental status of the methods. A similar, but less comprehensive summary is given by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB, 2014). Saleem (2011) lists pros and cons for all types of foundations, with emphasis on the technical aspects.

When using the vibration method, the foundation is driven into the bottom sediment by applying a powerful 20Hz oscillator that shakes the entire foundation (Saleem, 2011). This method works best in soft sediments like sand and gravel, but not in compact clay. If the foundation hits more compact layers, the power and the frequency of the oscillations must be increased. If the sediment is too compact, pile-driving is used instead. Sound pressure levels measured as equivalent dB (L_{eq}) in connection with vibration have been 15 – 20 dB below the pile-driving impulse noise (OSPAR, 2014).

In compact and mixed sediments, drilled foundations may be an alternative. Drilling can be carried out in water depths down to 80m and the diameter of the foundation can be up to 10m. However, the method is slower than pile-driving (BMUB, 2014). No noise levels have been measure in offshore conditions, but they are believed to be lower than at pile-driving (BMUB, 2014; OSPAR, 2014).

Of the alternative foundation types, the gravity foundation is the most proven. It gives a bigger local impact on the sea floor, but during installation only very low levels of low frequency continuous noise are generated, mainly in connection with removing sediments and from transport and maintenance ships. OSPAR (2014) as well as German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB, 2014) consider this method to be well proven down to water depths of 20m and report that work is being done to evaluate the method for water depths down to 45m.

Since scientific data is lacking on the impact of **leisure boats and tourism** on porpoises, mitigation recommendations can only be based on information from other species and activities that may be considered similar. There are national guidelines or regulations on whale watching in over 50 countries and, based on 103 documents on whale watching the International Whaling Commission (IWC) has agreed on general principles for reducing the negative impacts (http://iwc.int/wwguidelines). These principles touch on three areas:

- Management of whale watching, by:
  - Implementing measures for controlling the number and size of boats, and their activity patterns such as frequency and duration of the whale encounter
  - Follow up of the efficiency of these measures and if necessary adjust them
  - Integration of research on potential impacts, including the acoustic domain
  - Further education of whale watching operators on whale biology and applicable regulations and guidelines
- Design, maintenance and operation of whale watching vessels in order to:
  - Minimize the risk of injuring or negatively affect the whale by the propeller
  - Minimize underwater noise
  - Ensure that the captain of the boat can observe the whales at all times during the encounter
- Regulating of the interactions between whales and whale watching vessels. The operator must:
  - Have thorough knowledge of the behaviour of the whales and what behaviour changes might indicate disturbance
  - Determine the maximum speed during approach in relation to the whales and thereafter keep this constant
  - Approach the whales from an appropriate angle up to an appropriate distance; this varies between species.

For leisure boats some of these whale watching principles may be applicable, e.g. to carry out information campaigns on how to operate the boat in the vicinity of porpoises and how to set the echosounder in order to minimize the negative impact on the porpoises (i.e. selecting ping frequencies above the upper hearing frequency limit of porpoises, which is 150kHz). It may also be appropriate and necessary with regulations, such as designating protected areas with access prohibitions during certain periods of the year, or introducing speed limits in areas which have been identified as important for the species. In order to increase awareness and knowledge on porpoises in the general public it is important to work actively with a system where opportunistic porpoise observations can be reported in an effective and easy way. The Swedish Agency for Marine and Water Management (SwAM) has developed a smartphone app, also available via its web site (https://filemaker-08.it.gu.se/fmi/webd?homeurl=https://www.havochvatten.se/hav/uppdrag--kontakt/kontakta-oss/hav-i-sociala-medier/rappen.html#rappenv2; in Swedish), called "Rappen", by which the general public can report observations of invasive species, like jellyfish, crabs and fish, and selected national species, including sightings of porpoises. In addition to traditional information like size and estimated number of specimen, geo-tagged pictures can also be included in the report. All observations are validated by a team of experts and the data is then stored centrally by the Artportalen (https://www.artportalen.se/), a national reporting system for a variety of plant, animal and fungus species. It is operated by the Swedish Species Information Centre (http://www.artdatabanken.se/) at the Swedish University of Agricultural Sciences.

Reduction of underwater noise propagation

Most of the methods to **reduce the propagation of underwater noise** have been developed to mitigate pile-driving noise in connection with the construction of offshore wind power parks. Commonly used ways are to create air bubble curtains around the foundation, to contain it inside an insulated caisson (cofferdam) which may be emptied from water or not, or place structures with encapsulated air bubbles around it as sound insulation. Bubble curtains can also be used in order to reduce the impact of the shock pulse from underwater explosions, e.g. in connection with blasting works or clearing of mines.

The air bubble curtains can be generated by one or several big circular tubes or hoses with tight rows of small holes that release high pressure air. If there are strong water currents, such tube rings have to be placed in several levels in the water column to ensure that the bubbles are not swept away. Information on these methods can be found in the reports from OSPAR (2014) and the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB, 2014) on the reduction of underwater noise in connection with the construction of offshore wind power plants.

Three big-scale experiments have been carried out in southern North Sea with bubble curtains generated without any rigid structures in the water column and used in connection with pile-driving of wind mill foundations. In these experiments, when the bubble curtain was fully functional, the sound exposure level (SEL, dB re 1 µPa^2 s) was reduced by 7-13 dB (Grießmann et al., 2009; Betke, 2011; Pehlke et al., 2013). However, Betke (2011) reported big problems with water currents which in 75% of the duration of the experiment made the bubble curtain drift away so the foundation was not fully encircled.

When it comes to the bubble curtain methods with fixed air-pipe structures, five different ones were tested and evaluated in one and the same experiment. It was carried out in southern Baltic Sea, where an already established 2.2m diameter mono-pile foundation was hammered with the same power as in a normal pile-driving operation. All five methods were feasible from a practical point of view and had the potential to reduce the broadband noise by 7 – 9 dB, measured at a distance of 750 m (Wilke et al., 2012).

Reduction of the exposure to underwater noise

In order to **reduce the exposure to underwater noise** the following methods are available:

1. To plan the operation in time and space where there are as few porpoises as possible within the potentially harmful zone of impact, i.e. where there is risk for physiological injuries

2. To monitor porpoises within the potentially harmful zone of impact and stop the operation if porpoises are observed
3. To deter porpoises so they leave the potentially harmful zone of impact

For the first alternative seasonal distribution maps for the porpoises are needed. This has been provided by SAMBAH; the GIS layers for each month of the year can be accessed via SAMBAH.org.

Applying the second alternative requires effective ways to monitor porpoises. It can be done both visually and acoustically. However, visual spotting of porpoises is very difficult and only possible in good weather, below sea state 2-3 and only in daytime. Passive acoustics is more efficient, and can be done live by using a hydrophone system with a click detector making the ultrasonic sonar click audible to humans. The detection range such a system is only 3-400m, which is not enough to avoid harmful effects from piling noise or underwater explosions. Therefore a grid of such listening posts ranging out to at least 700m is needed. Such a multi-hydrophone system based on cables converging to a central observation post will be expensive and difficult to deploy; hence sonobuoys with wireless transmission of the sounds are recommended. One such system available on the market is the PamBuoy, manufactured by SMRU Ltd, Scotland. It can be purchased as well as rented. Using Static Acoustic Monitoring devices, such as C-PODs, can only give retrospective data of the impacts and are thus not a viable option for this purpose.

Irrespective of what observation technique is used, it should always be carried out by trained observers and follow a strict protocol that specifies how big areas should be covered and what effort should be required, how long before the start of the operation these observations should be started, how the decision chain is organized, what measured should be taken should a porpoise be detected, and finally how long a period with no porpoise detections should pass before the operation can be resumed. Information on this can be found in the UK guidelines for seismic explorations, underwater explosions and piling (JNCC, 2010b, 2010d, 2010a).

The methods used to evict porpoises from the area are ramping up the power of the hammer, airgun or sonar, the size of the explosive charge or using porpoise deterrent devices, so called pingers (Acoustic Deterrent Devices, ADDs) and/or seal scarers (Acoustic Harassment Devices, AHDs). Note that pingers generate much less sound source levels than seal scarers. A pinger would deter porpoises some hundred meters (Culik et al., 2001; Carlström et al., 2009) whereas seal scarers make the porpoises move away kilometres from the source (Johnston, 2002; Olesiuk, 2002). Seam Mammal Research Unit at St Andrews University (2007) has made a summary of the potential use of pingers and AHDs in connection with the construction of offshore win power plants and information on the practical application of ramping-up as well as using pinger can be found in the UK guidelines for seismic exploration, underwater explosions and piling (JNCC, 2010b, 2010d, 2010c).

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