Agenda Item 3	Species Action Plan
Information Document 3.1b	Current Knowledge and Gaps on Threats to the Critically Endangered Baltic Proper Harbour Porpoise Population
Action Requested	Take note
Submitted by	HELCOM

UNEP ASCOBANS

Note: Delegates are kindly reminded to bring their own document copies to the meeting, if needed.

Secretariat's Note

Action B8 of the HELCOM Baltic Sea Action Plan (BSAP) includes the task to, by 2022 at the latest, specify knowledge gaps on all threats to the Baltic Proper harbour porpoise population, and by 2023 for the western Baltic population, including by-catch and areas of high by-catch risk, underwater noise, contaminants, and prey depletion.

This document contains a review of the current state of knowledge on the impact of threats to Baltic Proper harbour porpoise as prepared by the BSAP B8 Action leads (Poland, Sweden and the German expert Sven Koschinski).

This document will be discussed at the second informal consultation session of the HELCOM Expert Group on Marine Mammals on 12-14 September 2023.

Current knowledge and knowledge gaps on threats to the Critically Endangered Baltic Proper harbour porpoise population (Action B8 under the Baltic Sea Action Plan)

B8: By 2022 at the latest, specify knowledge gaps on all threats to the Baltic Proper harbour porpoise population, and by 2023 for the western Baltic population, including by-catch and areas of high by-catch risk, underwater noise, contaminants and prey depletion.
Knowledge gaps related to areas of high by-catch risk are to be addressed and by 2028 at the latest additional areas of high by-catch risk for both Baltic Sea populations are to be determined.

1. To strengthen Baltic harbour porpoise population, by 2025 identify possible mitigation measures for threats other than by-catch and implement such measures as they become available.

CRITERIA FOR ACHIEVEMENT:

By 2022 knowledge gaps on all threats to the Baltic Proper harbour porpoise population have been specified and listed. (Joint supporting action);

By 2023 knowledge gaps on all threats to the western Baltic population have been specified and listed. (Joint supporting action);

By 2025 possible mitigation measures are identified and implemented as they become available. (National measure);

By 2028 knowledge gaps related to areas of high by-catch risk are addressed. (Joint supporting action);

By 2028 year, at the latest, additional areas of high by-catch risk for both Baltic Sea populations have been determined. (Joint supporting action).

Cross-reference to actions in other segments: S43, 44, 45, 46, 47, 48, 62

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Abstract
Successful management of a species requires information on threats and areas where conservation actions could best protect a species. For Critically Endangered species and populations, there is often a lack of information available, and management decisions need to use the precautionary principle, relying instead on information from similar species and environments. Here, we review the current state of knowledge on the impact of threats to the Critically Endangered Baltic Proper harbour porpoise (*Phocoena phocoena*), which is a conservation action agreed to by Contracting Parties of the Helsinki Commission (HELCOM), as a part of the updated Baltic Sea Action Plan. We find that there is an urgent need for an updated abundance estimate and new information on the distribution of the population in order to define important areas for the population and prioritised areas for protective measures for all threats. Further, in the whole distribution area activities must be carried out in a way that is not harmful to the population. As bycatch results in direct mortality of individuals, it must be reduced to levels the population can sustain (zero). It is also important to introduce ecosystem-based sustainable management of fisheries in order to ensure prey availability, maintain a functioning food web, and a healthy Baltic Sea. Contaminants and waste inputs to the marine environment should be reduced and at best avoided, as this negatively influences harbour porpoise health, reproduction and survival. Additionally, unprotected underwater explosions should be avoided as these result in direct mortality. There is also a need to regulate the use of existing and emerging noise pervasive sources such as seal scarers and acoustic antifouling devices which could substantially constrict habitat availability and quality. The impact of cumulative pressures on the population is one area where knowledge is still scarce. In general, it is difficult to assess the impact of each threat on the population-level, since in most cases even determining the impact at the individual-level is challenging. In conclusion, despite the gaps, the current knowledge about this population and the impact of threats, as well as the management instruments available for use, are sufficient to move forward and apply effective protection for this population. While there is evidence that bycatch is the main pressure impacting this population, urgent conservation action is needed in all sectors across all anthropogenic activities. Extinction of this population is a choice: decision makers have the fate of this genetically and biologically distinct marine mammal population in their hands.

Introduction

In the Baltic region, there are currently three recognised management units of harbour porpoises *(Phocoena phocoena* (Linnaeus, 1758)): the North Sea population, the Belt Sea (or western Baltic) population, and the Baltic Proper population. The Baltic Proper population is listed as Critically Endangered (CR) by HELCOM and IUCN (HELCOM 2013, Carlström et al., In Review). In the updated Baltic Sea Action Plan (BSAP) (HELCOM, 2021a), a number of conservation actions have been formulated aimed at improving the conservation status of this severely depleted population.

Several genetic and morphometric studies have concluded that Baltic Proper harbour porpoises form a separate population distinct from those living in the Belt Sea and Kattegat, and with a further distinction to the population of the Skagerrak and North Sea (e.g., Huggenberger *et al*., 2002; Wiemann et al., 2010; Galatius et al., 2012; Lah et al., 2016; Celemin et al., 2022). This conclusion is further supported by studies using acoustic monitoring and satellite tracking that describe seasonal migrations and spatial separation during the breeding season from the neighbouring Belt Sea population (Sveegaard et al., 2015; Carlén et al., 2018).

This paper aims to deliver on Action B8 of the BSAP which is: '*By 2022 at the latest, specify knowledge gaps on all threats to the Baltic Proper harbour porpoise population, and by 2023 for the western Baltic population, including by-catch and areas of high by-catch risk, underwater noise, contaminants and prey depletion. Knowledge gaps related to areas of high by-catch risk are to be addressed and by 2028 at the latest additional areas of high by-catch risk for both Baltic Sea populations are to be determined. To strengthen the Baltic harbour porpoise population, by 2025 identify possible mitigation measures for threats other than by-catch and implement such measures as they become available*'. This action has been formulated in the biodiversity segment of the plan with the ecological objectives of '*viable populations of all native species*', '*natural distribution, occurrence and quality of habitats and associated communities*' and a '*functional, healthy and resilient food web*'.

In order to address these knowledge gaps, a thorough review of existing information was completed, including summarising information on what is currently known about population distribution and abundance, both of which are essential data to be able to identify areas of highest risk to porpoises. It is worth noting, that if not otherwise stated, the knowledge and information presented below is based on the current situation for the population. It is possible that many factors, such as reproductive rate for example, previously varied from the current situation.

Abundance and distribution

Review of old newspapers in Sweden and Finland, and summary of available information on historic records of the species in other countries, has confirmed that in the early 1900s, harbour porpoises were regularly observed in the entire Baltic Sea, including the Gulfs of Bothnia, Finland and Riga, and the Baltic Proper (HELCOM, 2022). In the latter half of the 1900s, the population and its range was reduced considerably, due to direct catches and unintentional bycatch (Koschinski, 2001). Currently the species is rarely observed in the Baltic Proper, and even less so in the northern and eastern parts of the Baltic Sea (HELCOM, 2022; Koschinski, 2001).

Although there are no reliable estimates of pre-exploitation population size, historical data from bounty schemes, bycatch records and observations of dead stranded animals show that the species was numerous in the Baltic Proper, and in Bothnian Bay, during the first half of the 1900s (Johansen, 1929; Lönnberg, 1940; Tägström, 1940; Psuty, 2013). Additionally, based on high bycatch numbers, it still appears to have been relatively abundant in an area stretching from Hanö Bight to the waters surrounding Gotland in the early 1960s (Lindroth, 1962). An estimate of the historical population size, potentially using genetics, is urgently needed in order to set indicator thresholds for species assessments of both abundance and bycatch.

Based on acoustic data collected during the SAMBAH project (https://www.sambah.org/), in 2011-2013 the abundance of the Baltic Proper harbour porpoise was estimated to be 491 individuals (CV=0.68; 95% confidence interval = 71-1,105)). This is the only abundance estimate to date (Amundin et al., 2022). Based on a dynamic production model, population abundance and annual bycatch estimates, the population is estimated to have declined by 9% from 2009 to 2017 (NAMMCO & IMR, 2019). However, population-wide trend data are lacking due to a lack of repeated surveys of population abundance. Comparisons of detection rates at a limited number of acoustic monitoring stations in Danish, Polish and Swedish waters suggest potential local increases since 2011-2013 (Swistun et al., 2019; Sveegaard et al., 2020; Owen et al., 2021); however, it remains unknown whether any such increases are a result of changes in population abundance or shifts in distribution. In the summer of 2022, the County Administrative Boards in Gotland and Kalmar in Sweden completed a towed acoustic survey for harbour porpoises over 8 days in the large Natura 2000 area (Hoburgs bank och Midsjöbankarna) in the Baltic Proper as a part of a monitoring program under the areas Management Plan. This area was protected based on the results of the SAMBAH project, as it represented the most important (highest density) region for the population over the summer breeding season. The survey resulted in similar densities of harbour porpoises within the Natura 2000 area as during the SAMBAH survey (Boisseau et al., 2022). As the results of this survey are uncertain given the low number of clicks detected, and comparisons of the two surveys are difficult as the techniques (towed array vs static acoustic recorders) are different, the time frame sampled (8 days vs 2 years) is not the same, and the survey did not cover a large enough proportion of the distributional range, it is not possible to determine what this means for the current status of the population- whether it is increasing or decreasing, or whether its distribution has shifted.. An updated estimate of the size of the population (e.g. through projects such as SAMBAH II that still requires funding), and its current distributional range is urgently needed in order to accurately inform management, and to enable countries to deliver on the BSAP Action 8 to reduce "*knowledge gaps related to areas of high by-catch risk*", *and "identify possible mitigation measures for threats other than by-catch."*

Seasonal Movement Patterns

Based on the results of the SAMBAH study, the Baltic Proper harbour porpoise population is believed to have a seasonal movement pattern (Carlén et al., 2018). The results of SAMBAH revealed that during May-October, Baltic Proper harbour porpoises aggregate on and around the offshore banks south of Gotland and east of Öland, and most animals are believed to be east of the island Bornholm in the southern Baltic Sea. During November-April, detections were more spread out along the coasts and archipelagos of the Baltic Proper (Carlén et al., 2018). The results of national monitoring programs in some countries, and other research projects, have also indicated seasonal presence (Gallus et al., 2012; Swistun et al., 2019; Sveegaard et al., 2020; Owen et al., 2021). For example, increased presence of harbour porpoises in the southern Baltic Sea during winter has been associated with cold air temperatures (Gallus et al., 2012) and severe ice conditions (Johansen, 1929; Tägström, 1940; Lönnberg, 1940; Wölk, 1969).

It is not known how far west Baltic Proper harbour porpoises disperse in winter. Modelling of seasonal detection rates at acoustic monitoring stations in German waters revealed two peaks in detection rates, with the peak in winter assumed to correspond with an influx of Baltic Proper animals avoiding a freezing Baltic Sea, at a time when the neighbouring Belt Sea population is thought to congregate even further west (Gallus et al., 2012). This indicates a winter distribution of the Baltic Proper population extending at least as far west as to the offshore waters northeast of Rügen (Gallus et al., 2012). This delimitation of population distributions in the region was also confirmed by genetic analyses of genome-wide single nucleotide polymorphisms (SNPs), that showed genetic distinction of individuals sampled on either side of this area (Lah et al., 2016; Tiedemann, 2017). Additionally, a combination of satellite tag data from the neighbouring Belt Sea population and acoustic data have indicated a possible management border at 13.5 °E (Sveegaard et al., 2015). A tentative management border during November-April has been proposed at 13°E (ICES, 2020b). Between May and October, there is a separation between the Belt Sea population and the Baltic Proper harbour porpoise populations from the island of Hanö (Sweden) to Jarosławiec near Słupsk (Poland). To the north, a general pattern shows that during the 21st century, porpoises have primarily been sighted south of a line drawn approximately between latitude 60.5°N at the Swedish east coast and latitude 61°N at the Finnish west coast, and ICES WGMME therefore suggested this as the current northern management border of the Baltic Proper harbour porpoise population (ICES 2020b).

Life history

There is no specific information on life history parameters of the Baltic Proper population. When the population was still abundant, ageing technologies were not available and there was not a scientific interest in this species. Most studies did not distinguish between populations as putative population boundaries were not defined until recently. Additionally, due to the extremely low population size of the Baltic Proper population, very few specimens have been available (as stranded or bycaught animals) in the recent few decades, most of which have been too far decomposed for analysis of life history data. Thus, the information provided here is derived mostly from the neighbouring Belt Sea population, which is very similar from a biological perspective. However, the Belt Sea population is likely under less pressure (see below) and thus there may be some differences in life history parameters. The same applies when using data from older studies.

The age at sexual maturity has been calculated as 3.11 years for males and 3.5 years for females using Danish strandings data (Clausen & Andersen, 1988; Sørensen & Kinze, 1994). More recently, Kesselring et al. (2017) calculated the onset of sexual maturity in female harbour porpoises to an age of 4.95 (± 0.6) years with no significant differences detected between animals found stranded along the German North Sea and Belt Sea coasts (whether any of these were from the Baltic Proper or Belt Sea population is unknown). Based on this age of sexual maturity, and on the age distribution of sampled individuals, it was calculated that only 27.4% of female porpoises participate in reproduction (Kesselring et al., 2018). Additionally, the average age at death from German strandings differed significantly between populations with 5.70 (± 0.27) years for North Sea animals and 3.67 (± 0.30) years for Baltic Sea animals (Kesselring et al., 2017). In a long-lived, slow reproducing animal species such as the harbour porpoise, adult survival is of critical importance (Cervin et al., 2020). With an average of 45 to 48% of females (Clausen & Andersen, 1988; Sørensen & Kinze, 1994) and using the current Baltic Proper population estimate of 491 individuals (Amundin et al., 2022) the number of reproductive females could be as low as 60 to 70. Based on a Leslie matrix model available for porpoises in the Belt Sea, Kattegat, Skagerak and North Sea, Carlström et al. (In review) calculated a slightly higher value of 216 mature individuals including females and males. A large proportion of females reproduce in consecutive years (Sørensen & Kinze, 1994). Performing a population viability analysis that relied largely on demographic and life history information from the neighbouring Belt Sea population and using a reproductive rate of 0.73, in the baseline scenario with no anthropogenic threats present, the Baltic Proper population was found to be viable, with no risk of extinction and an estimated population growth rate of of 2.3% (Cervin et al., 2020).

Female harbour porpoises give birth to one calf after a gestation period of ten to eleven months (Börjesson & Read, 2003; Lockyer & Kinze, 2003; Hasselmeier et al., 2004; ASCOBANS, 2016). In German Baltic Sea waters, most births are recorded between June and August, however, differences between populations are possible (Börjesson & Read, 2003, Hasselmeier et al., 2004). Mating takes place shortly after birth. In the area with the highest detection rates for the Baltic Proper population around the Midsea Banks, bimodal peaks in detection rates have regularly been observed (Owen et al., 2021). These peaks have been hypothesised to be potential insight into the breeding behaviour of the population, with the first peak (May) potentially coinciding with calving, and the latter (September/October) with the arrival of males; although this is late compared to neighbouring populations (Owen et al., 2021). Lactation is for about eight to nine months (Sørensen & Kinze, 1994). Juveniles begin to forage for their own food from the age of five to six months. Females and offspring usually remain together until the calf begins to forage independently at around 11 months of age (Teilman et al., 2007) and/or until the birth of the next offspring (Schulze, 1996).

The main factor limiting knowledge on the life history of the population is a lack of samples available in recent times. Given the small population size, it is unlikely that a large increase in the number of specimens available for analysis of life history parameters will become accessible in the near future.

Energetic requirements

The harbour porpoise is one of the smallest cetacean species. Relative to their body mass, harbour porpoises need large amounts of prey each day to sustain themselves, and have been shown to forage almost continuously (Wisniewska et al., 2016). Porpoises are quite intolerable to lack of food and can quickly die of starvation (Kanwisher & Sundnes, 1965; Yasui & Gaskin, 1986; Kastelein et al., 1997; Koopman et al., 2002; Bjørge, 2003; Lockyer et al., 2003). Due to their small size, and thus a relatively large body surface to area ratio, they need to compensate for thermal energy loss in their cold water high-latitude habitats to avoid hypothermia. As an adaptation, the field metabolic rate (FMR) in this species is twice as high as that of a similar-sized terrestrial mammal. It has been shown that the FMR is stable over seasonally fluctuating water temperatures and heat loss is managed via cyclical fluctuations in energy intake serving to build up the thermal insulation layer (blubber) for the cold season. This reduces the energetic cost of thermoregulation. Energy intake needs to be increased in the autumn to build up the blubber layer. Further, females have a higher energy intake towards the end of pregnancy (March to July) and need a considerable amount of their yearly energy intake for reproduction (Rojano-Doñate et al., 2018). From this it can be concluded that limitations in energy intake could compromise reproductive success and thus have population consequences.

Energy intake influences body condition, which has been shown to vary with age, sex, size, season and life stage. Based on studies from the North Sea, diet varied depending on the nutritional condition (or body condition) of the individual porpoises. In animals of poor condition most empty stomachs and highest proportion of nutrient poor fish was found (Leopold & Meesters, 2015). Besides thermal insulation, the blubber acts as energy storage and its amount also influences buoyancy. It has been shown in seals that deviations from neutral buoyancy increases locomotion costs during foraging (Adachi et al., 2014). Thus, a lean animal not only has a deficit in stored energy but may also require more energy for diving. Under such limiting conditions, it would also be more difficult to compensate for a loss of energy that has already occurred (Leopold & Meesters, 2015). It can be concluded that with respect to maintaining their energy budget, prey quantity (number, size) and prey quality (energy content per prey item) are important variables (Leopold, 2015). Indeed, the energy density of the diet and body condition of the individual has been shown to affect the reproductive success of female harbour porpoises (IJsseldijk et al., 2021). This indicates that reduced quality and quantity of cod, herring and sprat, which are thought to be three of the main prey species for harbour porpoises in the Baltic Sea (see *Prey composition* section below), may impede the recovery of the Baltic Proper harbour porpoise.

Prey composition

In the North Sea, the stomach contents of harbour porpoises have revealed the presence of both benthic and pelagic prey, with animals feeding in a variety of micro-habitats (Leopold 2015). In individual Belt Sea harbour porpoises equipped with data loggers (D-tags), feeding on gobies at the bottom has been demonstrated (Wisniewska et al., 2016). Prey analyses based on stomach contents often show mixed results because they rarely account for individual differences, and only represent the hard parts of the most recent items ingested. It is unknown which foraging methods Baltic Proper harbour porpoises rely on. However, the shape of the skull of porpoises in Baltic Proper and Belt Sea populations is different, which is believed to indicate a morphological adaptation to demersal and benthic prey in the shallow Belt Sea waters, and pelagic prey in the Baltic Proper (Galatius et al., 2012).

In the Baltic Sea, prey composition varies between areas, with the prey of harbour porpoises likely including pelagic schooling fish as well as demersal and benthic species (Aarefjord et al., 1995; Santos & Pierce, 2003; Sveegaard et al., 2012; Andreasen et al., 2017). Most dietary studies are from the Western Baltic, Belt Sea and Kattegat area where age, sex, and seasonal differences were found in the diet of individuals (Sveegaard et al., 2012; Andreasen et al., 2017). The size of the harbour porpoise prey in the western Baltic Sea (data from 1980-2011) includes a wide range of lengths from approximately 2.5 to 63 cm, with one- to two-year-old cod and medium-sized herring being the most common prey. Gobies (Gobiidae spp.) were also frequently consumed, especially by juvenile porpoises in which they accounted for 25% of prey mass (Andreasen et al., 2017). Data from German waters of Mecklenburg-Vorpommern (31 stomachs, 2013-2019) suggest that more than 90% of the diet, in terms of biomass, was small-size cod (mostly below 30 cm), followed by whiting (Klemens, 2019). It should be noted that the porpoises in these studies have not been genetically assigned to a population. Based on the sampling locations, it is most likely that the majority of those analysed by Andreasen et al. (2017) and Klemens (2019) were animals from the Belt Sea population, and only a small proportion (if any) were from the Baltic Proper population.

The only dietary study available that is likely animals from the Baltic Proper is on individuals bycaught in the salmon driftnet fishery in 1960-1961 from Hanö Bight to the waters around Gotland. Based on stomach content analysis, the most common prey items of animals were sprat (*Sprattus sprattus*), transparent goby (*Aphia minuta*), herring (*Clupea harengus*) and cod (*Gadus morhua*) (Lindroth, 1962). It is unknown whether this still reflects the current diet of the Baltic Proper population.

Sensory capabilities

Like all odontocetes, harbour porpoises use echolocation, to gain information about the environment around them for communication, foraging, and navigation. They produce narrow-band high-frequency (NBHF) clicks, with a peak frequency around 130 kHz (Au et al., 1999, Macaulay et al., 2020; Villadsgaard et al., 2007) and listen for the echo. Echolocation can provide animals with information on the location, size, and acoustic density of nearby items, such as prey, but also allows them to spatially orientate (Verfuß et al., 2005). Harbour porpoises have a typical mammalian u-shaped audiogram with the most sensitive hearing (defined as within 10 dB of maximum sensitivity) from 16 to 140 kHz (Kastelein et al., 2017), sharply decreasing above, and with reasonable hearing at frequencies down to about 1 kHz. When foraging, “buzzes” are produced where the interclick-interval is greatly reduced as the porpoise approaches prey. Similar click trains are also used in social interactions, particularly between mothers and calves (Sørensen et al., 2018). Therefore, harbour porpoises rely on their sound production and hearing to communicate with conspecifics, avoid threats, and to find prey.

Harbour porpoises have one eye on either side of their head, providing them with a 120-130 degree field of view. Based on eye morphology, harbour porpoises are assumed to have good vision similar to that of other cetaceans and humans (Kastelein et al., 1990). It has been shown that vision likely aids echolocation and fine-scale foraging, allowing for better control of trajectory during an approach towards an object (Maezawa et al., 2019). Additionally, visual deprivation has recently been shown to increase the dive response of harbour porpoises by reducing the heart rate by half and thus conserving oxygen and allowing for longer dive times (Bakkeren et al., 2023). Therefore, vision may play an important role in how harbour porpoises respond to threats, and help to improve foraging efficiency.

Despite the identification of putative chemoreceptive cells in the nasal cavity of harbour porpoises (Behrmann et al., 1989), toothed whales such as the harbour porpoise are thought to have lost their olfactory system during their evolution from a terrestrial to aquatic environment (review by Kremers et al., 2016). Similarly, odontocetes also typically show a reduced gustatory system, which is then further reduced during development from juvenile to adult (Komatsu & Yamasaki, 1980), with animals likely only able to taste salt (Feng et al., 2014; Kishida et al., 2015). Despite these apparent lack of chemosensory systems, several studies have shown that odontocetes react to chemical stimuli, such as prey-related chemicals (Kremers et al., 2016; Bouchard et al., 2022). However, whether or to what extent these senses are used for foraging or threat avoidance remains unknown.

Conservation

All harbour porpoise populations in the European Union region, are protected under the EU Habitats Directive (HD), with the species listed in Annex IV, which legally requires Member States to establish a system of strict protection. Member States must report (Article 17) on population status, range, habitat, and future prospects (in relation to Favourable Reference Values) every six years. For three consecutive assessment periods under Article 17 reporting of the HD, all relevant EU Member State (MS) assessments and the EU biogeographical assessment have classified the conservation status of the Baltic Proper Harbour porpoise as "Unfavourable-Bad" (U2). The species is also listed in Annex II of the HD, requiring the designation of special areas of conservation (SACs) in a coherent Natura 2000 network. The Swedish SAC *Hoburgs bank and Midsea Bank* (SE0330308) covers an area of year-round importance for the population, likely including parts of an important breeding ground (Carlén et al., 2018). Protected areas of seasonal importance during the time of greater dispersal outside of the breeding season are the SACs *Sydvästskånes utsjövatten* (SE0430187), *Adler Grund and Rønne Bank* (DK00VA261), *Adlergrund* (DE1251301), *Westliche Rönnebank* (DE1249301), *Pommersche Bucht mit Oderbank* (DE1652301), *Greifswalder Boddenrandschwelle und Teile der Pommerschen Bucht* (DE1749302), *Ostoja na Zatoce Pomorskiej* (PLH990002), *Wolin i Uznam* (PLH320019) and *Ostoja Słowińska* (PLH220023) as well as the special protection area (SPA) *Pommersche Bucht* (DE1552401), designated under the Birds Directive, as part of a marine nature reserve under German legislation.

Until recently, for most of the sites mentioned above, no specific measures to protect harbour porpoises were in place. Management plans should include definitions of specific conservation objectives and timeframes, identification of pressures and threats, identification of necessary and effective measures, as well as provisions for monitoring of the species and the impact of any implemented measures. Unfortunately, there is a large variability in the quality and level of detail in management or conservation plans between the sites, and many of the objectives are not SMART (Specific, Measurable, Achievable, Relevant, and Time-Bound) objectives as required by the EU to effectively manage SACs.

The harbour porpoise is further protected under the Marine Strategy Framework Directive (MSFD) which aims to maintain biological diversity under Descriptor 1 (D1). Under this Descriptor, Member States are required to establish thresholds for indicators for the species achieving Good Environmental Status (GES) for five criteria (mortality rate D1C1, population abundance D1C2, Population demographics D1C3, species distributional range and pattern D1C4, and habitat for the species D1C5). Member States are also required to monitor the harbour porpoise, in order to provide data to assess each of these indicators and detect early changes in species status. The thresholds for each of the required indicators are always developed and agreed regionally, within conventions such as the Helsinki Commission (HELCOM) responsible for preparing Holistic Assessments on the state of the

Baltic Sea (HOLAS). During the most recent assessment (HOLAS III), the Baltic Proper population did not achieve GES for abundance, distribution or bycatch (HELCOM, 2023c, 2023d, 2023a), the only three indicators assessed for this population.

The EU Common Fisheries Policy (1380/2013) also provides some level of legal protection for harbour porpoises. It should ensure that the impact of fishing on the marine environment is minimised, reducing bycatch of protected species (such as harbour porpoises) and making sustainable use of resources (protecting harbour porpoise prey species).

In 2020, the EU Commission issued an infringement notice to Sweden for not sufficiently implementing the measures required under Article 6 (2) and (4) of the HD and the Common Fisheries Policy. In 2022, the Commission Delegated Regulation (EU) 2022/303 entered into force containing i.a. provisions for year-round or seasonal closures for static net fisheries or the use of acoustic deterrent devices (so-called 'pingers') in these fishing métiers within the above-mentioned protected areas. In addition, in 2023, the EU Commission released a new Action Plan for "Protecting and restoring marine ecosystems for sustainable and resilient fisheries", where the Commission calls on Member States to "adopt national measures or submit joint recommendations to the Commission to minimise by-catch (or reduce it to the level that enables the full recovery of the populations) of harbour porpoise in the Baltic Proper" by the end of 2023. It is intended that this new action plan will result in better implementation of existing policy, and the creation of new joint recommendations, that will result in stronger protection for harbour porpoises. Except for one small area in Polish waters (part of the Middle bank), currently, no conservation measures have been agreed upon outside protected areas. The wide-spread use of pingers has been proposed as a useful measure but some militaries claim that this would compromise national security. During the ASCOBANS JG 17 (2021) meeting few countries informed that according to their militaries, pingers are a national security problem and suggested putting forward options for the conservation of harbour porpoises other than the widespread use of pingers.

The conservation of harbour porpoises is also the centre of the regionally agreed recommendations such as the ASCOBANS Recovery Plan for Baltic Harbour Porpoises (Jastarnia Plan), HELCOM Recommendation 17/2, and HELCOM Recommendation 37/2.

Threats and data gaps

The harbour porpoise is a highly mobile species that uses specific areas in different seasons, which makes it highly susceptible to a large range of threats. Identification and localisation of areas of highest risk from threats for the species would assist managers and decision makers to properly target conservation measures. Several major threats to the Baltic Proper harbour porpoise population have been identified such as bycatch, prey depletion, underwater noise (both continuous and impulsive), waste, and contaminants (ASCOBANS, 2016, ICES, 2019). However, several data gaps exist both in terms of the location, intensity and frequency of threats, as well as updated information on the density and distribution of harbour porpoises. This prevents understanding how much each threat can affect the Baltic Proper harbour porpoise population and contributes to increased mortality rates. Due to the low number of reproducing females, the associated low genetic diversity, and the multitude of threats and pressures, the risk of extinction of this population is considered very high (as demonstrated by its Critically Endangered status). As a result, the introduction of effective protection measures should not be postponed until all of these data gaps are filled, instead managers should make their decisions based on the best available science, and additional measures should be implemented (and enforced) quickly.

Bycatch rate and areas of high bycatch risk

Historically, harbour porpoises were intentionally hunted, and unintentionally bycaught in fishing gear, throughout the distribution range of the Baltic Proper population (HELCOM, 2022). Historic catch and bycatch data are incomplete and can be considered as minimum numbers. Data from Polish fisheries reports show that in the area around the Hel Peninsula and Puck Bay, at least 676 harbour porpoises were unintentionally caught from 1922 to 1933. During 1934-1935, the minimum number was about 400, and the total number was roughly estimated to be 800 (Psuty, 2013). From November 1960 to October 1961, at least 50 harbour porpoises were bycaught in waters from Hanö Bight to Gotland where a driftnet fishery for salmon took place (Lindroth, 1962).

Today, similar to many other small cetacean species (Brownell et a. 2019), bycatch in fishing gear remains the most significant threat to the Baltic Proper harbour porpoise, and the threat level is classified as high (ICES, 2019). The majority (at least 97%) of the bycatch records in the Baltic Proper have been reported to occur in static nets, such as gillnets, entangling nets, or trammel nets (Berggren, 1994; Skóra and Kuklik, 2003; EC-DGMARE, 2014). The most common types of statics nets in which bycatch has occurred in the Baltic Proper are semi-driftnets (anchored at one end) set for salmonids, and bottom-set gill nets set for cod. In addition to static nets, harbour porpoises are also bycaught in trawl fisheries (ICES, 2020a) but in much lower numbers than static nets. The number of Baltic Proper harbour porpoises bycaught in 2017 has been estimated to be 7 individuals, compared to the annual Potential Biological Removal (PBR) limit of only 0.7 individuals (NAMMCO & IMR, 2019). Thus, the bycatch indicator threshold agreed by all Contracting Parties of HELCOM for the Baltic Proper harbour porpoise population is set to zero. As bycatch still occurs in the Baltic Proper, and this threshold of zero bycatch was exceeded, GES was not achieved in the most recent HOLAS III assessment (HELCOM, 2023a). PBR is estimated via a simulation method to predict the long-term population development based on a simple population model under scenarios of additional potential mortality (Wade 1998). If the number of bycaught animals exceeds the PBR limit, as regularly occurs for the Proper Baltic harbour porpoise, the population is condemned to extinction. The current bycatch level is a serious threat to the population, especially due to the low numbers of individuals participating in reproduction.

The number of bycaught animals, with PBR regularly exceeded, and the deficiency of protection measures in large parts of the distribution area is a significant threat for the population, which requires urgent attention and changes. In 2020, HELCOM adopted a revised recommendation on protection of harbour porpoises in the Baltic Sea area (HELCOM, 2020a). Consequently, it recommends giving highest priority to avoiding bycatch. The update on the HELCOM Baltic Sea Action Plan includes actions to develop, implement, promote, and evaluate bycatch mitigation measures with the aim to reach bycatch rates close to zero (HELCOM, 2021a). The new EU Action plan (COM(2023) 102 final), also requires Member States to reduce bycatch to the level that enables the full recovery of the Baltic Proper population by the end of 2023- which is reducing bycatch to zero.

Knowledge gaps on bycatch

The major data gaps on bycatch of harbour porpoises can be divided into three elements:

1. Lack of bycatch monitoring and reporting preventing accurate estimates of bycatch rate,

2. Imprecise and incomplete reporting of data on fishing effort (especially at a relevant spatiotemporal scale and small vessels below 12 m), which prevents calculations of total bycatch and,
3. Updated information on the distribution and density of harbour porpoises, preventing identification of the areas of highest overlap with fisheries where there is the largest risk for the population.

These knowledge gaps are also listed in the *HELCOM Roadmap on fisheries data* (HELCOM, 2020b).

ICES collects information on bycatch of protected species from various monitoring programmes under EU legislation (mainly EU Technical Regulation 2019/1241) and scientific monitoring programs (currently mainly under the EU Data Collection Framework, DCF). ICES Advice (2017) states that bycatch observations "are insufficient to enable any assessment of the overall impact of EU fisheries on [marine mammals]". Since then it has been repeatedly reiterated (e.g., ICES Advice, 2022) but not yet acted upon. Sampling under the current DCF can in principle contribute to the assessment of bycatch of Protected, Endangered and Threatened Species (PETS), but is largely insufficient on its own as currently implemented by Member States. DCF sampling focuses on discards and mainly on fishing gears (e.g. towed gears) which are not a major concern for porpoise bycatch. Since current national DCF monitoring programmes only to a very limited extent target marine mammal bycatch, coverage is very low in static gear which is the major problem for harbour porpoises (ICES, 2022a). In addition, EU Regulation 2019/1241 obliges countries to monitor bycatch of cetaceans only on fishing vessels of overall length of 15 m or more. Assessments carried out by WGBYC (2018) demonstrated that bottom trawling is generally relatively oversampled with respect to monitoring of protected species bycatch, and passive gear types (e.g. fyke nets (FYK), trammel nets (GTR), set gillnets (GNS), set longlines (LLS), pots and traps (FPO)) are undersampled in the Baltic Sea (ICES, 2018, 2019). Among the undersampled gears are those which represent the highest bycatch risk for the Baltic Proper harbour porpoise population. Therefore, the lack of appropriate bycatch monitoring programs despite legislation requiring monitoring of bycatch in all relevant fisheries, prevents an assessment of the extent of bycatch in this Critically Endangered population.

Further, data on fishing effort are necessary to estimate total bycatch. To calculate total bycatch, at a minimum, an estimate of the bycatch rate expressed as the number of animals bycaught per unit of fishing effort (BPUE) is multiplied by the total fishing effort of the relevant fleet in the area. The EU Control Regulation specifies what type of fishing vessel tracking system is mandatory for various fleet segments and how fishing effort shall be reported. Vessels ≥ 12 m in length must have a Vessel Monitoring System (VMS) and an electronic logbook. Vessels > 10 m in length (> 8 m in the Baltic Sea when they have a cod quota) must have a logbook. Smaller vessels are not required to carry a logbook or fill out a landing declaration. For smaller vessels, estimates of effort are derived by individual Member States in a variety of ways such as monthly journals (Germany), coastal logbooks (Sweden), sales records (Denmark) or extrapolated sampling data, which do not provide data on fishing effort precise enough for estimation of total bycatch numbers of harbour porpoise or other protected species of marine mammals or birds. This lack of information on fishing effort also prevents locating high risk bycatch areas with sufficient confidence. Additionally, small vessels are the fleet segment which by far dominates fishing with static nets and thus need to be the main focus of any harbour porpoise bycatch monitoring programme. However, currently the effort data available from this segment has the lowest quality of all.

To increase the precision of extrapolations (from bycatch rate per effort to total bycatch) the preferred metric would be total "soak time of nets in kilometre hours" for the observed effort. Also, the current obligations for the recording rate of VMS give a limited view of where and when the fisheries take place and with what effort. Furthermore, small vessels (below 12 m) are not obliged to use VMS equipment. These currently only report effort at the spatial resolution of Baltic Squares (1/9 of the basic Baltic Sea ICES statistical rectangle). The positioning of fishing effort is especially important in relation to a hotspot approach to bycatch mitigation measures, described below. An estimate for fishing effort for small vessels without a tracking system, can be reported after landing, meaning it is hard to accurately locate areas of overlap between harbour porpoise presence and fisheries. Additionally, much of the data currently collected on fishing effort in logbooks requires substantial cleaning for clerical errors by scientists attempting to utilise the data (Kindt-Larsen et al., 2023). Such inaccuracies in the data collected on fishing effort reduce the accuracy of the management recommendations that come out of analyses using these data, with the responsibility of improving data quality on the authority responsible for fishing effort data collection. However, the work on the new EU Control Regulation is ongoing and the Commission intended to improve reported data on fishing effort for vessels below 12 m. The proposal by the Commission included an enhanced obligation of having VMS or other tracking systems in place, even on small vessels. This would enable improved data collection on the spatiotemporal distribution of passive fisheries, through improved reporting of fishing effort via logbooks. Above proposals were finally included into the new EU Control Regulation which is planned for adoption during the Council meeting in October-November 2023.

There is not enough data on population abundance and trends to know how current bycatch levels are impacting on the population. Based on demographic and life history data from the Belt Sea population, in the baseline case where all threats are removed, likely reflecting the case that widespread bycatch mitigation measures were in place, the Baltic Proper population has been estimated to be viable with no risk of extinction (Cervin et al., 2020). However, taking into account that 1) the Baltic Proper harbour porpoise population is severely depleted (e.g., NAMMCO & IMR, 2019), 2) life-history information gained from animals in German Baltic waters under similar pressures indicates that only ~27% of females are living long enough to produce a calf (Kesselring et al., 2017, 2018), 3) Female porpoises in the Baltic Sea waters have a shorter average lifespan (3.7 years) than in the North Sea (5.7 years) (Kesselring et al., 2017, 2018), and 4) PBR model estimates that any level of bycatch above zero will prevent the population reaching conservation targets, it is very likely that the Baltic Proper harbour porpoise is not resilient to current bycatch levels. With the current level of bycatch (estimated 7 animals per year), a population viability analysis demonstrated that the population will collapse (to <50 animals, with a probability 0.4-1.0) over the next century (Cervin et al., 2020), likely resulting in the extinction of this protected marine mammal.

Areas of high bycatch risk for the Baltic Proper population which could be focus areas for mitigation measures are also largely unknown. The HELCOM ACTION project (HELCOM, 2021b) provided initial data on high bycatch risk areas in parts of the Baltic Sea on the basis of spatiotemporal data on relative density of harbour porpoise (taken from the now outdated SAMBAH data from 2011-2013) and available distribution data of relevant fishing effort , and thereby identified areas where monitoring of bycatch needs to be intensified, or where preventive measures could be focused in order to have the best effect. However, there is a strong limitation in this method due to the limited availability of fishing effort data described above, and the need for more recent data on abundance and distribution of the Baltic Proper harbour porpoise population.

Prey depletion

Changes in prey fish stocks

Taking into account the high metabolic rate (see chapter energetic requirements), harbour porpoises are also sensitive to the depletion of high quality prey (Leopold & Meesters, 2015). In recent decades, considerable abiotic and biotic changes have taken place in the Baltic Sea (Reusch et al., 2018). Besides the eutrophication related expansion of anoxic areas in the Baltic Proper, overexploitation of key fish species in combination with climate change have caused ecosystem regime shifts in the Central Baltic Sea (Casini et al., 2008, 2012; Möllmann et al., 2009; Eriksson et al., 2011) which has implications for prey availability and diet composition.

By mainly targeting larger predatory fish for decades, commercial **fisheries** have led to the decrease cod (*Gadus morhua*), and indirectly, a rapid increase in the densities of some of their prey consisting of smaller mesopredators such as sprat (*Sprattus sprattus*), stickleback (*Gasterosteus aculeatus*) and gobies (Eriksson et al., 2011). These in turn feed on eggs and larvae of larger predatory fish during certain live stages. Such ecosystem-scale changes are further stabilised by continuing fisheries-induced feedback loops in the food web (Möllmann et al., 2009). Since the 1970s, most stocks of cod and herring (*Clupea harengus*) in ICES subdivisions 25 to 32 in the Baltic Sea have decreased (ICES, 2022b, c) mainly driven by fisheries (Möllmann et al, 2009, Bastardie et al., 2021). For the Eastern Baltic cod, spawning stock biomass is presently close to the lowest level observed since the 1950s (ICES, 2021). The stock shows a regime shift from a high reproductive potential before the 1980s to low potential since then (Voss and Quaas, 2022). Herring represents a low-trophic level key species in the Baltic Sea food web because it transfers nutrients from zooplankton to higher trophic levels consisting of predatory fish and mammals (Scotti et al., 2022). Their decline can lead to trophic cascades and contribute to a recent increase in three-spined sticklebacks. Sticklebacks compete with herring for zooplankton in offshore areas and feed on herring eggs in coastal areas which in turn can negatively affect recruitment success (Olsson et al., 2019; ICES, 2022d). The energy content of sprat can be very high (Pedersen & Hislop, 2005) and thus can be considered a high quality prey. Their spawning stock biomass has fluctuated considerably due to a combination of top-down and bottom-up effects such as fishing pressure, recruitment, and natural mortality due to predator-prey relationships, especially with cod (ICES, 2022e; Bastardie et al., 2021). Sprat spawning stock biomass fluctuations still appear to be within safe biological limits in the Baltic Sea, according to biological benchmarks used in fisheries management (ICES 2022e). Future predictions concerning changing hydrographic conditions of the Baltic Sea, and as a result, changing trophic cascades suggest that several additional elements may be necessary for the proper assessment of maximum sustainable yield (MSY) for each stock, such as pressures on a stock caused by climate change and eutrophication.

In addition to fishing pressure and species interactions, climate change and eutrophication are also predicted to be drivers of biomass, distribution, and condition of likely prey species of the Baltic Proper harbour porpoise (e.g. Bartolino et al., 2014; Bossier et al., 2021; Voss and Quaas, 2022). **Climate change** is expected to have an increasing negative impact in the future. Climate change can affect fish stocks directly (as warming decreases oxygen levels), or indirectly due to reduced recruitment and growth (e.g., by effects on the availability of food for larvae), or can impact the distributional range of species or their prey e.g., by changes in water temperature, salinity or ecological interactions (e.g., competition, also with invasive species) (MacKenzie et al., 2007). In addition, habitat loss and habitat degradation caused by **eutrophication,** in combination with the hydro-geographic situation of the Baltic Sea, lead to hypoxic and anoxic conditions. Such conditions can impact prey stocks and further reduce the potential for recovery of the Baltic Proper harbour porpoise. The immense increase in hypoxic and anoxic areas from 1900 to 2010 is shown in Fig. 1. In recent times, hypoxia development in the Baltic Sea has shown two regimes, and there is indication of a third. The first regime was characterised by a threefold increase of the hypoxic area between 1993 and 1999, and the second by a stationary process until 2017 (Kõuts et al., 2021). Recently, anoxia has reached a new stage in 2018-2019, with anoxic conditions regularly occurring in previously hypoxic areas in the southern basins of the Baltic Proper and even in coastal areas (Reusch et al., 2018; Hansson et al., 2019). As a consequence, the most important spawning area for Eastern Baltic cod – the Bornholm Basin – is only a fraction of its historical size. For similar reasons, the Gdansk Basin and the Gotland Basin have also had a very limited contribution to cod recruitment since the 1990s (Köster et al., 2017). Decreasing feeding levels of small cod since 2005 indicate severe growth limitation and increased starvation-related cod mortality which are likely the results of a decrease in benthic prey abundance due to increased hypoxic areas (Neuenfeldt et al., 2020).

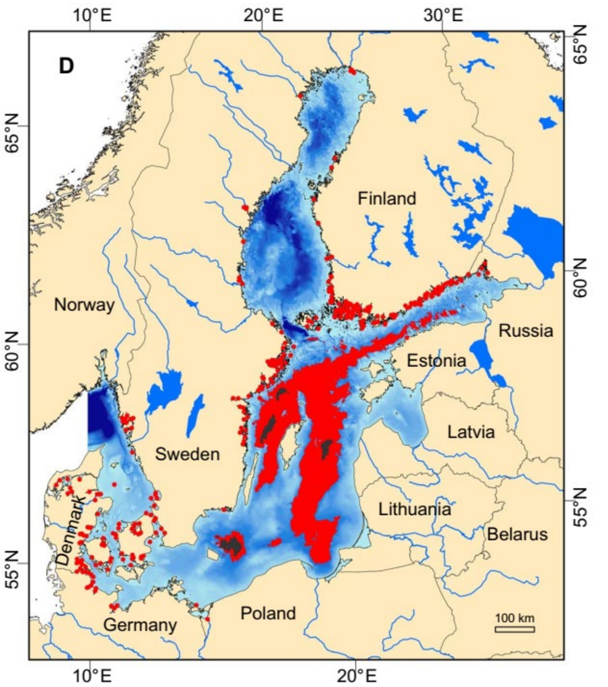

Fig. 1 Expansion of hypoxic zones in the Baltic Sea during 115 years of monitoring. Black shading shows the situation for the period 1900–1910, whereas red shading indicates the period 2001–2010. Coastal hypoxia is depicted by red dots (taken from: Reusch et al., 2018).

A gradual but continued **deterioration of fish habitat,** especially in shallow coastal areas and estuaries is of particular concern for stocks of potential prey. Reasons for this could be coastal hypoxia, cascading effects of removal of predatory fish on plankton composition with increased blooms of mat-forming filamentous algae and cyanobacteria (Casini et al., 2008; Eriksson et al., 2011, Reusch et al., 2018). Further, development and construction of infrastructure projects such as wind farms, pipelines or harbours, fish farms as well as bottom trawling, leading to physical alteration of fish habitats and often coincide with important areas for recruitment (Seitz et al., 2014), which can also have implications for prey availability for porpoises.

Knowledge gaps related to prey depletion

As prey depletion does not lead to the direct loss of individuals but affects their long-term viability, the threat to the Baltic Proper harbour porpoise is less obvious compared to bycatch. Its importance is not sufficiently understood because measuring prey depletion requires current and baseline information, on porpoise presence as well as prey preferences and prey availability (both in terms of quantity and quality), which is not available.

As shown above, various pressures have distorted the food web in the Baltic Proper and likely affected the availability and quality of harbour porpoise prey, possibly reducing the quality of their habitat and increasing their vulnerability to disturbance. To some extent, the depletion of one prey species can be compensated for by a shift to another if available in a sufficient quality and quantity. However, it is also known that a reduced availability of high quality prey and shift to food of a lower energetic value can severely affect the individual viability (Leopold 2015). Findings from the Belt Sea population indicate that depletion of cod and herring as important prey, and a shift to small gobies, places individuals at their energetic limit (Wisniewska et al., 2016; Rojano-Doñate et al., 2018), which if wide-spread across many individuals, would have population-level consequences.

The knowledge on Baltic Proper harbour porpoise diet is based on only one dietary study that is 60 years old (Lindroth, 1962). However, to some extent information from Belt Sea and North Sea populations can be used as a reference. The current diet of Baltic Proper harbour porpoises is unknown with respect to prey species and size as well as seasonal, interannual, or individual variation. Whether or not dietary shifts are possible to compensate for resource limitation also needs to be analysed. This can include modelling energetic intake to help understand when limitations in prey availability begins to impact individuals and the population. Such models should also consider the low density of this severely depleted population, and the variety of cumulative pressures impacting the energetics and reproduction of the Baltic Proper harbour porpoise. Possible energetic consequences of distortions in the food web for Baltic Proper harbour porpoises have not been investigated yet. In particular, it is unknown to what extent mesopredators such as stickleback, sprat, and gobies contribute to their diet and how the energetic requirements are met and the body condition is affected by the current diet. This can have repercussions for the recovery potential of the population.

Another major issue with understanding the potential impact of prey depletion is insufficient monitoring of the changes in the distribution and quality of potential prey species (not just commercially caught species) at spatial and temporal scales that would enable comparisons to harbour porpoise distribution and density. This would enable determining where the Baltic Proper population of harbour porpoises is distributed in relation to prey, and to see how this shifts over time. The areas of largest overlap of porpoise distribution and distribution of high quality prey would indicate important feeding areas in which protection measures might be most effective with respect to energetics of individual animals.

The main drivers of prey depletion have been identified as fisheries, climate change, eutrophication and habitat deterioration. These drivers can be additive and interlinked. The contribution of each driver and their interaction is not completely understood. Generally, there is deficiency of information and data on how habitat loss and habitat degradation for prey species caused by eutrophication (Carstensen et al., 2014, Neuenfeldt et al., 2009) impact harbour porpoise distribution and foraging opportunities around hypoxic and anoxic areas in the Baltic Sea. However, overfishing is commonly accepted as one of the major threats causing prey depletion globally.

Noise

Various sources of underwater noise have the potential to impact harbour porpoise populations. Effects of noise can range from acoustic disturbance, to temporary (TTS) or permanent hearing threshold shift (PTS), or even physical injuries and mortality. The most detrimental effect from noise on individuals is injury or death due to high intensity **impulsive noise**. PTS has direct implications for porpoises' viability and cannot be compensated for as they rely on their hearing to find prey, communicate, and orientate. In a small, critically endangered population, such direct impacts on only a few individuals will also have negative repercussions for the population.

With respect to an animal's vulnerability to noise, the spectral characteristics of the noise are highly important. For both injury and disturbance, frequency weighting with respect to porpoises' hearing abilities is a way to assess noise impact and to regulate noise. The most recent guidance for marine mammals in order to avoid temporary hearing loss and injury to the auditory system is given by Southall et al. (2019). Thresholds are based on levels required to induce a 6 dB temporary threshold shift (6dB) in experiments with captive marine mammals. Differing hearing abilities were accounted for by using different frequency weighting functions for different functional hearing groups. These resemble inverted audiograms. For impulsive noise and low frequency non-impulsive (continuous or intermittent) noise there is strong support for thresholds using the weighting function for very high frequency hearing specialists. For non-impulsive sound above 20 kHz there is a discrepancy between the predicted thresholds and some experimental results which require further attention in future research (Tougaard et al., 2022).

With respect to disturbance, harbour porpoises are especially sensitive to the mid- (1-10 kHz) and high-frequency (10-140 kHz) part of the spectrum at which they show behavioural reactions (Wisniewska et al., 2018). It has been demonstrated that even low levels of mid- and/or high-frequency components of broadband sounds, such as from ships, elicit a behavioural response (Dyndo et al., 2015). In addition to attenuation by noise propagation, mid- and high-frequency sound is absorbed by salts contained in seawater. Significant absorption is seen in seawater at frequencies above 5 kHz and distances >10 km. However, due to the low salinity in the Baltic Sea, the absorption of sound is lower than in oceanic waters (Richardson et al., 1995). Further, in stratified waters of the Baltic Sea sound channels could produce effects which locally increase sound propagation (Pihl et al., 2011; Sigray et al., 2016). This results in increased received levels of mid- and high-frequency sounds, and greater impact ranges compared to oceanic environments. For this reason, more caution is needed when transferring research results from other marine areas to the Baltic Sea.

The severity of the impact of noise on individual animals depends on how frequently they are exposed to noise, as well as the intensity and duration. If disturbance occurs too often, in a too large area or for too long a period, this can have energetic consequences for the individual. This can affect the nutritional state, survival or reproductive success and thus have negative population consequences (National Research Council, 2005). Disturbance includes displacement, masking of communication and other biologically significant sounds, missed opportunities resulting in a reduction of feeding or mating opportunities, and increased acute or chronic stress. Considerable displacement has been shown during construction of offshore wind farms, due to piling noise and the use of acoustic deterrent devices (ADDs) which are also commonly used in fish farms (Olesiuk et al., 2002; Tougaard et al., 2009; Brandt et al., 2016; Dähne et al., 2017). Avoidance behaviour associated with ceasing of foraging sequences in echolocation has been demonstrated as response to ships' noise (Wisniewska et al., 2018). Missed feeding opportunities have also been demonstrated in porpoises' response to seismic surveys (Pirotta et al., 2014).

There is limited data on stress responses of porpoises to noise which are difficult to study in the wild. Some general principles can be concluded from studies on humans or other animal species: In aquatic animals these include immediate (acute) release of stress hormones followed by changes in blood parameters (e.g., glucose) and long-term effects related to growth, behaviour, fertility and mortality (Aguilar de Soto & Kight, 2016). The latter can be directly related to individual fitness and potentially have negative population impacts. Repeated or chronic stress in humans is linked to poor health conditions or effects in reproduction (Wright et al., 2011). Rolland et al. (2012) presented evidence of chronic stress in North Atlantic right whales related to low-frequency ship noise exposure.

Masking is to some extent a natural phenomenon as even in pristine conditions ambient noise covers a broad frequency range. However, anthropogenic noise elevates the background noise which then can interfere with the detection of biologically meaningful signals and thus reduces the bioacoustic space of marine mammals (Clark et al., 2009, Hatch et al., 2012). The amount of overlap between a signal and noise in time, space and frequency determines the potential for masking. In marine mammals, a number of behavioural and physiological adaptations have evolved to overcome masking (cf. Mooney et al., 2018). Harbour porpoises use echolocation and communication signals in a frequency band much higher than most natural and anthropogenic noise. Their signals are repetitive coded stereotyped ultrasound clicks (Koschinski et al., 2008) which will not be masked completely, even by pulsed sound from hydroacoustic survey equipment in the same frequency band (Branstetter and Finneran, 2008; Trickey et al., 2010). However, even a partial masking can negatively affect the ability to discern and interpret a signal. From humans it is known that at levels 20 dB or more below the level required to mask speech noise can e. g., reduce telephone speech intelligibility (Houser et al., 2017). Compared to marine mammals using low-frequency signals for communication (such as seals), the harbour porpoise is likely less vulnerable to masking of communication and echolocation. However, elevated broadband background noise has the potential to mask other potentially biologically significant sounds at lower frequencies which are received by passive listening e.g., from prey, predators (e.g. grey seal) or fishing gear and other dangers. A recent study indicates passive listening for locating prey in a species closely related to the harbour porpoise, the East Asian finless porpoise (Cheng et al., 2022).

The most commonly occurring source of **continuous noise** in the Baltic Sea is shipping. Individual harbour porpoises have been shown to exhibit strong avoidance behaviour and ceasing of foraging behaviour as a result of shipping noise (Wisniewska et al., 2018). The reaction distance was estimated at 7 km for high-speed ferries. This impact can have energetic consequences if it occurs regularly and is unable to be compensated for otherwise.

Shipping is often considered a low-frequency noise which is ubiquitous as background or ambient noise, but low-frequency bands are only part of a vessel's spectrum. Vessels radiate broadband noise consisting of noise from engines, auxiliary machinery, and cavitation (Arveson & Vendittis, 2000; Wittekind 2014). The latter is most pronounced if the propellers are poorly designed or the hull and propellers are not well maintained. Cavitation noise increases with speed and is among the most disturbing noise sources in shipping as it covers a broad range of frequencies including the range of best hearing of harbour porpoises (Arveson & Vendittis, 2000; Wittekind, 2014). In noise measurements in the Kattegat and Great Belt, vessel noise substantially elevated the ambient noise in the entire recording band from 25 Hz to 160 kHz (Hermannsen et al., 2014). Low frequency tones radiated from propeller blade rate of large commercial vessels may elicit less behavioural responses in harbour porpoises as the hearing sensitivity to those frequencies is rather low. Whereas hydraulic or electric powered propulsion such as in dynamic positioning systems (which are typical for e.g. working and construction vessels) or thrusters can create considerably strong tones with a range of harmonics extending to frequencies around 1 kHz (Richardson et al., 1995) which has the potential to cause strong behavioural responses (Dyndo et al., 2015). Due to their generally higher revolutions per minute (rpm), smaller vessels such as recreational vessels, or high-speed vessels frequently produce tonal sounds at higher frequencies than most large commercial vessels (Richardson et al., 1995). In these vessels, tonal noise occurs at frequencies of higher hearing sensitivity which also elicits strong responses (Dyndo et al., 2015). Effects of such broadband noise are currently not included in MSFD continuous noise indicators.

An emerging noise source is ultrasonic antifouling devices used for cleaning propellers, engine cooling systems, and even the hull. Manufacturers of such devices claim to be environmentally friendly because toxic paints can be avoided, but completely disregard their noise emissions. These systems are currently unregulated. Trickey et al. (2022) found that ultrasonic antifouling devices on cruise ships caused clear avoidance by Cuvier's beaked whales (*Ziphius cavirostris*). A spectrogram of a recording from a cruise ship indicating a fundamental frequency of approximately 23 kHz and strong harmonics covering the frequencies of porpoises' best hearing (16 to 140 kHz) is shown in Fig. 2. Widespread use of these devices has the potential for population consequences of disturbance.

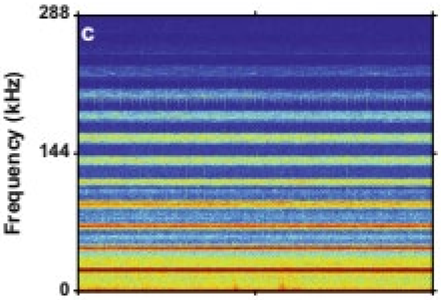

Fig. 2. Spectrogram of ultrasonic antifouling signals recorded from cruise ship *Oceania Regatta* (taken from Trickey et al., 2022)

In the period 2016 to 2021, the most commonly occurring events of **impulsive** noise sources in the Baltic Sea were from sonars or seal scarers, explosions, airgun arrays and seismic surveys. About 1400 sonar or seal scarer events, 600 seismic airgun events and 500 pile driving events were reported over the six year period (HELCOM, 2023b). Depending on the level and exposure duration, impulsive noise such as from piling or seismic surveys has a potential to cause a TTS or even PTS and thus reducing hearing sensitivity (Lucke et al., 2009; Schaffeld et al., 2020). Further, these impulsive noise sources cause displacement or elicit behavioural reactions resulting e.g., in a reduced foraging rate (Tougaard et al., 2009; Brandt et al., 2011; Thompson et al., 2013; Pirotta et al., 2014; Dähne et al., 2013, 2017; Sarnocińska et al., 2020). The zone of displacement during impact piling has been shown to extend over 20 km (Tougaard et al., 2009). Depending on the received level, this displacement can last for up to two days until animals begin returning to an area (Brandt et al., 2016).

The loudest point source emitters are underwater explosions, e.g. from clearance of unexploded ordnance (UXO) or construction work. In the Baltic Sea, approximately 175,000 mines are estimated to have been laid during the world wars of which a large fraction is expected to still remain on the sea bottom (Wichert, 2011) and might be found during surveys preparing for infrastructure and renewable energy development. Between 2016 and

2021, over 800 explosions were reported of which only a very minor fraction was mitigated, e.g. with bubble curtains (HELCOM, 2023b). Explosions of UXO have been linked to blast injuries and death of harbour porpoises in the Baltic Sea (Siebert et al., 2022). For the Dutch North Sea, it has been estimated that 88 explosions in a 1-year period for clearing UXO would cause between 1,280 and 5,450 events of permanent hearing loss in harbour porpoises (Benda-Beckmann et al., 2015), indicating that mine clearance could have a major impact on harbour porpoise populations. This potentially lethal effect is not covered by the existing MSFD impulsive noise indicator.

Noise sources of **intermittent sound** with some characteristics of both, continuous and impulsive sound are of special interest as acoustic deterrent devices (ADDs) are frequently used as a mitigation measure to prevent bycatch of harbour porpoises and other species. ADDs with lower source levels (‘pingers’) are typically used in static net fisheries in certain areas to scare porpoises away from nets and reduce bycatch. Much louder devices, so-called ‘seal scarers’ are being used to protect porpoises from intense impulsive noise such as piling or explosions which have a strong potential for injury. These devices are also used to prevent predation by seals at aquaculture fish pens. As an emerging noise source, seal scarers are increasingly used even in fisheries to protect the catch against seal depredation (Nordic Council of Ministers, 2023). A negative side effect of seal scarers is that porpoises are very sensitive to seal scarring signals, can experience TTS or PTS, and are displaced over large distances. A widespread use of ADDs (pingers or seal scarers) has the potential for habitat degradation or even habitat loss (Findlay et al., 2021).

Especially in combination with prey depletion, reduced foraging by any kind of acoustic disturbance, can have energetic consequences for individual animals and also affect the population (see chapter energetic requirements).

Knowledge gaps related to noise

Underwater noise is regulated under the MSFD and assessed in two HELCOM indicators, one on impulsive and one on continuous (ambient) noise. Both indicators only address the pressure but not the impact of underwater noise. Although some initial thresholds have been set for the holistic assessment of the state of the Baltic Sea (HOLAS III), it is not clear what thresholds for which frequencies are required to avoid population consequences for Baltic Proper harbour porpoises and other noise sensitive species.

Displacement by noise can be considered (temporal or permanent) habitat loss. Other forms of disturbance (masking, missed opportunities, stress) represent habitat deterioration by limiting the animals’ ability to function within normal biological limits (e.g., typical foraging, navigation, social, breeding behaviour) which could impact growth, reproductive success, or the probability of survival. The impact of noise on the quality of the habitat and repercussions on the population are unknown.

Offshore development is still limited but increasing in the Baltic Sea and there are extensive plans for the development of offshore wind farms (4C Offshore, 2022). Activities linked to different phases of the life cycle of an offshore wind farm generate impulsive or continuous underwater noise, e.g. seabed exploration, explosions for clearance of cable corridors and wind farm areas, pile driving, turbine operation, service vessel operation, and decommissioning. Environmental impact assessments only assess the single project, but the cumulative impact of all projects remain unclear.

The largest and most important knowledge gaps related to underwater noise are the extent of energetic consequences of single and multiple disturbances, and what the repercussions of disturbance of individuals will have on the population. Further, since these effects act cumulatively with e.g., prey depletion, health status, and direct mortality such as from bycatch, methods to assess cumulative effects need to be developed.

Continuous noise, such as ship noise or wind farm turbine noise, is widespread, but information on impacts of such noise at the individual- and, especially, population-level of Baltic Proper harbour porpoise is largely lacking. The broadband component of noise from passing vessels at a distance of 1.2 km is estimated to cause hearing range reductions >20dB at 1 and 10 kHz by masking (Hermannsen et al., 2014). Further, strong avoidance behaviour and cessation of feeding behaviour have been recorded (Dyndo et al., 2015; Wisniewska et al., 2018). Recent research has shown that despite large changes in shipping noise and traffic in an area, harbour porpoises in the Kattegat (likely the Belt Sea population) continued to use preferred habitat (Owen et al., *In review*). However, the impact of increased disturbance on foraging and mating success of individuals, and how this impacts the population remains unknown.

Direct injury, for example to the inner ear, leading to partial hearing impairment is considered less relevant for this type of noise, but empirical evidence is lacking. Even less is known about possible physiological impact (cardiovascular and stress effects) of continuous noise exposure, preventing meaningful assessment of these effects (HELCOM, 2023f).

According to the EU Technical Group on Underwater Noise (TG NOISE) which was tasked to develop thresholds for underwater noise, good status for continuous noise is achieved when less than a given percentage (still to be determined by HELCOM) of the habitat (which still requires definition) is at levels above the “Level of Onset of Biologically adverse Effects” (LOBE). TG Noise deliverable 4 (DL4) defines the LOBE as: “The noise level at which individual animals start to have adverse effects that could affect their fitness”. Initial LOBE values have been selected by the HELCOM BLUES project after consultation in EG Noise and based on the scientific literature. However, there is substantial uncertainty around the values chosen. It is currently not known from what levels at which frequencies harbour porpoises experience biologically adverse effects and what proportion of the habitat can be tolerated above LOBE for what fraction of time. The indicator only assesses noise in the 64, 125 and 500 Hz decidecade bands. It is unclear if specific frequencies in the spectrum elicit the strong avoidance described in the literature or the whole spectrum as perceived by the animal, or the perceived movement of the noise source. MSFD monitoring also allows assessing noise at higher frequencies which are also recorded by monitoring stations. From the noise section above it can be concluded that higher frequency bands are very likely more relevant for harbour porpoises. The modelled noise of commercial vessels does not account for this and thus it is unclear what area is affected by relevant frequency bands from noise of commercial ships and also recreational boats and what the effect for the population is. It is further likely that the LOBE varies during the year, between years and with function or importance of specific areas, and even during the course of a day (Rojano-Doñate et al., 2018), depending on the individual’s current reproductive status, energetic requirements, nutritional state and the prey availability in terms of quantity and quality. When setting the LOBE, a level of precaution needs to be chosen which takes the most vulnerable individuals into account, especially when dealing with a Critically Endangered population.

The HELCOM BLUES project has made considerable progress in noise mapping of commercial ships. However, noise mapping of recreational boats is completely lacking (Hermannsen et.al. 2019) and the impact of this noise source (alone, or cumulatively with other noise sources) is unknown.

For low frequency continuous noise, the ability to mask biologically relevant signals thus compromising prey-predator interactions and the ability to detect threats, is of particular importance. It is not known if eavesdropping plays a role in avoiding dangers and locating prey and how this would be impacted by a reduction of the bioacoustic space.

Ultrasonic anti-fouling devices are an emerging noise source and potential threat if widely used. It is currently unclear how porpoises react to the different types of antifouling devices and what mechanisms are relevant (continuous, pulsed, frequency, harmonics). Further, the potential for TTS (or even PTS in potential widespread use) caused by transiting ships equipped with these devices is unclear. Individual energetic and population consequences of disturbance by these devices and other noise sources are unknown, taking also other pressures into account which can act in a cumulative way.

There are similar knowledge gaps related to **impulsive noise**. In general there is incomplete knowledge which frequency weighting represents the biological mechanisms best. Also it is not fully understood how multiple pulses such as in piling or seismic noise accumulates in the ear. To derive conclusions for the Baltic Proper population this can be further studied with any harbour porpoise population.

Additionally, the HELCOM indicator on impulsive noise does not assess injury or death which might commonly occur, especially in UXO clearance using underwater explosions. It is currently unknown how many porpoises are being injured or killed. With respect to disturbance, which is supposed to be assessed by the indicator on impulsive noise, LOBE needs to be determined for the Baltic Proper harbour porpoise, taking into account the factors described above for continuous noise. Likewise, also a spatial threshold (short term/long-term) needs to be determined at levels which enable the full recovery of the Baltic Proper population.

The type and extent of the impact of certain hydroacoustic research equipment such as sediment profilers, boomers or sparker etc. on harbour porpoises has not been investigated. Echo sounders and fish finders produce lower levels of impulsive noise compared to piling or airguns, but are omnipresent in the Baltic Sea. Further, they are operating at the frequencies of the best hearing for harbour porpoises. The extent of the disturbance caused by these widely used devices has never been investigated.

Although some events from military activities, such as sonar events or explosions are being reported to the impulsive noise registry, the spatio-temporal extent, levels and frequencies used during military activities are unclear. Underwater explosions commonly occur during military exercises. However, information is scarce on if and what mitigation methods are being used and whether mitigation is effective.

Contaminants

Hazardous substances are entering the Baltic Sea via different routes. Direct discharges, inputs via rivers, atmospheric inputs as well as sea-based sources are of importance. Inputs from Wastewater Treatment Plants (WWTP), runoff from agriculture or urban areas, industrial emissions and discharges from shipping lead to a Baltic Sea being polluted by a wide variety of hazardous substances. An emerging source of contaminants is the increasing use of exhaust gas cleaning systems (scrubbers) in commercial vessels which effectively washes heavy metals and Polycyclic aromatic hydrocarbons (PAH) into the marine environment, especially if operated open-loop. Different types of PFAS are used in many products, from makeup and clothing to cleaning detergents and fire-fighting foams.

Along with bycatch, **pollutants** are classified as a high threat to harbour porpoise (ICES, 2019) and are also considered to be a factor in the decline of the Baltic Proper harbour porpoise (Kannan et al., 1993; Koschinski, 2001; HELCOM, 2013). Cetaceans are high trophic level foragers and are thus exposed to a high bioaccumulation of these substances. Biomagnifying pollutants such as persistent organic pollutants (POPs, e.g. PCBs, dioxins and PFAS) and heavy metals (e.g. mercury) are of particular concern. They may act as endocrine disruptive chemicals, affecting the reproductive system, thyroid gland, neuroendocrine system, immune system, and the systems that control nutrient partitioning (Rhind 2008).

In harbour porpoises, high burdens of **polychlorinated biphenyls** (PCBs) have been found to be associated with reduced immune system function, health status, and fertility (Beineke et al., 2007a, 2007b; Jepson et al., 2005; Murphy et al., 2015). Most of the data on the PCB concentrations of the Baltic Proper harbour porpoise population are from the 1980 or 90s (Berggren et al., 1999; Bruhn et al., 1999; Falandysz et al., 2002; Kannan et al., 1993), and were often well above a proposed threshold for adverse health effects (Jepson et al., 2005). Moreover, the levels were up to 254% higher than mean levels of PCBs in corresponding samples from the Kattegat and Skagerrak (Berggren et al., 1999). Toxic equivalence (TEQ) values of dioxins, dioxin-like PCBs and chloro-organic contaminants in herring fillets sampled at 11 locations ranging from west of the British Isles to the Latvian coast in the Baltic Proper during 1996-2004 show an increase of about 35 fold from west to east (Karl and Ruoff, 2007).

Since the start of regulation of the use of PCBs in the 1980s, PCB concentrations in marine mammals initially declined worldwide, but have since stabilised at toxicologically significant levels in several European cetacean species (Law, 2014: Jepson et al., 2016). A similar temporal pattern is seen in several POPs and their TEQ values in Baltic herring and seabird eggs (European Food Safety Authority, 2005; Jörundsdóttir et al., 2006; Miller et al., 2014). A recent study in the UK (Williams et al., 2023) showed that mean PCB blubber concentrations were observed to decline in all harbour porpoise Assessment Units and OSPAR Assessment Areas in UK waters. However, a high proportion of animals were exposed to concentrations deemed to be a toxicological threat, though the relative proportion declined in most Assessment Units/Areas over the last 10 years of the assessment. The study suggests that although PCBs were banned now more than 40 years ago, they are not disappearing and that their bioaccumulation in marine mammals depends on (1) population trophic ecology and (2) history of pollution at a very local scale. This stresses the fact that assessing PCB levels in marine mammals today is still important.

Concerning **metal concentration**, there is growing concern about the health status of the harbour porpoise in the North Sea and also in the Baltic Sea and adjacent areas. The interaction between toxicological results (Zn, Cd, Cu, Fe, Se, Hg), and the most common pathological findings, namely emaciation and lesions of the respiratory system, were investigated in 132 porpoises collected along the coasts of northern France, Belgium, Germany, Denmark, Iceland and Norway between 1994 and 2001. Increasing Zn levels were observed with deteriorating health conditions (emaciation and bronchopneumonia) (Das et al., 2004). According to Szefer et al. (2002) the concentrations of selected metals such as Cd, Pb, Cu, Zn, Cr, Ni, Mn, and Fe were determined in liver, kidney, and muscle of harbour porpoise from three geographical regions, i.e., the Baltic Sea, Danish, and Greenland coastal waters. The concentrations of Cd in liver and kidney increased with age of the specimens analysed. The Baltic Proper harbour porpoises carry a significant mercury burden (Szefer et al., 1995), which has been associated with prevalence of parasitic infection and infectious diseases (Siebert et al., 1999). The livers of two Polish porpoises had markedly elevated levels of silver, indicating that they had been exposed to point sources of pollution (e.g. harbours or industrial plants). Dietz et al. (2021) showed how harbour porpoises from the Kattegat/Skagerrak Seas and Norway present levels of mercury in the range of observed hepatic toxicity. The same was observed for grey seal adults from Kattegat/Skagerrak Seas or Norway up to Estonia and Northern Sweden.

Moreover, porpoises from the Polish coast had relatively high **concentrations of the pesticides** aldrin, dieldrin and chlordane, and their blubber also contained mirex, heptachlor and heptachlor epoxide (Kannan et al., 1993; Strandberg et al., 1998). In the Swedish Baltic Sea, porpoises were found to have three times the level of PCBs and more than 10 times the level of DDT compared to porpoises from the Kattegat/Skagerrak Seas or Norway (Berggren et al., 1999).

Oil pollution is caused not only as a result of major oil incidents, but also from diffuse sources, such as leaks, illegal tank-cleaning operations at sea, or discharges into rivers which are then carried into the sea. The impact of oil pollution on harbour porpoises is unknown, unlike birds, cetaceans are not generally regarded as being particularly vulnerable to oil spills. However, oil can be swallowed or get into the respiration tract. Volatile components can be transferred into the blood. In cetaceans, acute and chronic lung lesions as well as negative consequences for the immune system have been described (Barron 2012; Venn-Watson et al., 2015). There are no records of any spills in which a substantial number of harbour porpoises were affected, within Europe or anywhere in the world. No measurable effect of the "Erika" oil spill off the Atlantic coasts of France, was found in cetaceans or seals either (Ridoux et al 2004).

Knowledge gaps related to contaminants

The current levels in the Baltic Sea biota indicate that **PCBs, PBDEs, PFAS** contamination remains a serious threat to the health and reproductive status of the Baltic Proper harbour porpoise population, but a lack of samples prevents direct studies. The lack of samples is due to a combination of the small population size and a low willingness to report and land bycaught harbour porpoises (Amudin et al., 2022). In addition, recent studies show that the effects of PCBs pollution continue to affect cetaceans including harbour porpoise in European waters (Jepson & Law, 2016; Desforges et al., 2018), causing e.g. reproductive failure (Jepson et al., 2016) and increasing the risk of infectious disease (Hall et al., 2006). However, the impact of exposure to PCB congeners on marine mammals is still largely unknown (Jepson et al., 2016) and it remains undetermined whether immunological changes are directly contaminant-induced or a sequel of concurrent infectious diseases and poor health status, respectively (Lehnert et al., 2019). Even though studies from the southern part of the North Sea revealed that harbour porpoises with high PCBs concentrations were observed to die more often from an infectious disease and/or debilitations (like severe emaciation) than from an acute cause of death, such as bycatch or predation, the clear correlation cannot be proven (van den Heuvel-Greve et al., 2021). Concerning **PFAS**, few data are available for harbour porpoises in the North Sea. Among the reported effects of PFASs are reproductive toxicity, neurotoxicity, immunotoxicity and hepatotoxicity. Given the persistence and bioaccumulation potential of PFASs, their toxicity to wildlife at high trophic levels is of concern (Galatius et al., 2013). A recent review on health effects of contaminants in the Baltic is available in Sonne et al. (2020a).

While data on contaminants (such as PCBs, PBDEs, etc.) for the Baltic Proper harbour porpoise are not available, a study on harbour porpoises from the southern North Sea detected the lowest mean contaminant concentrations in blubber samples of foetuses and adult females (van den Heuvel-Greve et al., 2021). Additionally, neonate harbour porpoises contained higher contaminant concentrations than foetuses as a result of both transplacental transfer and lactational transfer. For the same reason, PCB concentrations were significantly higher in adult males compared with adult females (van den Heuvel-Greve et al., 2021). Even though Baltic Proper harbour porpoises likely follow a similar pattern to the southern North Sea population, the impact of PCB accumulation in different life stages and sexes of Baltic Proper harbour porpoises need to be studied further.

Heavy metals accumulate throughout the lifespan of marine mammals. Siebert et al. (1999) found significant associations between mercury levels, severity of pathological lesions and the nutritional state of harbour porpoises. Additionally, Desforges et al. (2021) have associated higher concentrations of total mercury with inhibition of the glutamate excitatory neurotransmitter in pilot whales (*Globicephala melas*), harbour porpoises, narwhals (*Monodon monoceros*), polar bears (*Ursus maritimus*) and ringed seals (*Pusa hispida*) from the Arctic. While there is some information on current trace element pollution levels in southern Baltic Sea harbour porpoises, information from the Baltic Proper harbour porpoise is based on very rare, old and scattered data, limiting the assessment of the health status of this population. Despite the lack of data in the Baltic Proper, from other areas and mammal species we have enough information on the negative consequences of mercury to conclude that action is required.

The impact of **pharmaceuticals,** such as diclofenac, on the marine environment including Baltic Proper harbour porpoise is also unknown, however concentrations of diclofenac have been detected in water, sediments and biota in the Baltic Sea. Further data and analyses to determine the environmental effects of increased diclofenac concentrations, the dispersal from source, and the spatial distribution in water, sediments and biota are required to guide status evaluation (HELCOM, 2023g.).

Little is known about many chemical substances that exist in the marine environment and may affect the health status and breeding performance of harbour porpoises. For example, nothing is known about the long-term effects of oil pollution on harbour porpoises. This especially relates to ecosystem effects of oil as well as chemical dispersants (if used in oil spills), which are relevant with respect to porpoise prey. Additionally, there are **contaminants of emerging concern (CECs)**, including UV filters from sunscreen, agricultural and industrial chemicals, explosives and pharmaceuticals that we know very little about. They refer to chemicals and toxics that have been found in water bodies that may cause ecological or human health impacts and are not currently regulated.

Wide scope target and suspect screening are promising means to detect and assess the effects of **CECs** such as recently conducted in marine mammals of the Baltic Sea. For this purpose, 11 pooled liver samples and one nonpooled muscle sample from 11 individuals across four marine mammal species including the harbour porpoise from Germany, Sweden, Denmark and Poland were analysed for the presence of 65,690 substances. Overall, 47 contaminants from different chemical classes were determined in the analysed samples. Among these were chemicals which are already known to cause toxic effects such as PCBs and DDT and their biotransformation products but also a number of agricultural chemicals (and their transformation products), industrial chemicals and pharmaceuticals (and their transformation products) currently not in the focus of toxicology. The measured concentration levels of individual substances were benchmarked against their Predicted No-effect Concentration (PNEC) values for marine fish retrieved from the NORMAN Ecotoxicology Database and 33 compounds exceeded these ecotoxicological threshold values, indicating potential adverse effects on the affected marine mammals' individuals health. None of the targeted explosives chemicals were detected above their limit of detection in any of the samples. Five organophosphorous flame retardants were determined in at least one sample, with tris(3-chloropropyl)phosphate being present in ten out of 12 samples. The suspect screening revealed the presence of an additional 30 substances in the studied samples and allowed for a semi-quantitative estimate of their concentrations. These compounds were then prioritised following the same procedure as in the wide-scope target screening. As a result, the industrial chemicals 12-aminododecanoic acid and 1,3-dimethyl-3- phenylbutyl acetate were the top ranking substances followed by the UV filter octinoxate. The majority of the detected chemicals were registered under REACH indicating their annual high tonnage production (Slobodnik et al., 2022). Even alternative flame retardants are increasingly being found in marine mammals giving rise to environmental concern and requiring further research (Berger et al., 2023). At present, there is not enough knowledge to assess CEC's impacts on Baltic Proper harbour porpoise, but their presence in the environment and knowledge on their chemical characteristics and/or toxicity require being alert and improving our knowledge.

Waste

In the second half of the 20th century, the use of plastics and other synthetic materials has hugely increased (Laist, 1987), and the quantity of plastic debris entering the marine environment has undergone a similar increase (Jambeck et al 2015). Many of these products degrade slowly and the accumulating debris pose an increasingly significant threat to marine megafauna (Laist et al 1999; Baulch and Perry, 2014). The main sources of marine litter include vessels (including fishing), offshore installations, and land-based sources (Cozar et al 2014; Jambeck et al 2015). The key issues with marine litter for cetaceans are **entanglements and plastic ingestion**. Concerning research on entanglement in abandoned, lost or derelict, fishing gear (ALDFG), it has been confined largely to 'passive gears' such as gillnets, trammel nets, wreck nets, traps, and small seine nets. Under certain conditions, derelict gear can continue to catch and kill organisms for years or decades (termed 'ghost fishing') (Gilman et al., 2022). Even though fishermen often attempt to recover their nets given the cost of replacement, WWF Poland (2013) estimated that in the Baltic Sea, every year, around 5,500-10,000 pieces of nets have been lost. Unintentional net loss is caused by various reasons, but often by gear conflicts such as losses of static nets due to trawling. Gears are however also abandoned intentionally (Brown et al 2005, FAO 2009). Recreational fishermen may also lose nets due to lack of training, knowledge or responsibility. Another threat to harbour porpoises could be caused by strangulation or plastic ingestion that can have lethal effects (internal injury, suffocation, and blockage) or lead to starvation and delayed death. Further individual consequences of ingestion could also be inflammation and intestinal perforation (Leopold and Camphuysen, 2006; Unger et al., 2017; Franeker et al., 2018). A less well known and understood potential pressure is the uptake of PCBs and other POPs absorbed by ingested microplastic particles (Arthur and Baker, 2011, Philipp et al., 2021).

Knowledge gaps on impact of waste on Baltic Proper harbour porpoise

Although there is a large knowledge gap concerning the extent of the threat to Baltic Proper harbour porpoise caused by marine litter including **abandoned, lost or discarded fishing gear - ALDFG**, on a basis of information from other marine regions, it is known that about 68% of cetacean species, including harbour porpoises, are affected by interacting with marine litter (Eisfeld-Pierantonio et al., 2022). ALDFG are considered the most direct threat posed by waste for the Baltic Proper harbour porpoise population. Entanglement in ALDFG, is generally considered far more likely a cause of mortality than ingestion (FAO, 2009). According to the CMS (2018), in some cases this risk may be as severe as when the gear is actively fishing, but there are too little data to help evaluate this. In addition, in stranded animals it is difficult to differentiate between entrapment in ALDFG and entanglement in active gear (Eisfeld-Pierantonio et al., 2022).

There is also an ongoing debate on the actual effects of plastics on cetaceans and, in particular, with reference to the **ingestion of microplastics** and their potential toxicological and pathogenic effects (Eisfeld-Pierantonio et al., 2022). Philipp et al. (2021) investigated microplastics occurrence in the samples from harbour porpoises stranded along the German North and Baltic Seas between 2014 and 2018 where the authors not only observed a high frequency of occurrence of microplastics in the gastrointestinal tract (28 individuals out of 30) but, more importantly, highlighted a correlation between the nutritional status of cetaceans and the amount of ingested microplastics. The question however remains how high microplastics ingestion can affect the health status. According to Nelms et al. (2019) a possible relationship was found between the cause of death category and microplastic abundance, indicating that cetaceans that died due to infectious diseases had a slightly higher number of particles than those that died of trauma and other drivers of mortality. It is not possible, however, to draw any firm conclusions on the potential biological significance of this observation and further research is required to better understand the potential chronic effects of microplastic exposure on animal health, particularly as marine mammals are widely considered important sentinels for the implications of pollution for the marine environment.

Disease

Van Bressem et al (2009) reviewed infectious diseases in cetaceans, examined their potential to impact populations, re-assessed zoonotic risk and evaluated the role of environmental stressors. Cetacean morbilliviruses and papillomaviruses as well as Brucella spp. and *Toxoplasma gondii* were thought to induce high mortality rates, lower reproductive success and to increase the virulence of other diseases. For this reason, population effects of diseases are important to consider. Environmental quality such as concentration of contaminants, seem to play a role in the emergence and pathogenicity of morbillivirus epidemics, lobomycosis/LLD, toxoplasmosis, poxvirus-associated tattoo skin disease and, in harbour porpoises, infectious diseases of multifactorial aetiology. This is also confirmed by the studies on harbour porpoises in the North and Baltic Seas (see also section on contaminants). To evaluate immune responses in healthy and diseased harbour porpoise cells, cytokine expression analyses and lymphocyte proliferation assays, together with toxicological analyses were performed in stranded and bycaught animals as well as in animals kept in permanent human care. Severely diseased harbour porpoises showed a reduced proliferative capacity of peripheral blood lymphocytes together with diminished transcription of transforming growth factor-b and tumour necrosis factor-a, impaired function of peripheral blood leukocytes, indicating immune exhaustion and increased disease susceptibility, compared to healthy controls. These factors are associated but not correlated with accumulation of PCBs, DDT and DDE in harbour porpoise blood samples. This indicates immune exhaustion and increased disease susceptibility (Lehnert et al., 2019). A recent review on pathogens of marine mammals from the Baltic is available in Sonne et al. (2020b).

One of the largest health assessments of harbour porpoises from the Baltic was conducted by Siebert et al. (2020). Data were collected from the animals coming from Latvia, Poland, Germany and Denmark for years between 1990 and 2015 and were either by-caught or found dead on the coastline. The respiratory tract had the highest number of pathological lesions, and 45.5 to 100% of the animals from the different countries were recognised as by-caught individuals. Data on health status and the causes of death are valuable for management.

An additional study completed post-mortem examinations on 128 stranded harbour porpoises, collected over 15 years from Swedish waters (Neimanis et al., 2022). The majority of animals likely originated from the Belt Sea and the North Sea populations. Population assignment was based on stranding location and not genetic determination; however, six porpoises were collected from the overlapping management area of the Belt Sea and Baltic Proper porpoise populations and may have been individuals from the Baltic Proper population. The analysis revealed that pneumonia was a frequent cause of death (21%). Infectious diseases were caused by bacterial infections (n = 10), parasitic infections (n = 6), fungal infection (n = 2) and brain inflammation (encephalitis) of undetermined cause (n = 1). Of the bacterial infections, seven manifested as pneumonia. One calf suffered from sepsis as a result of a chronic, infected bite wound and another had a *fibronosuppurative pericaditis, myocarditis* and *lymphadenitis*. In the six animals diagnosed with primary parasitic infections, severe parasitic pneumonia was seen in five animals. Besides infections that were the direct cause of death, the vast majority of stranded porpoises (61%) had milder parasitic infections and associated inflammatory tissue changes.

From the necropsies associated with strandings data, parasite levels are known to be generally quite high in harbour porpoises in the Baltic Sea (Siebert et al., 2001; Lehnert et al., 2005; Dzido et al., 2021). In comparison, harbour porpoises from Greenlandic waters appear to be healthier than those from Baltic waters, likely due to much lower levels of environmental contaminants (Wünschmann et al., 2001). Harbour porpoises in waters from Norway and Iceland had milder lungworm parasitism associated with a lower incidence of severe lesions than animals from German Baltic Sea waters, also reflecting differences in host populations and/or environmental circumstances (Siebert et al., 2006). The immune system of harbour porpoises can also be negatively influenced by increased contaminant loads (De Guise et al., 1995; De Swart et al., 1996), and harbour porpoises with higher levels of pollutants have been shown to have a high rate of infection (Siebert et al., 1999; Das et al., 2004; Jepson et al., 2005).

Knowledge gaps related to disease

Disease factors and mortality etiologies of free-ranging wild cetaceans such as the harbour porpoise are difficult to study. Specifically, there is little information on diseases of Baltic Proper harbour porpoises due to their rarity. However, stranded animals and carcasses can provide invaluable information on the health status and biology of this species (Siebert et al., 2020) if available.

Although diseases are often considered a natural cause of death, it is worth underlining that porpoise population health may mirror the overall health and stability of marine ecosystems and the effects of human activities on coastal environments. Diseases may be spread across species boundaries, one way or the other, and an outbreak can result from anthropogenic activity (Fayer et al., 2004). Contaminants are known to affect the immune system. Monitoring health, diseases and causes of death of porpoises allows for identification of threats to these animals, to other animals, or to humans and to the environment. Taking into account that the Baltic proper harbour porpoise population is severely depleted, major infections and die offs may lead to the extinction of the population, however, with lower density of the population infection risk might also be lower.

Studies to investigate the disease factors and mortality etiologies of harbour porpoises should continue through established stranding and post-mortem work. The number of specimens should be increased, e.g., by an obligation to land bycaught porpoises. Additional research (including a meta-analysis of necropsy data that have accumulated over time) would help to understand further the causes, seasonality, long-term trends, frequency in different sex and age categories, and the environmental conditions that may enhance the occurrence of infectious disease and parasite burden as a cause of death of harbour porpoises.

Vessel strikes

A vessel strike is defined as any impact between any part of a watercraft (most commonly bow or propeller) and a live marine animal (Peel et al., 2018). Vessel strikes often result in physical trauma or death (e.g. Moore et al., 2013; Ritter, 2012). The issue of fatal collisions with commercial ships and ferries usually refers to large whales such as baleen whales, and reports of vessel strikes with smaller species are scarce. However, injury indicative of vessel strikes such as blunt trauma, skull fracture or multiple lacerations (Fig. 3) is frequently reported from various parts of the world, including vessel strikes with harbour porpoises (Parsons & Jefferson, 2000; Sabin et al., 2005; Ijsseldijk et al., 2016).

Fig. 3. Lethal propeller injury in a harbour porpoise caused by a small vessel with a high RPM. Photo credit: David Nairn, Clyde Porpoises (CIC).

Knowledge gaps related to collisions

Although the literature does not contain many reports of vessel strikes with small cetaceans, reporting bias, poor quality of carcasses that come to shore, or lower susceptibility for vessel strikes are possible explanations. In addition, strong avoidance behaviour of porpoises may in most cases prevent strikes (Polachek and Thorpe, 1990; Camphuysen and Siemensma, 2011). However, it is known that vessel strikes do occur and contribute to direct additional mortality by anthropogenic activities. Unlike in large whales the type of vessel involved in vessel strikes is usually not known. Propeller injuries such as the one shown in Fig. 3 are likely related to fast small vessels with a high rotation speed of the propeller such as in speed boats or rigid hull inflatable boats (RIBs), typically operating in coastal waters. Blunt trauma from a vessel strike where the animal is likely hit by the bow or rudder may also be caused by larger fast vessels such as high-speed ferries, catamarans or crew transfer vessels which also operate in offshore areas. The knowledge of the origin of vessel strike injuries, available through e.g. stranding networks, would help designing mitigation measures such as routing, speed reduction zones (Schoeman et al., 2020), or hosting of service personnel in offshore wind farms overnight to reduce high-speed vessel traffic.

With extensive plans for the development of wind energy for the Baltic Sea, it is likely that an increase in vessel traffic during the construction of offshore wind projects as well as during their operation period will elevate the risk of vessel strikes both at the offshore wind project site and the transit corridors to and from the port.

Conclusions

From the analysis above the following conclusions related to Baltic Proper harbour porpoises can be drawn:

1. **There are still a number of knowledge gaps, but a lot of information necessary for protection is known or can be derived from other porpoise populations.**

In conservation, the precautionary principle should be used, especially when dealing with Critically Endangered populations, as it allows for the implementation of measures immediately, even when knowledge gaps about the specific population are present. The available knowledge, in some cases gained from either other harbour porpoise populations, or at an individual level, demonstrates the vulnerability of harbour porpoise populations towards all of the threats discussed. While understanding population level impacts of threats is important, for extremely small populations such as the Baltic Proper population of harbour porpoises, any impact on an individual will have a population level impact. Additionally, much of the required population-specific knowledge may be impossible to obtain until after the population recovers, meaning that in the majority of cases reliance on data from neighbouring populations is the only option to aid conservation. In some cases it may be possible that upcoming new methods, such as acoustic analyses to detect the presence of calves (e.g. see Delgado-García. 2017), can assist with filling in some of the many knowledge gaps on this population.

2. Extinction of this population is a choice, meaning that decision makers have it in their hands. It is known what caused the decline of this population and what measures are needed. The instruments for effective protection are at hand.

The extinction risk increases with decreasing population size. Thus, there is no time to waste. Recovery of this population is possible. Adaptive management is needed, where fast and proactive decisions to protect the population are put in place, and then modified at a later stage to reduce the burden on specific stakeholders as more information on possible population recovery becomes available.

3. Conservation action is needed in all sectors across all anthropogenic activities.

Measures that have a direct effect on the population (i.e. those directly reducing additional anthropogenic mortality) are the most effective. Measures limiting bycatch and fatalities caused by explosions fall in this category. Other measures act indirectly by e.g. improving the nutritional state or reproductive success of the population. All actions aiming at restoring fish stocks, lowering pollution, or reducing disturbance fall under this category. Most actions aimed at significantly reducing the identified threats require far-sightedness and patience, as these can only be determined to be effective after a long time due to the low reproductive rate and the small size of the population. In other cases the pressure will continue after action is taken, for example, even if the introduction and discharge of contaminants are immediately stopped, the already existing load will continue to affect the marine environment and health status or viability of Baltic Proper harbour porpoises.

4. There is evidence that bycatch is the main pressure and requires immediate and effective action.

It is evident that the Baltic Proper population cannot withstand current bycatch levels, even on the basis of incomplete data. Based on available life history data, bycatch of this population should be zero to allow recovery. Given the difficulties associated with robustly assessing the level of bycatch, the only way to ensure zero bycatch of this Critically Endangered population is the implementation of effective bycatch mitigation measures in the whole distribution range. Such mitigation measures include static net closures, changing of gear type, reductions in effort or gear modifications such as pingers, or limitations on soak time. A strict bycatch reporting obligation and landing of porpoises for the whole area may help closing data gaps outlined here. The monitoring program mentioned under point 5 below, will help determine the areas of high importance for the population which could change over time.

5. There is an urgent need for an updated abundance estimate and new information on the distribution of the population in order to best position protective measures and define important areas

Currently there is only a single abundance estimate of the Baltic Proper population of harbour porpoises, which is now over a decade old and unlikely to reflect the current situation. This is also true for the only maps of population density across its range which are required to ensure that management actions are targeted to the most important areas for the population. Multinational collaborative studies to assess abundance and distribution, such as the SAMBAH II project, and development of harmonised monitoring programs across the Baltic region are urgently needed. Additionally, in order to ensure that management actions are implemented in the most effective way, more and better data on the location of threats is also required.

6. The Baltic Proper food web is distorted which can impact prey quality and quantity for the Baltic Proper harbour porpoise. It is important to introduce ecosystem-based sustainable management of fisheries, aquaculture and agriculture, in order to restore and maintain a functioning food web, and a healthy Baltic Sea

Although the current variation in prey composition is not known, it is very likely that porpoise prey is affected in one way or another by fisheries, eutrophication, climate change and other factors. These multiple pressures on the food web require a multi-sectoral approach aiming at the recovery of fish stocks and natural trophic interactions to increase the resilience of the system. Trends in removal of predatory fish, declining fish stocks, reduced mean fish size, and reduced recruitment and growth need to be reversed taking the ecosystem into account. As part of this multi-sectoral approach, when determining the total allowable catch (TAC), ecosystem-based management needs to be implemented in fisheries, taking into account low recruitment of fish species by different factors including climate change. When determining MSY for each fish stock, trophic interactions between fish species, and thus recovery plans for multiple fish species (including non-commercially exploited fish species) need to be considered. Better understanding of trophic cascade effects should be a focal area of fisheries research in the Baltic Sea.

7. Cumulative pressures need to be taken into account. Disturbance (e.g., by underwater noise) is worse when prey is depleted and missed feeding opportunities cannot be fully compensated for.

There is circumstantial evidence that harbour porpoises are especially vulnerable to disturbance due to their high metabolic rate and the need to feed constantly. In this light, prey species, size, and energy content matters as it determines how many missed opportunities can be compensated for by prey of a good quality and sufficient quantity. Research on prey composition and monitoring of nutritional status would be a first step to better understand energetic consequences of disturbance for individuals and possible impact on the population. It is likely that autumn (when blubber is deposited to prepare for the winter) and spring (when more energy is required for pregnancy and lactation) are especially sensitive periods. With fertility and reproductive success very likely impacted by environmental contaminants (see point 8) that are virtually impossible to be removed from the environment, all other threats need to be minimised to allow the population to recover.

8. There is a general need to avoid contaminants and waste entering the marine environment as they negatively influence harbour porpoise health, reproduction and survival.

Even in the event of reduced pollutant sources, improvement in the environment is not observed for a long time due to long lasting exposure and effects. Taking this knowledge into account, prevention of new contaminants from entering the food web should be of utmost importance.

Contaminants: Emissions of hazardous substances especially persistent, bioaccumulative and toxic (PBT-) substances to the marine environment should be further reduced. Although there are only few samples available to study contaminants in the Baltic Proper harbour porpoise tissues, high contaminants' concentrations are suspected to affect the health status, including the increasing the risk of infectious disease and reproductive failure. This threat is of particular importance in the Baltic Sea where higher concentrations of contaminants (e.g. PBDE, Mercury, PCBs) are observed compared to other parts of the world. Actions of the BSAP relating to hazardous substances should be ambitiously implemented.

Waste: Plastic debris can pose a threat to harbour porpoise through entanglements and ingestion. Data on entanglement of small cetaceans in ghost nets are generally lacking mostly due to difficulties to differentiate between actual entanglement in ALDFG and entanglement in active gear (bycatch). There is a need to establish relevant funding mechanisms in order to remove ghost nets and other plastic items from the marine environment on a regular basis. Preventive actions to avoid gear loss must be urgently taken. Data on ingestion of microplastics are available for the Baltic Sea harbour porpoises, especially from the necropsy of individuals from the Belt Sea population. However, the toxicological and pathogenic effects of microplastics on cetaceans are still poorly understood. Microplastic is a potential vector for POP burden but further studies are needed.

9. Avoid unprotected underwater explosions.

Explosions of UXO have been linked to blast injuries and death of harbour porpoises in the Baltic Sea. In small populations of long-lived late reproducing populations, the direct mortality associated with explosions (e.g., during UXO clearance) affects the population. Even in larger harbour porpoise populations, a population impact of regular UXO clearing activities has been shown (Benda-Beckmann et al., 2015). Explosions are the loudest point source emitters of impulsive noise. They are among the most commonly occurring events of impulsive noise sources in the Baltic Sea (HELCOM Impulsive noise indicator report - HELCOM 2023e). Therefore, UXO explosions in situ should be avoided. If this is not possible due to safety reasons, relevant noise/blast mitigation measures including e.g. bubble curtains, should be implemented.

10. There is a need to regulate and limit the use of emerging noise sources such as seal scarers and acoustic antifouling devices.

Licensing and/or limiting seal scarers and acoustic antifouling devices will help to minimise their impacts. The HELCOM Regional Action Plan for Underwater Noise (HELCOM Recommendation 42-43/1) proposes to develop and agree on common guidelines and regulations of the design and use of deterrent devices. Due to their large impact area, a widespread use of seal scarers (such as in fisheries and aquaculture), should be avoided.

There is also a need to investigate and regulate acoustic antifouling devices. Behavioural studies could use individuals of other harbour porpoise populations as a model. A regulation must be introduced at an early stage before these devices are omnipresent in the Baltic Sea.

11. A common database including the cause of death, health status, contaminant load, and population assignment of each animal investigated would help in quantifying the population-level impact of each activity.

Knowledge gaps related to bycatch rates, contaminant loads, health status, vessel strikes, and plastic ingestion, can be addressed in established stranding networks and strandings databases in order to improve the availability of data from all stranded animals. Databases currently available or under development should be coordinated. This is especially needed in the Baltic Proper. Post mortem investigations in the Baltic region should include routine sampling of genetics in order to determine whether the individual is from the Baltic Proper population.

Disease factors and mortality etiologies are difficult to study and only few samples are available for the Baltic proper harbour porpoise, with current knowledge coming mainly from the neighbouring Belt Sea population. However, parasite infections in the Baltic Sea, including the Baltic Proper population, seem to be higher than in other areas (e.g. Greenland). It seems that environmental factors such as level of contaminants, play a role in the health status of harbour porpoises.

12. In general it is difficult to assess the impact on populations since in most cases the impact on individuals can be evaluated at best.

Available methods for the transfer of impacts on the individuals to the population-level such as PCoD require extensive modelling exercises which are not operational. The development of practical standard methods for fulfilling legal requirements (e.g., for underwater noise the MSFD requires assessment of the impact on populations which is the prerequisite for necessary measures) would help implementing measures on the basis of indications of energetic consequences of individuals.

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