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Summary of the SAMBAH project

Mats Amundin et al.

INTERNATIONAL WHALING COMMISSION

SAMBAH

STATIC ACOUSTIC MONITORING OF THE BALTIC SEA HARBOUR PORPOISE

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Summary of the SAMBAH project

SAMBAH targeted the Baltic Proper population of harbour porpoise (*Phocoena phocoena*). Three recent studies using genetics (Wiemann et al. 2010), morphometrics (Galatius, Kinze, and Teilmann 2012) and data from satellite tagged animals in combination with passive acoustic detections (Sveegaard et al. 2015) support the existence of three different harbour porpoise populations in the Baltic Sea region; one having its main distribution in the North Sea, Skagerrak and northern Kattegat, one in southern Kattegat, the Belt Sea and the southwestern Baltic Sea, and one in the Baltic Proper. The Baltic Proper population is small and has been drastically reduced during the last decades. The species is listed in Annexes II and IV of the EC Habitats Directive as well as in the national red lists of several Member States. When SAMBAH started, the conservation status of the population in combination with a complex of threats necessitated improved methodologies for collecting data on population size and distribution, and fluctuations over time. The overall objective of the project was to launch a best practice methodology for this purpose and to provide data for a reliable assessment of distribution and preferred habitats of the species. This would make possible an appropriate designation of SCIs for the species within the Natura 2000 network as well as the implementation of other relevant mitigation measures.

SAMBAH objective 1 was to estimate densities, produce distribution maps and estimate abundances of harbour porpoises in the project area. Density and abundance estimates have been produced by season for the whole study area and within country. Distribution maps showing probability of detection was produced per month. Estimates of density and abundance are necessary to assess the conservation status of the population and the negative impact of anthropogenic activities such as bycatch. It will also serve as a baseline for possible future surveys to follow up the effects of conservation measurements taken. Distribution maps are essential to identify areas of importance and areas with higher risk of conflicts with anthropogenic activities.

SAMBAH objective 2 was to identify hotspots, habitat preferences, and areas with higher risk of conflicts with anthropogenic activities for the Baltic Sea harbour porpoise. In Swedish waters, these results have been used to identify appropriate areas for protection, and within these areas to suggest appropriate management of anthropogenic activities with known or potential negative impact.

SAMBAH objective 3 was to increase the knowledge about the Baltic Sea harbour porpoise among policymakers, managers, stakeholders, users of the marine environment and the general public, in the EU Member States bordering the Baltic Sea. This is necessary to reach the ultimate aim of the project, a favourable conservation status of the Baltic Sea harbour porpoise.

SAMBAH objective 4 was to implement best practice methods for cost efficient, large-scale surveillance of harbour porpoises in a low density area. The implementation of coherent methods throughout the distribution range of the Baltic Sea harbour porpoise aimed at

facilitating future monitoring actions in order to follow up the effects of conservations measurements taken on a local, regional, national or transnational scale.

Project consortium

SAMBAH was coordinated by Dr Mats Amundin at Kolmårdens Djurpark AB, with nine associated beneficiaries in Sweden, Finland, Poland and Denmark. The project also included actions in Estonia, Latvia and Lithuania through subcontractors and in Germany through cooperation with the German Oceanographic Museum. The added value of the SAMBAH partners has been very high. All partners have added their specific expertise, competence and network of contacts to the project, which have been immensely valuable, both for purely technical reasons such as handling C-PODs in the field (anchoring etc.) and estimating the detection function of C-PODs, but also for their local knowledge necessary for conducting fieldwork, and their national contacts which has helped spreading information about the project and gaining approval for project results among a wider group of stakeholders.

Project execution

Essentially, SAMBAH can be said to consist of three phases; preparation, field work and analyses. The preparation phase included preparation of field work such as acquiring permits to deploy equipment, readying equipment and personnel for deployment, preparing the database to receive field data and procurement procedures for external assistance and porpoise click detectors. The field work included a two-year field period collecting data on harbour porpoise presence using porpoise click detectors and collecting auxiliary data from satellite tagged animals and other methods. The analysis phase included estimation of porpoise density and distribution in the study area, and application of those results to identify suitable areas for protection in Swedish waters.

Methods

Data collection

In SAMBAH, passive acoustic data on harbour porpoise occurrence were collected for two full years, from 1 May 2011 to 30 April 2013. The study area (Fig. 1) encompassed the Baltic Sea from the Archipelago Sea around Åland in the north (south of approximately LAT 61° N) to the Darss sill (between Denmark and Germany, approximately LON 12° E) and the Limhamn/Drogden sill (between Sweden and Denmark, approximately LAT 55° 50' N) in the south-west. The northern limit of the project area was based on the current distribution of opportunistic sightings (HELCOM 2015). The south-western limit followed the definition that has been used in previous studies of the genetic population structure of the harbour porpoise in the Baltic region (Berggren *et al.*, 2002). The Russian waters of the Kaliningrad Oblast enclave and the St Petersburg area in the eastern-most part of Gulf of Finland were not included in the survey. The study area was limited to waters between 5-80 m depth, to avoid damage to the moorings in shallow waters, and due to the difficulties of anchoring detectors at greater depths. Overall, the study site covers approximately 166 800 km^2.

The survey was designed to have approximately 300 passive acoustic monitoring stations in the study area. To achieve the desired number of stations, a primary grid of stations was created with a distance of 23.5 km between positions. A secondary grid with the same distance between stations, offset by 11.75 km from the primary grid, was created to serve as replacement in case positions in the primary grid were considered unacceptable. The grids were placed over the study area with a random starting point and at a random angle. The random placement of the grid of stations ensured a reasonable representation of covariate ranges and combinations for species distribution modelling. The final design had 304 stations (Fig. 1).

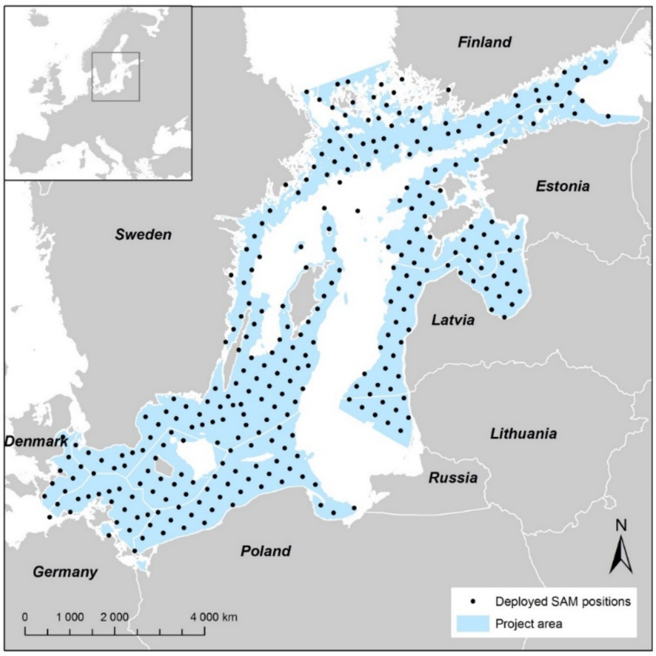

Figure 1. The study area in the depth interval 5-80 m shown in blue and deployed stations shown as black dots.

Among the available passive acoustic detectors, C-PODs (www.chelonia.co.uk) were selected for this study based on its successful performance in numerous previous studies (c.f. Brandt et al. 2011; Carlström 2005). C-PODs have an omni-directional hydrophone with linear sensitivity between 80-130 kHz, and extract and store a selection of parameters that describe the clicks, which reduces the amount of stored data drastically, allowing for several months of data collection before servicing is needed. Post-processing used the KERNO classifier to extract coherent click trains and classify possible cetacean clicks, and a secondary encounter classifier (Hel1), specifically designed for Baltic Sea conditions, was developed to reduce the false positive rate. This is important in a low density area where false positive detections may ultimately trigger conservation actions to no avail. The C-POD detection threshold at 130 kHz is well standardized compared to older instruments (Dähne et al. 2013) indicating that detection ranges of individual C-PODs should be similar, which is essential when estimating density and abundance.

As expected some C-PODs were lost at sea, most of them likely due to trawling, others due to ships running over buoys or failing anchoring systems; buoys sinking or acoustic releasers failing to release. There were also some initial issues with C-PODs stopping prematurely when switching from the between the two stacks of batteries. All these factors resulted in loss of data, but still the data recovery rate of 68% is quite good for a project of this size and we consider this a success. The data collected where aggregated per month and station, giving information on the number of detected clicks per month and station, together with the total time surveyed per month and station.

Density and abundance estimation

The methods used here for estimating density and abundance from passive acoustic detections are based on point transect methods (Buckland et al. 2001). However, while point transect methods are based on measuring the distance to each detected animal, the passive acoustic devices used in a study such as this do not allow for estimating distances to the source of the sound detected. Therefore, alternative methods had to be employed to calculate the detection function of the C-PODs.

The detection function describes the probability of a porpoise to be detected as a function of its distance to the detector. From this it is possible to calculate the effective detection radius (EDR) and effective detection area (EDA), which can be used to estimate absolute density and hence abundance. Except for the distance between the porpoise and the C-POD, the detection function depends on a number of things, including the amount of time a porpoise generates clicks, how the porpoises rather narrow echolocation beam is pointed in relation to the detector, the source level of emitted clicks and the attenuation of the sound in the water, which in turn is affected by environmental factors such as the temperature and salinity of the water, the presence of pycnoclines and the type of bottom sediment.

To estimate the detection function of C-PODs, four main experiments were conducted. Firstly, man-made harbour porpoise-like sounds were played at different distances from the

C-PODs deployed in the study area, during summer and winter seasons. This was expected to give information on how the detection function was affected by the varying environmental conditions over space and time in the vast study area. Secondly, free-swimming porpoises where tracked acoustically in an area with a dense grid of C-PODs (a POD garden) set up in an area in the Great Belt. The reason this experiment was executed outside the study area was that the density of porpoises here is much higher, which greatly increased the chances of collecting enough data. Thirdly, the man-made porpoise like sound was played to the C-PODs in the POD garden in the Great Belt, to give a conversion factor between the live free-swimming porpoises outside the study area and the man-made porpoise sounds within the study area. Lastly, the click rate of free-swimming harbour porpoises was estimated per diel phase by tagging harbour porpoises incidentally caught in pound nets in Danish waters with acoustic tags. The detection function for C-PODs in the study area was then modelled based on all these input data.

Since porpoise echolocation clicks do not allow us to tell the difference between individuals, density estimation was based on one second intervals. This allowed us to assume that one detection positive second corresponded to one individual.

Density was initially estimated separately for each individual station, month and diel phase (morning, day, evening and night as follows

$$\hat{D}_{imd} = \frac{n_{imd}}{T_{imd}\hat{v}_{imd}} \tag{1}$$

where *D* is density, *n* the number of click positive seconds (CPS), *T* the number of seconds of monitoring effort, *ν* the effective detection area (EDA), the hat symbol ^ indicates an estimate and subscripts *imd* indicate that all quantities are for sampling location *i* in month *m* and diel phase *d*. Density per station and month was estimated as a weighted mean of the diel phase density estimates:

$$\hat{D}_{im} = \sum_{d=1}^{4} w_{imd}\hat{D}_{imd} \tag{2}$$

where w_{imd} is the proportion of the 15th day of month *m* at location *i* that is made up of diel period *d* (1=morning/dawn, 2=day, 3=evening/dusk, 4=night). Density at higher levels of aggregation was estimated as the mean of the relevant station- and month-specific estimates. Abundance was estimated as density multiplied by the relevant survey area.

The data from playbacks and the hydrophone array experiment were combined to model the detection probability function of free-swimming porpoises in the Baltic Proper, which was then used in the density estimation together with data from satellite tagged animals and the C-POD data from the study area. The following general equation was used for the density estimation:

$$\hat{D}_{imd} = \frac{n_{imd}}{T_{imd}\hat{v}_{imd}} \quad (1)$$

where D is density, n the number of click positive seconds (CPS), T the number of seconds of monitoring effort, v the effective detection area (EDA), the hat symbol ^ indicates an estimate and subscripts imd indicate that all quantities are for sampling location i in month m and diel phase d.

Modelling of porpoise distribution

To achieve monthly surface covering maps of harbour porpoise distribution in the study area, species distribution modelling was employed. Response data was the presence or absence of harbour porpoise detections aggregated per month per station, so that one or more detections at a station during a month is considered a presence and no detections at a station during a month is considered an absence. Modelling was carried out using generalized additive modelling (GAM) in R version 3.1.3 (R Core Team 2015), using the packages mgcv (Wood 2011) and scam (Pya and Wood 2015). Occurrence of porpoise detections was modelled using a binomial distribution with a logit link function.

The aim here was not to determine the influence of different environmental covariates on harbour porpoise distribution, but rather to achieve the best possible predictions. A pre-determined set of 10 candidate models was compared and the best model was chosen based on AIC (Akaike 1974). The selection of candidate models was based on a priori knowledge from previous studies in other areas regarding the covariates that could best explain spatial distribution of harbour porpoises, and on what covariates were available for use. Only static variables were used, i.e., variables that do not vary over time (Table 1, paper I). All candidate models (Table 2, paper I) included an interaction term between two-dimensional spatial coordinates in the Zone 32 (N) Transverse Mercator projection with the WGS84 datum (UTMX, UTMY). This interaction term was set to give a different tensor 2D-smooth for each month of the year, to account for changes in spatial patterns depending on time of year. Time of year was taken into account in all models by including a cyclic spline smooth for month, and depth was included in all candidate models. All models also included time surveyed as a covariate (normalised to have a maximum value of 1) and as a weight (normalised to have a mean value of 1). Time surveyed was truncated if less than one day per month and station. The inclusion of time surveyed accounted for the fact that the time surveyed per station and month varied due to data losses, and ensured that stations with lower effort did not have as much impact on the model as stations with full effort, which may bias the results.

Results

Spatial and seasonal division based on detection rates

When designing this study, we were expecting seasonal differences in harbour porpoise distribution. It seemed logical that porpoises would not spend the whole year in the same place; if nothing else they would have to move when the ice settled in the northern areas. Since we aimed to estimate density and abundance per season, the spatial and seasonal distribution of harbour porpoise detections was visually inspected and a seasonal division into summer (May – Oct) and winter (Nov – Apr) was established, based on distributional patterns in the data being clearly different between those two seasons (Fig. 2). While animals were cleary more widely dispersed during the winter period, they were aggregated in two major clusters during summer. One such cluster occurred in the southwest, and previous studies indicate this cluster is very likely made up of animals from the Belt Se a population (c.f. Benke et al. 2014; Sveegaard et al. 2015). Given the fact that satellite tagged harbour porpoises from this population have never been shown to enter as far into t6he Baltic Sea as the other cluster (Sveegaard et al. 2015), situated on and around the offshore banks in the Baltic Proper, and the existence of a spatial separation between the two clusters, we believe that this second cluster represents the remnant Baltic Proper harbour porpoise population. For the abundance estimate to correctly reflect the size of this population, we decided to divide the study area into two subareas during summer, so that abundance could be calculated separately for these two subareas. During winter, with animals spread more widely and no clear separation between clusters, it was assumed that the two populations overlap in at least part of the area, and abundance was calculated for the entire study area.

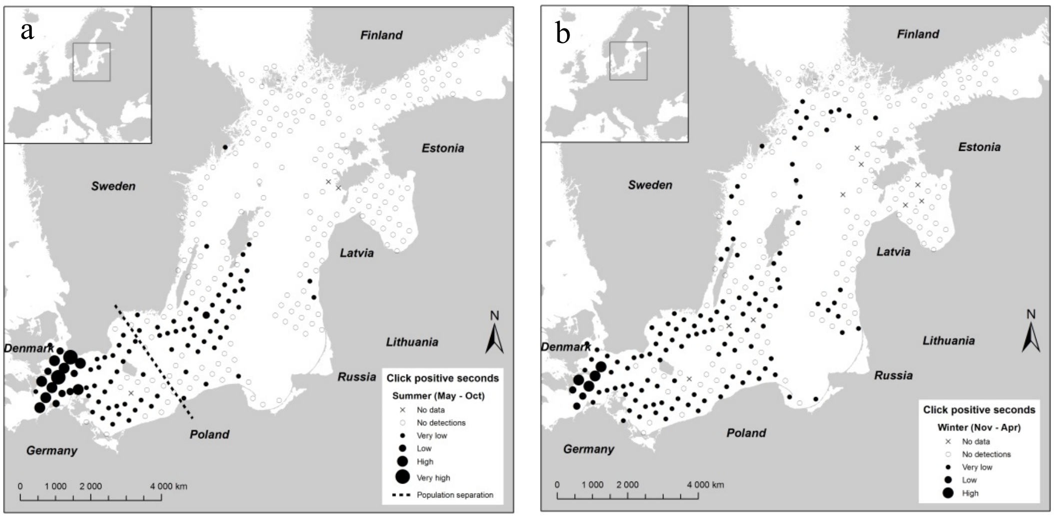

Figure 2. Average relative detection rates (click positive seconds/time surveyed) per station and month for summer (May – Oct, a) and winter (Nov – Apr, b), with the delimitation of population areas in (a).

Density and abundance estimation

Results of density and abundance analysis are summarized in Table 1, where the estimate for Summer/NE is believed to represent the size of the Baltic Proper population of harbour porpoise.

Season/region	Density (D)	95% Lower CI (D)	95% Upper CI (D)	Number of porpoises (N)	95% Lower CI (N)	95% Upper CI (N)
Winter	0.06578	0.3323	0.14353	10958	5535	23910
Summer/NE	0.00375	0.00060	0.00823	497	80	1091
Summer/SW	0.62946	0.39613	1.1894	21390	13461	38024

Table 1. Estimates of density and abundance of porpoises in the SAMBAH study area. The summer estimate for the north-eastern part of the project area is thought to represent the Baltic Proper population.

Modelling of porpoise distribution

Model predictions show the monthly probability of acoustically detecting harbour porpoises. Fig 3 shows seasonal averages for probability of detection.

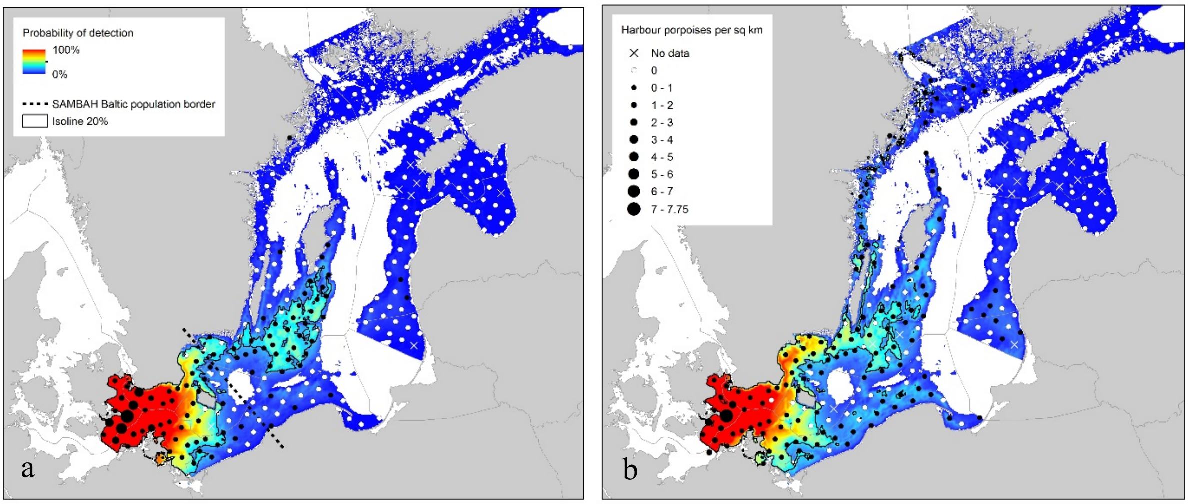

Figure 3. Mean probability of detection of harbour porpoise for summer (May – Oct, a) and winter (Nov- Apr, b). The dotted line indicates the border used for abundance estimation of the Baltic harbour porpoise population in SAMBAH.

Investigations on overlap between important areas for porpoises and anthropogenic activities were also carried out. In Fig. 4 is an example of catches in gillnet fisheries shown together with important areas for harbour porpoises. The dashed line indicates the proposed delimitation border between a cluster of the Baltic Proper porpoise population found the central Baltic Sea and another cluster found in the south-west, with porpoises from the Belt Sea population.

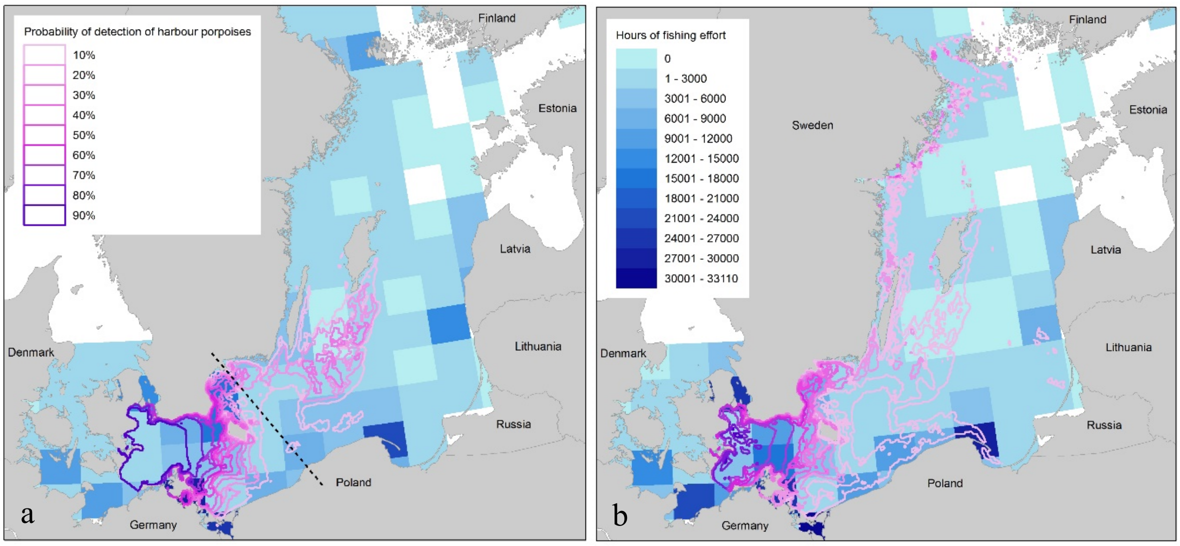

Figure 4. Total hours fished with gillnets of mesh size ≥90 mm per ICES square in Apr – Sep (a) and Oct – Mar (b) 2014 (STECF, 2015; data downloaded from the European Commission DCF – Data dissemination database https://datacollection.jrc.ec.europa.eu/dd/effort/maps) shown together with average probability of detection of harbour porpoises for May – Oct (a) and Nov – Apr (b). The legend for the fishing effort is shown in (b). The dotted line indicates the border used for abundance estimation of the Baltic harbour porpoise population in SAMBAH.

Discussion

New knowledge on spatial and seasonal distribution

Before this study was carried out, the main distribution of harbour porpoises in the Baltic Sea was thought to be in coastal areas, since the only available recent information on distribution came from opportunistic sightings (HELCOM 2015), and such sightings occur where there is overlap between porpoises and people, i.e. in near-shore areas. In offshore areas the effort is too low to detect any significant number of animals despite their presence.

Thus, this study provides essential new knowledge on the spatio-temporal distribution of harbour porpoises in the Baltic Sea. Specifically, results show a spatial separation between the Belt Sea and the Baltic Proper populations during the breeding season, supporting previous studies suggesting the existence of a separate Baltic Proper population of harbour porpoises. Our results also suggest the existence of a previously unknown critical breeding ground for the Baltic Proper population of harbour porpoises around the offshore banks in the central Baltic Proper, given that this is where most of the population seem to be during the breeding season. Additionally, we found that the winter distribution of harbour porpoises is much more wide than previously thought, and that animals move surprisingly far north during winter. Actually, the main part of detections in Finnish and northern Swedish waters occur in January – March.

Abundance estimates for a never-before surveyed area

Previously conducted aerial line-transect surveys focussed on the Belt Sea and southwestern Baltic Sea, and extended to the north-east to only include covered only a small part of the southern Baltic Proper, excluding for example the offshore banks where the main aggregation of animals was found in this study. Hence, the abundance estimate for the Baltic Proper arrived at here cannot be compared to previous estimates.

Our estimate of 500 individuals for the Baltic Proper population supports the fact that the Baltic Proper population of harbour porpoises is critically endangered. An analysis of Potential Biological Removal (PBR, Wade 1998) indicates that an anthropogenic mortality of more than 1 animal per year is unacceptable if the population should recover to 80% of its carrying capacity. The current rate of bycatch in fisheries is unknown, but was estimated to 7 animals per year in 2002 (Berggren et al. 2002). Although the gillnet fishing effort has decreased dramatically in the last decade, primarily due to the increase in the grey seal population and hence in damaged fishing gear (Sara Königson, SLU Aqua, pers. comm., 2016), there is a real risk that the bycatch rate is still unsustainable. Including other threats such as underwater noise means that a recovery will be difficult, and that there is even risk for extinction.

Passive acoustics as a tool to estimate distribution and abundance of marine mammals
This study has shown that passive acoustics are very well suited for investigating the distribution and abundance of harbour porpoises, and the methods used here can easily be adapted to any species of echolocating of marine mammal. The study design rendered data extremely well suited for species distribution modelling, primarily due to the number of stations and the random design which ensured representation of different combinations of covariate values, and model evaluation measures show that models fit the data very well. Methods for density and abundance estimation has partly been developed during the project lifetime, and lessons were learned along the way. Most importantly, acoustic monitoring devices should be developed to measure distances to detected clicks. This would make it possible to directly estimate the detection function, and thus the EDA, in the study area. However, it is already possible to use the methods developed to estimate absolute densities and abundances of toothed whales.

Implications of results
With the results on abundance and distribution presented here, we now have a better chance than ever to take effective conservation measures for this endangered population. By combining distribution maps from this study with spatio-temporal information on fishing effort, it will be possible to examine the overlap between higher densities of harbour porpoises and large fishing effort with gear types known to cause bycatch (Kindt-Larsen et al. in press). In the identified high-risk areas, mitigating bycatch can then involve both replacing bottom set gillnets with other types of gear and/or closing certain types of fisheries in areas important to harbour porpoises during part of the year. Additionally, in some cases using porpoise deterrence devices such as pingers may also be an option to mitigate bycatch (Dawson et al. 2013) but may cause substantial habitat loss (Kyhn et al. 2015).

Mitigation of anthropogenic impulsive underwater noise, which often originates from construction of for example offshore windfarms or military activities, includes avoiding generation of such sounds (emission) in or near important harbour porpoise areas at relevant times of the year, attenuating the noise at the source through various dampening techniques (Lucke et al. 2011; OSPAR Commission 2014), or limiting the risk of injury through deterring animals from the affected area using acoustic devices (SMRU Ltd 2007; Brandt et al. 2013). Mitigation of continuous noise, often originating from shipping, is often more complex but includes techniques for silencing vessel noise, speed limits for shipping and re-routing of shipping lanes (Haren 2007; International Maritime Organization 2014). With this new information on the distribution of porpoises, these mitigation measures can be applied to the Baltic Proper harbour porpoise population, and the abundance estimate given here can be used as a base-line to evaluate effectiveness of measures taken.

Concluding remarks

This study provides new and important information on the spatial and seasonal distribution and abundance of the Baltic Sea harbour porpoise, including evidence of a vital breeding ground. It also supports the existence of a separate population of harbour porpoises in the Baltic Proper. The abundance estimate of this isolated population of ca. 500 (95% CI 80-1,091) show that it is very vulnerable. We therefore suggest that marine protected areas (MPAs) such as Natura 2000 sites, should be designated for porpoises on and around the offshore banks in the Baltic Proper, as well as south of Öland island, in the Hanö Bight and along the Polish coast. Management plans specifying effective measures to ensure the conservation of harbour porpoises should be assigned for these areas as well as already existing sites, and should include measures to mitigate bycatch as well as other anthropogenic threats such as underwater noise and habitat deterioration. Additionally, to achieve the ASCOBANS goal of zero bycatch, fisheries regulations must be employed not only within future and current MPAs but in a larger area encompassing the entire Baltic Proper south of Gotland island.

We have shown here that passive acoustics are very well suited for investigating the distribution and abundance of harbour porpoises, and the methods used here can easily be adapted to any species of echolocating of marine mammal.

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