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marine conservation research.org

Akustisk övervakning av tumlare i sydöstra Östersjön

Akustisk och visuell inventering av östersjötumlare över Hoburgs bank och midsjöbankarna

En rapport framtagen av Marine Conservation Research, Länsstyrelsen i Gotlands län och Kalmar län

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Rapportens metadata

Acoustic and visual survey for marine mammals conducted over Hoburg’s bank and the midsea banks, Baltic Sea, Sweden from 8-16 August 2022

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Sammanfattning på svenska

Länsstyrelsen i Gotlands och Kalmar län tillsammans med Marine Conservation research teamet genomförde en visuell och akustisk fartygsbaserad linjetransektundersökning för närvaro och distribution av marina däggdjur över Hoburgs Bank och Midsjöbankarna (norr och söder) från 8 till 16 augusti 2022. Undersökningen omfattade 1 692 km akustisk ansträngning, varav 830 km också inkluderade visuell ansträngning. Alla planerade transekter undersöktes med åtminstone akustisk ansträngning.

Akustiska undersökningar utfördes med hjälp av en rad hydrofonelement som bogserades 140 m bakom undersökningsfartyget vid 5-8 knop; detektion av tumlarklick utfördes med hjälp av mjukvarupaketet PAMGuard och validerades av en mänsklig observatör.

Visuella undersökningar utfördes från fartygets fördäck under dagsljus under lämpliga sjöförhållanden (sjötillstånd 3 eller mindre) av två observatörer med ungefärliga ögonhöjder på 3,5 m över havet. Det gjordes 10 observationer av gråsälar men inga tumlare sågs. Det gjordes minst 12 akustiska detekteringar av tumlare.

När man endast beaktade "spår" (dvs. en sekvens på ≥ tre klick med ett tydligt transektspår, ”tracks” i rapporten) uppskattades tumlarens densitet till 1,2 tumlare per 1000 km^2 (95 % KI 0,3–4,4, CV = 75 %) i hela studieområdet. Detta steg till 2,5 tumlare per 1000 km^2 (95 % KI 0,6–10,2, CV = 80 %) när en korrigering infördes för de djur som sannolikt hade missats.

Dessa densiteter gällde för hela området i undersökningsblockets uppskattningar av 22 tumlare (95 % KI 6–82), vilket ökade till 47 tumlare (95 % KI 12–191), när en korrigering för tillgänglighet tillämpades. Det bör noteras att de höga variationskoefficienterna ledde till den motsvarande höga osäkerheten, vilket återspeglas i de breda konfidensintervallen.

Även om direkta jämförelser med tidigare studier är utmanande, överensstämmer densitetsuppskattningarna som presenteras här i stort sett med de för SAMBAH-projektet för Egentliga Östersjön (0,5-8,3 tumlare 1000 km^2 för maj-okt).

2022 års undersökning var begränsad i omfattning och varaktighet, men ger en baslinje som ytterligare undersökningar kan bygga på. Upprepade undersökningar skulle förbättra förtroendet för dessa ursprungliga uppskattningar och möjliggöra effektiv övervakning av förändringar i den lokala tumlartätheten över tid.

Denna inventering genomfördes med medel från Havs- och vattenmyndigheten och Naturvårdsverket.

Innehållsförteckning

Acoustic and visual survey for marine mammals conducted over Hoburg's bank and the midsea banks, Baltic Sea, Sweden from 8-16 August 2022

Summary

The Länsstyrelsen and MCR team conducted a visual and acoustic vessel-based line-transect survey for the presence and distribution of marine mammals over Hoburg's Bank and Midsjöbankarna from 8th to 16th August 2022. The survey incorporated 1,692 km of on-track acoustic effort over this region of the Baltic Proper, of which 830 km also included visual effort.

All of the planned transects were surveyed with at least acoustic effort. Acoustic surveys were conducted using an array of hydrophone elements towed 140 m behind the survey vessel at 5-8 knots; detection of candidate porpoise clicks was conducted using the software package PAMGuard and validated by a human observer. Visual surveys were conducted from the foredeck of the vessel during daylight hours in suitable sea state conditions (sea state 3 or less) by two observers with approximate eye heights of 3.5 m above sea level. There were 10 sightings of grey seals but no harbour porpoises were seen. There were at least 12 acoustic detections of harbour porpoises.

When considering only 'tracks' (i.e. a sequence of ≥ three clicks with a clear bearing trail), the density of porpoises was estimated as 1.2 porpoises 1000 km^{-2} (95 % CI 0.3-4.4, CV = 75 %) throughout the study area; this rose to 2.5 porpoises 1000 km^{-2} (95 % CI 0.6-10.2, CV = 80 %) when incorporating a correction for those animals likely to have been missed. These densities applied to the whole survey block derived abundance estimates of 22 porpoises (95 % CI 6-82), rising to 47 porpoises (95 % CI 12-191), when a correction for availability was applied. It should be noted the high coefficients of variation led to the correspondingly high uncertainty as reflected in the wide confidence intervals.

Although direct comparison with previous studies is challenging, the density estimates presented here broadly align with those of the SAMBAH project for the Baltic Proper (0.5-8.3 porpoises 1000 km^{-2} for May-Oct). The 2022 survey was limited in scope and duration but provides a baseline upon which further surveys could build. Repeated surveys would improve the confidence of these initial estimates and allow effective monitoring of changes to local porpoise density over time.

Introduction

Cetaceans (whales, dolphins and porpoises) in the Baltic Sea are protected by both national legislation and international agreements. These include the European Marine Strategy Framework Directive (MSFD) [2008/56/EU], the goal of which is to effectively protect the marine environment across Europe by achieving Good Environmental Status (GES) according to eleven qualitative descriptors. Furthermore, ten states are parties to the Agreement on the Conservation of Small Cetaceans of the Baltic, Northeast Atlantic, Irish and North Seas (ASCOBANS), five of which neighbour the Baltic Sea. ASCOBANS developed a Recovery Plan for Baltic harbour porpoises (*Phocoena phocoena*) that recommended an improvement in our knowledge of key subject areas including the habitat preferences of porpoises, and the development and application of new techniques such as acoustic monitoring for assessing trends in abundance (the 'Jastarnia Plan'; ASCOBANS 2009). It also stated the necessity to develop and implement appropriate management plans within protected areas to improve the status of harbour porpoises. In addition to these agreements, the European Union's Habitats Directive directly obliges member states to designate Special Areas of Conservation (SAC) for harbour porpoises and provide strict protection for all cetacean species within their marine waters. Within the Swedish Baltic Sea, several Natura 2000 sites have been adopted as Sites of Community Importance (SCI) for harbour porpoises, but there is currently only one protected area in the Baltic Proper (i.e. east of 13.5°E). Hoburg's Bank and Midsjöbankarna was implemented as a Special Protection Area (SPA) for harbour porpoises in 2016 but was only designated as an SCI in December 2017. The area is not currently designated as a Special Area of Conservation (SAC).

Despite these protections, the abundance and distribution of harbour porpoises in the Baltic Proper has declined considerably during the last century (Koschinski, 2001; Gillespie et al., 2005) and the species is currently listed as 'Critically Endangered' in the Baltic Proper (Hammond et al., 2016). The most significant threat to porpoises both globally and in the Baltic Sea is incidental bycatch in fishing nets, principally gillnets (Koschinski, 2001). The current bycatch rate in the Baltic Sea is thought to be unsustainable, and Baltic porpoises may become extinct in the near future unless appropriate conservation measures are implemented (Hammond et al., 2016). The harbour porpoise is the only cetacean species resident in Swedish waters. Harbour porpoises reproduce seasonally and the mating in the Baltic Proper appears to take place in summer months (Kesselring et al., 2017). Data relating to the Baltic Sea population of harbour porpoises has data is largely deficient, with the first official population size estimate only being made available by the SAMBAH project (Static Acoustic Monitoring of the Baltic Sea Harbour Porpoise) from May 2011 to April 2013 (Amundin et al., 2021). This study estimated a summer abundance of 491 porpoises in the Baltic Proper (CV 68%; 95% CI 71-1105), dropping to 243 porpoises in the winter (CV 54%; 95% CI 94-560). Of two high density clusters identified in May-October, one was centred around the offshore banks south and southwest of Gotland in the region now incorporated in the Hoburg's Bank and Midsjöbankarna Natura 2000 site, with peak densities estimated in August. As this higher-density area is clearly separated from the known distribution range of the Belt Sea population during the summer breeding season, it seems feasible that Hoburg's Bank and northern and southern mid sea banks may represent an important breeding site for the Baltic Proper population (Carlén et al., 2018). As such, the effective protection of porpoises in this region should be considered of high priority.

Most information on the spatial and temporal distribution of harbour porpoises in the Baltic Proper is derived from reports of bycatch, strandings and opportunistic sightings. Previous aerial line transect surveys largely excluded the Baltic Proper (Berggren et al., 2002; Scheidat et al., 2008). To date, survey effort on Hoburg's Bank has largely relied on static recorders (Carlén et al., 2018, Amundin et al., 2021). Although a line-transect visual-acoustic vessel survey of the Baltic Proper in 2002 documented a porpoise encounter in the region that would be designated as Hoburg's Bank and Midsjöbankarna (Gillespie et al., 2005), only information on relative densities could be presented at that time. The goal of the survey described here was to characterise the density and abundance of harbour porpoises on Hoburg's Bank and Midsjöbankarna in the peak period of August as identified from the SAMBAH project. A line-transect survey was conducted by vessel using both acoustic and visual techniques. As the methodologies are conducted independently of each other, a survey of this type can provide two separate estimates of density. In addition, vessel surveys may allow visual estimates of cluster size, which can be used to refine acoustic density estimation, and any species-ID imagery can be used in outreach efforts. This report summarises the acoustic detections and sightings of marine mammals made during a line-transect survey in August 2022.

Methods

The Länsstyrelsen and MCR team conducted a visual and acoustic survey for the presence and distribution of marine mammals over Hoburg's Bank and Midsjöbankarna from 8th to 16th August 2022. The survey was conducted from a 14 m Salona 44 sailing yacht (S/V Karla Stockholm) with a Yanmar 55 hp diesel engine. The survey block was based on the footprint of the Natura 2000 site "Hoburgs bank och Midsjöbankarna" established in 2016 to protect two habitat types under the European Union's Habitats Directive and four species under the Nature Directives, including the harbour porpoise. The nine-day systematic survey was designed using standardised distance-sampling protocols to allow unbiased estimates of harbour porpoise density (Figure 2). Survey transect lines were randomly designed using the software package *Distance* to provide an even coverage of the survey block. Survey effort was divided in to two sets of equal-spaced zigzag transects of approximately equal total length (primary and secondary transects); this approach is most efficient when using sailing vessels as it reduces off-effort periods between transects and improves the likelihood of completing individual transects under sail. A survey speed of 5 to 8 knots was maintained when on transect, using the engine when necessary to achieve this. GPS data (date, time, latitude, longitude, heading and speed) were automatically logged every 10 s to a database in the *Logger* software package (marineconservationresearch.org). Estimates of environmental variables (such as sea state, wave and swell height) and survey effort (numbers and positions of observers) were logged hourly, or when these details changed, in *Logger*. All times used by computers and cameras on the vessel were synchronised to match the GPS in Coordinated Universal Time (UTC).

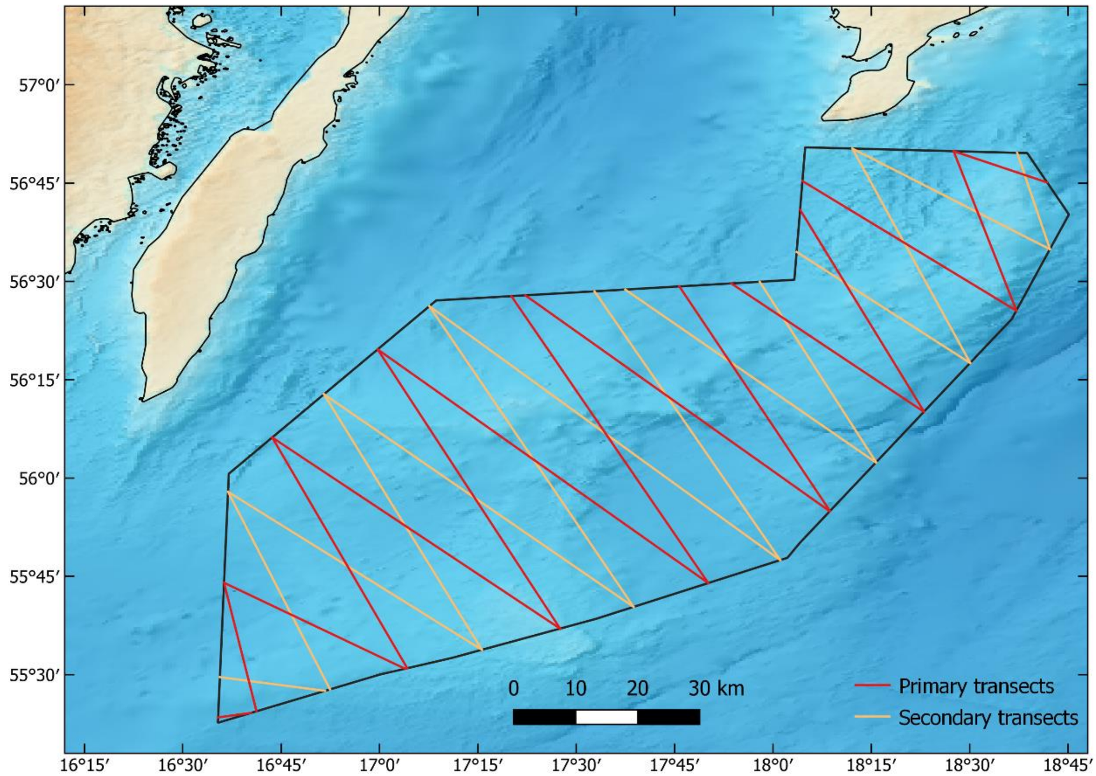

Figure 1. The study area showing the survey block to the south of Sweden's coastal islands Öland and Gotland. Survey transects were designed as equal-spaced zigzags using the software package Distance to provide almost uniform coverage probability.

Acoustic effort

While on survey, a hydrophone array was towed 140 m behind the vessel. The array contained two pairs of broadband elements (with sensitivity of 2 to 200 kHz) and one low frequency element (with sensitivity of 0-40 kHz; see Figure 2). Acoustic surveys took place 24 hrs/day in all sea states. The acoustic detection of odontocetes, including porpoises, was automated using click-detection algorithms in PAMGuard software (see below). Regular checks of PAMGuard were made for 2 minutes every 15 minutes by an operator to ensure there were no problems with the array and to monitor for other cetacean vocalisations, such as dolphin whistles. Four-channel recordings of the two pairs of broadband elements were made continuously at 500 kHz directly to hard drive as 16-bit wav files.

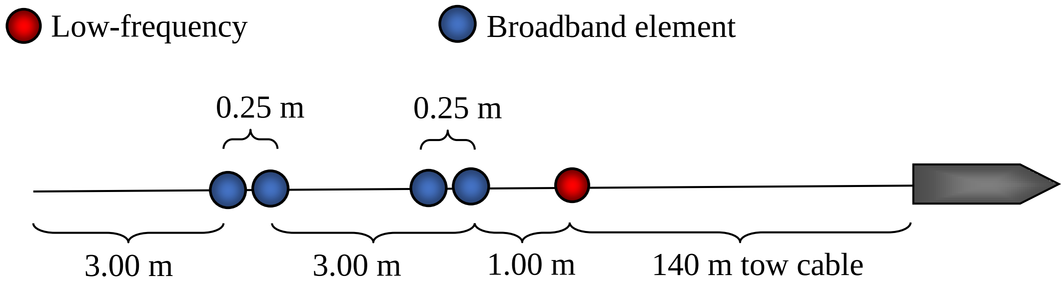

Figure 2. The hydrophone array with the positions of the broadband and low frequency elements.

PAMGuard is an open-source software program for acoustic detection, localisation and classification of marine mammals (Gillespie et al., 2008). PAMGuard was employed throughout the survey with a click detector module set up to detect harbour porpoise clicks. Harbour porpoises produce high-frequency, narrow band clicks with peak frequencies between 115 and 145 kHz (Teilmann et al., 2002; Kyhn et al., 2013). Candidate clicks were classified as harbour porpoise clicks if they met the following criteria: the click had a peak frequency between 100 and 160 kHz, the energy of the click was at least 5 dB above the background noise levels and less than 2 ms in duration, with a relatively flat structure revealed in a Wigner plot (see

Figure 3 below). Candidate porpoise clicks would typically appear as a track in PAMGuard as the vessel passed a harbour porpoise, with the bearing of clicks passing from in front of the array (i.e., the top of the bearing display) to behind the array (the bottom of the display). However, some candidate click trains were too short to reliably show a clear transition in bearing. Each acoustic detection was therefore classified as either a ‘track’ (a sequence of clicks with a clear and defined bearing trail) or an ‘event’ (two clicks with limited bearing information).

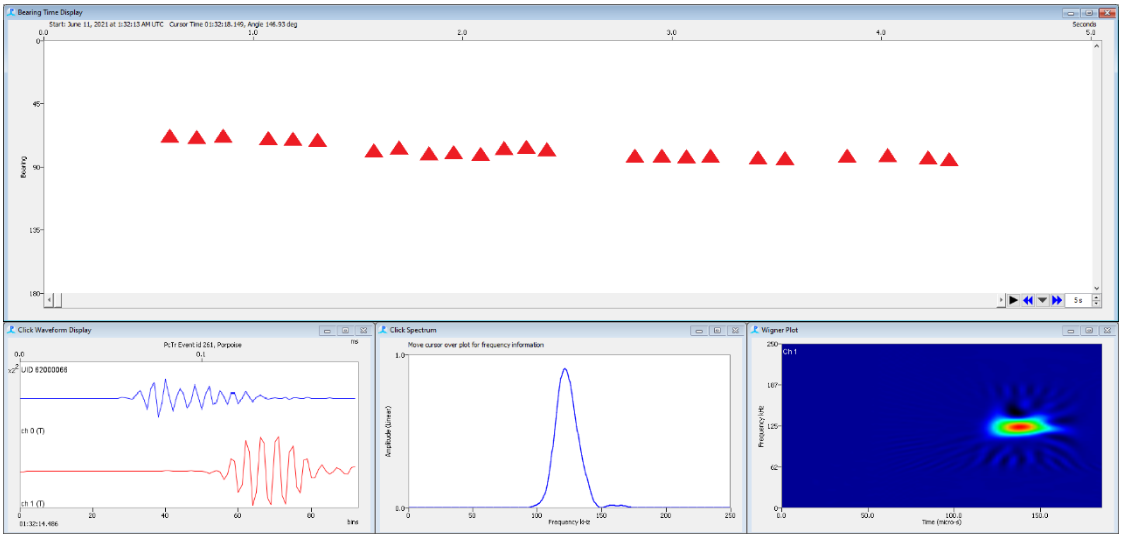

Figure 3. A typical harbour porpoise click train (red triangles) shown in PAMGuard. The top window shows bearing information for click-like events; the lower windows show a selected click's waveform (left), average spectrum (centre) and Wigner plot (right). The selected click displays the characteristic sinusoidal waveform, narrowband ultrasonic peak frequency (115–145) kHz and flat Wigner plot of harbour porpoises.

Differences in bearing information were used to identify individual click trains and estimate cluster size. Estimates of slant range were made in PAMGuard using the Target Motion Analysis (TMA) module's least squares optimization algorithm. A moving hydrophone array will detect a series of clicks from a focal porpoise; if the source is assumed to be stationary then each click will be detected with a set of time delays on the various elements. Successive sets of time delays can be visualised as 2D bearings converging on the likely location of the source (Figure 4). To differentiate between left and right convergence points, PAMGuard calculates a chi-squared goodness of fit between the simulated and observed bearings and the side with the smaller value is considered the best convergence point.

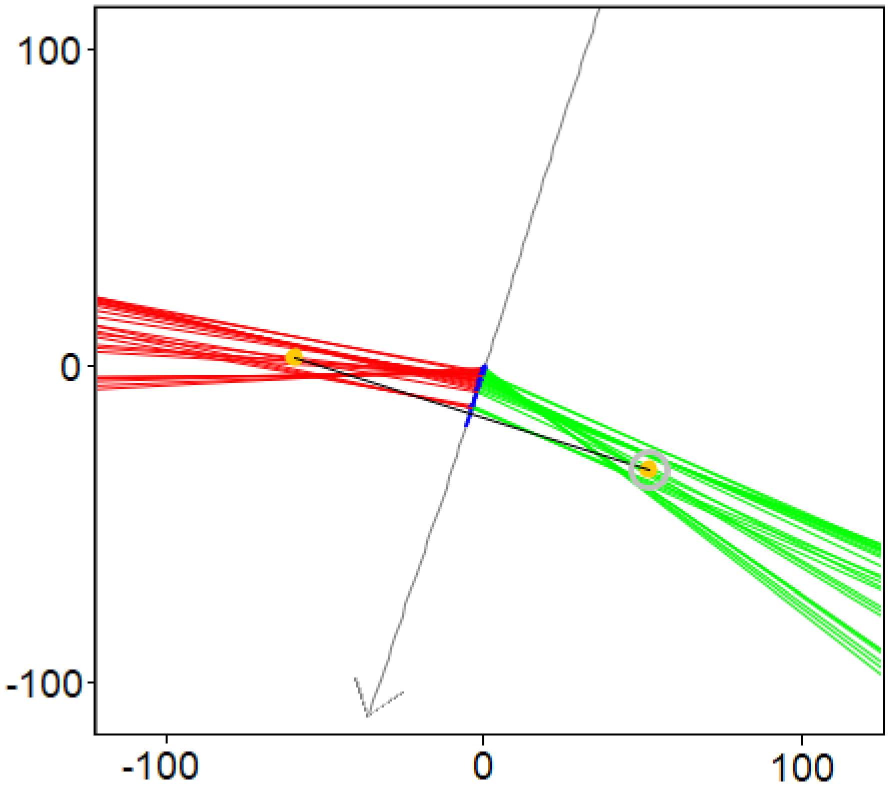

Figure 4. Estimating slant range in PAMGuard using target motion analysis (units in metres). The vessel's track is shown as the grey line, with bearing lines for consecutive porpoise clicks projected to either side of the vessel. PAMGuard uses incremental changes in the vessel's heading to resolve left/right ambiguity vie Maximum Likelihood Estimation. In this example, the vocalising porpoise was 69 m to port of the hydrophone array's beam.

Visual effort

Visual surveys were conducted from the foredeck of the vessel during daylight hours in suitable sea state conditions (sea state 3 or less). The approximate eye height of an observer in this location was 3.5 m above sea level. Two observers scanned opposing quadrants, concentrating their effort on the transect ahead of the vessel, with the port observer scanning from 270° to 10°, and the starboard observer scanning from 350° to 90°. Observers scanned with naked eyes, using 7x50 binoculars to confirm species identity and estimate group-size. Observers would convey all details of an encounter to a separate member of the team acting as data logger. The details logged for each sighting included species identity and estimates of relative bearing and distance to the centre of each group, along with estimate group size; these parameters were used in subsequent distance sampling analysis. Sightings of all marine mammals were logged including seals.

Acoustic density estimation of harbour porpoises

Slant ranges to porpoise clicks were imported into the *Distance* software to generate acoustic detection functions and density estimates using multiple covariates distance sampling (MCDS). Detection functions are the basis of distance sampling methods and allow for the estimation of density by modelling *g(x)*, the probability of detecting a porpoise given that it is at distance *x* from the transect. To maximise the available sample size, both 'tracks' and 'events' were included. As the distance estimates to two-click 'events' were derived from only two bearing lines, they should not be considered reliable. A subsequent analysis using 'tracks' only was therefore conducted to provide a precautionary estimate of local abundance. Robust estimates of detection function require at least 60-80 encounters (Buckland et al., 2001). As it is challenging to acquire large numbers of detections for low density populations, such as porpoises in the Baltic Sea, it is possible to increase the sample size by including acoustic detections made by similarly equipment following similar survey protocols. Thus, a larger acoustic dataset of porpoise detections collected in the North Sea using a similar survey protocol (Cucknell et al., 2017) was incorporated into the estimation of detection functions.

Several 'effort covariates' that could modify the noise field around the hydrophone array, and thus affect the likelihood of detecting porpoise clicks, were included in the MCDS approach and were thus able to modify the scale of the detection function without affecting its shape. These effort covariates were estimated in the field at least every hour and included sea state (Beaufort scale), wave height (m) and swell height (m); the speed of the research vessel (knots) was also included (logged every 10 seconds via GPS). Covariates were first investigated for correlation using Spearman's correlation coefficient to remove any potential redundancy; all remaining covariates and combinations of them were incorporated into model generation. Models were initially generated with single covariates; models combining two and three covariates were subsequently generated. The selection of the best detection function was made using Akaike's Information Criterion (AIC). Densities could then be estimated using traditional designed-based approaches (Marques et al., 2013).

Although harbour porpoises echolocate regularly (Akamatsu et al., 2007; Linnenschmidt et al., 2013; Wright et al., 2021), their clicks are highly directional and thus not all vocalisations will be detected by a hydrophone array, even at close ranges. It therefore cannot be assumed that the probability of detection for an animal directly on the trackline, $g(0)$, is 1. Availability for detection is influenced by both porpoise behaviour (specifically the proportion of time porpoises spend clicking) and by survey protocol (as survey speed affects the length of the finite time window during which animals can be detected). As the acoustic protocol used in 2022 was the same used in a 2011 survey of the North Sea (Cucknell et al. 2017), and assuming the diving behaviour of the porpoises is broadly similar between the two study areas, the 2011 $g(0)$ estimate of 0.46 was used (se of 0.14 as expected for a binomial distribution), based on 6 sightings being detected acoustically during 13 trials. Densities were estimated both with and without a correction for $g(0)$.

Results

The weather was broadly favourable for acoustic survey work during the project's duration; however, at times elevated sea states (Figure 5) made conditions sub-optimal for the visual detection of a cryptic species such as the harbour porpoise. The survey incorporated 1,692 km of on-track acoustic effort in the waters of Hoburg's Bank and Midsjöbankarna, of which 830 km involved visual effort (

Table 1). All of the planned transects were surveyed with at least acoustic effort (Figure 6).

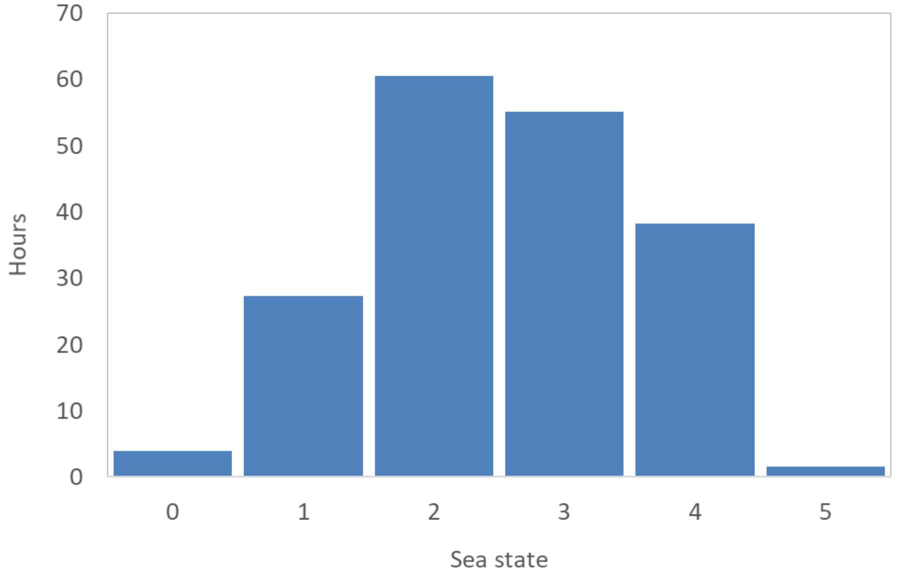

Figure 5. Histogram of sea states encountered during the survey.

Table 1. Summary of dedicated (on transect) and opportunistic (on passage) survey effort.

Effort status	Kilometres	Time (hh:mm)
On transect (acoustic only)	862	72:16
On transect (acoustic & visual)	830	69:52
On passage	205	20:15
On passage (acoustic only)	174	14:29
On passage (acoustic & visual)	46	4:18
Other	17	5:32
Total	2131	186:45

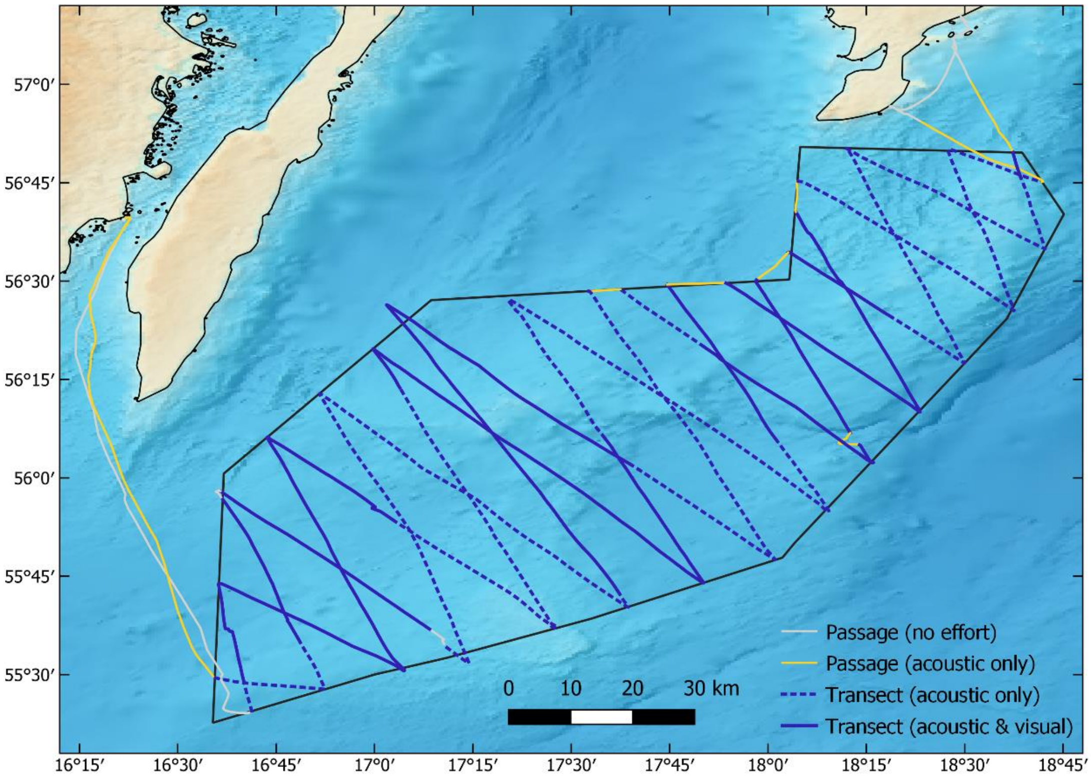

Figure 6. Survey tracks undertaken in the Natura 2000 site Hoburg’s Bank and Midsjöbankarna and southern midsea bank; solid lines represent joint visual acoustic on-track effort, dotted lines represent only on-track acoustic effort, yellow lines represent off-track acoustic effort and grey lines represent periods without acoustic or visual effort.

Visual observations

During the survey, there were 10 sightings of single grey seals (*Halichoerus grypus*; Figure 7). No harbour porpoises were seen.

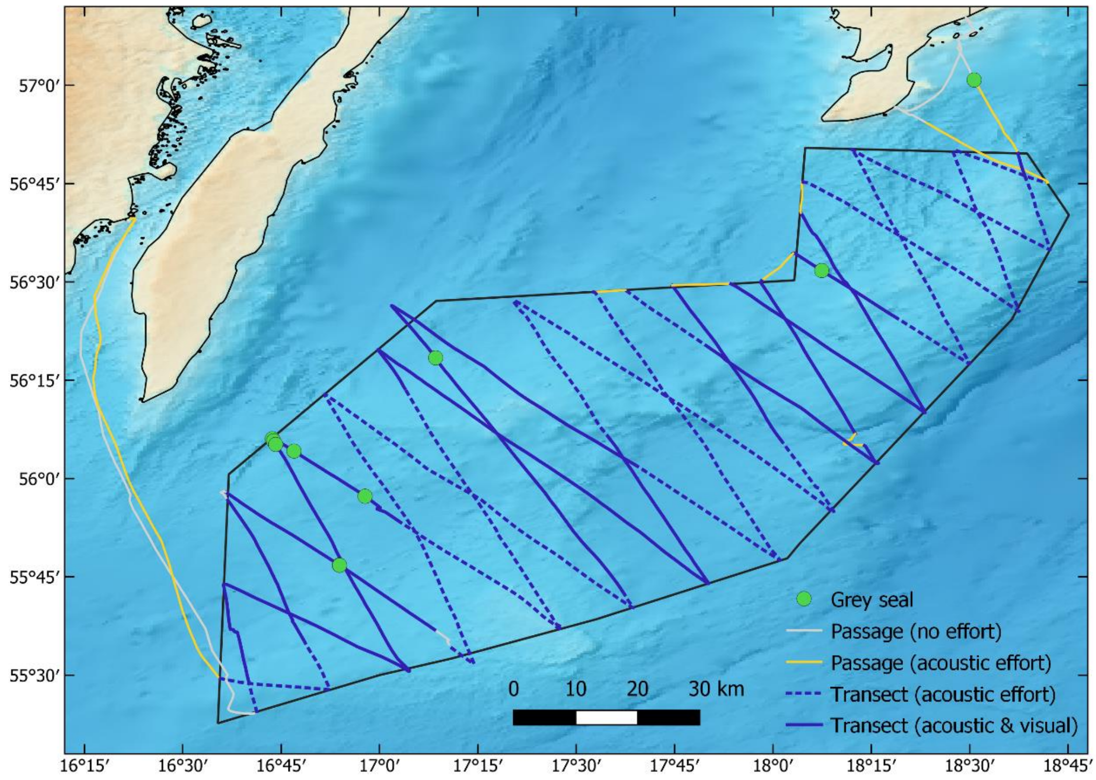

Figure 7. All sightings made during the survey; only grey seals were seen (n = 10).

Acoustic detections of harbour porpoises

During the survey, there were 12 acoustic detections of harbour porpoises, each representing a single individual (

Table 2). The majority (*n* = 10) of detections occurred close to dusk or dawn (Figure 8); in the absence of information over which stage of twilight is most relevant to the behaviour of porpoises and their prey, three definitions were used with astronomical twilight occurring when the sun is between 12 degrees and 18 degrees below the horizon, nautical twilight when the sun is between 6 degrees and 12 degrees, and civil twilight when the sun is less than 6 degrees. The majority of acoustic detections were clustered in two regions, centred at approximately 17°30' E and 18°30' E (Figure 9).

Table 2. Summary of acoustic detections of harbour porpoise made during the survey (all of single individuals). Acoustic detections were defined as ‘tracks’ (>2 clicks with a clear and defined bearing trail) or ‘events’ (≤ 2 clicks with limited bearing information).

Date	Time	Transect	Detection type
11/08/22	11:21	10 (primary)	Track
12/08/22	00:47	13 (primary)	Event
	01:28	13 (primary)	Event
	01:29	13 (primary)	Event
	01:30	13 (primary)	Track
	03:12	14 (primary)	Track
	03:12	14 (primary)	Event
14/08/22	15:24	06 (secondary)	Event
	18:27	05 (secondary)	Track
	19:26	05 (secondary)	Track
	19:40	05 (secondary)	Event
15/08/22	00:50	04 (secondary)	Event

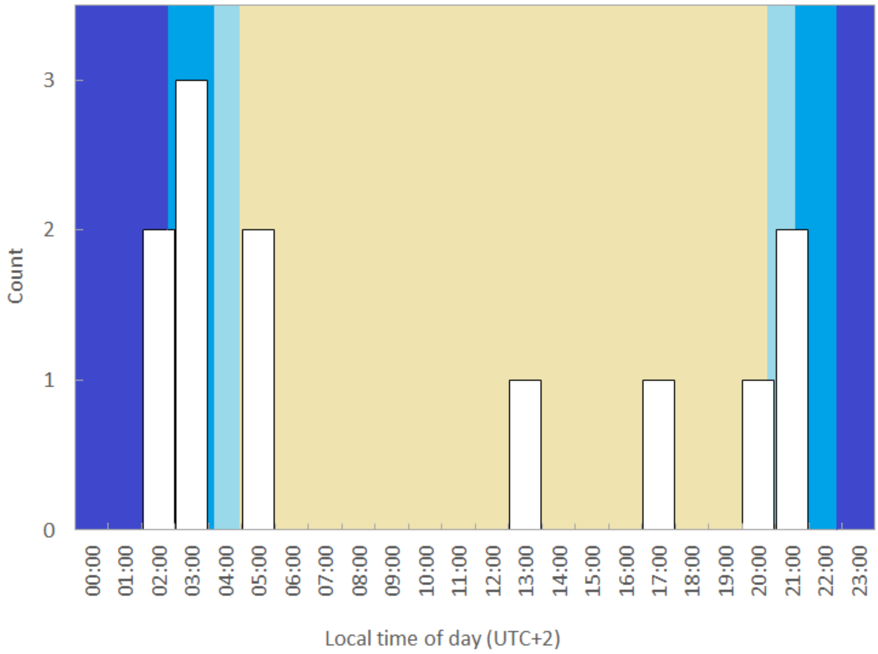

Figure 8. Timing of all 12 acoustic detections. The timings of local twilight are shown (astronomical twilight = dark blue, nautical twilight = mid-blue, civil twilight = light blue).

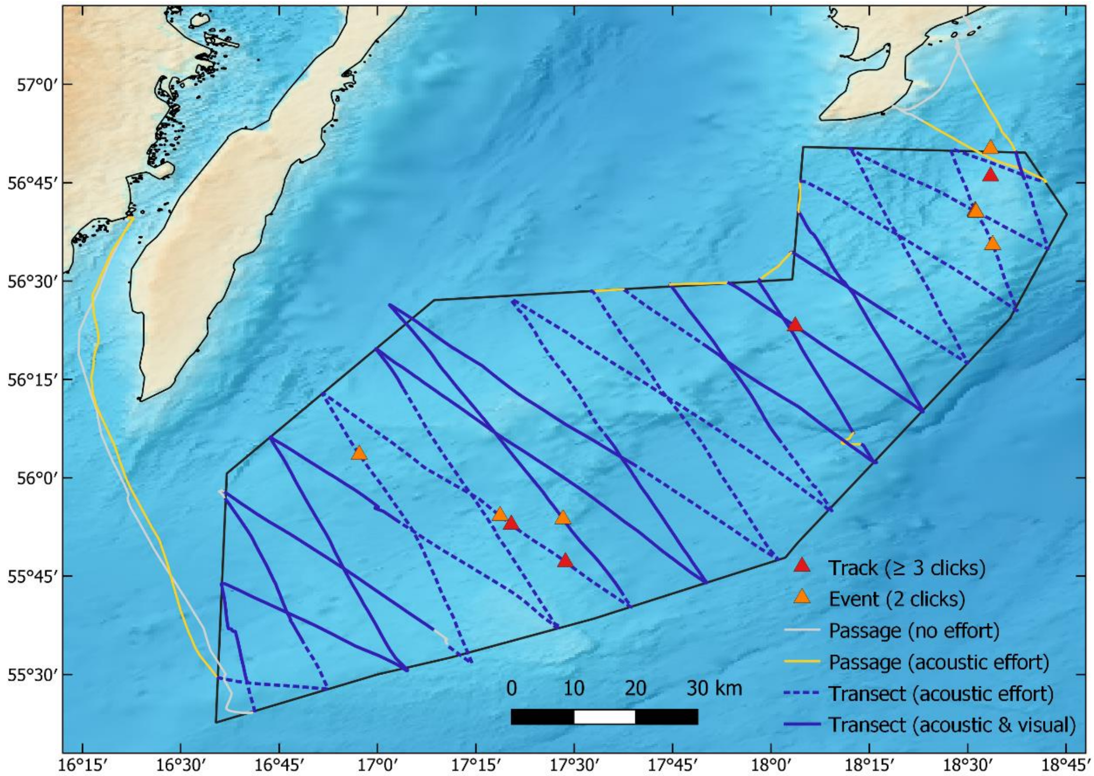

Figure 9. All acoustic detections of harbour porpoise clicks made during the 2022 survey. ‘Tracks’ (>2 clicks with a clear and defined bearing trail) are represented by red triangles; ‘events’ (≤ 2 clicks with limited bearing information) by orange triangles.

Acoustic density estimation of harbour porpoises

All twelve of the porpoise detections made on-track were included in subsequent density estimation. As the 2022 dataset was too small for robust modelling, a larger acoustic dataset of porpoise detections collected in the North Sea using a similar survey protocol (Cucknell et al., 2017) was included to improve the detection function (n = 373). Detections were truncated at 450 m to exclude 5 % of the largest perpendicular distances. Of the four effort covariates initially considered for improving of the detection function, wave height was excluded for being significantly correlated ($r_s(383) = 19.575$, $p < 0.01$) with swell height, leaving vessel speed, sea state and swell height for inclusion in modelling of the detection function. A hazard rate key function with two cosine adjustment terms generated a detection function with the closest fit to the distance estimates based on AIC scores. Histograms of slant ranges showed a lower detection rate between 0 and 100 m than at greater distances (Figure 10), presumably due to the responsive movement or porpoise moving away from the survey vessel. A goodness of fit test suggested the detection function was sufficiently aligned to the observed distances ($X^2_{(5,362)} = 9.37$, $p = 0.052$). Inclusion of covariates did not improve the detection function based on AIC score. The effective strip half-width (EShW) for the global dataset was 628 m and can be defined as the distance at which as many objects are detected beyond the EShW as are missed within the EShW. A separate modelling exercise using the covariate ‘year’ did not improve the model fit, suggesting the probability of detecting porpoises did not vary between the 2022 survey and the 2011 survey of the North Sea.

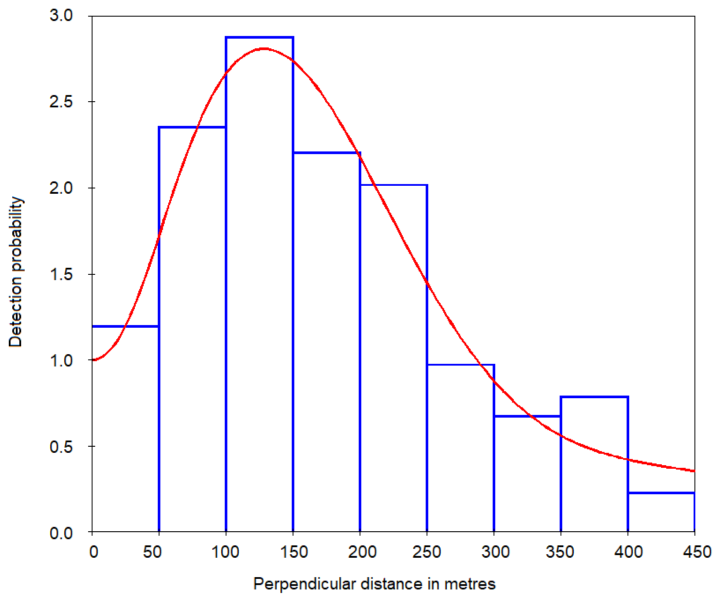

Figure 10. Histogram of slant ranges to harbour porpoise click trains fitted with hazard-rate key with two cosine adjustments. The dataset include both the 2022 detections (n = 12) and a comparable dataset from 2011 (n = 373). The final model did not include any covariates.

Density and abundance estimates for porpoises were made assuming *g*(0) was unity; additional estimates were made using a *g*(0) value of 0.46, as derived for the 2011 analysis (

Table 3). As the seven short 'events' only consisted of two clicks, their associated slant range estimates should be treated with caution. Thus, densities derived using only the five detections classified as 'tracks' should be considered more appropriate in terms of generating reliable estimates.

Table 3. Density (D) and abundance estimates (N) for the survey block in 2022, the area of which was 18,794 km2. The detection function was modelled using a hazard rate key function with two cosine adjustment terms (without covariates). Estimates are presented as both uncorrected (g(0) = 1) and corrected (g(0) = 0.46). Densities presented as individuals per 1000 km2; values in parentheses represent 95 % confidence limits.

	g(0) = 1.00			g(0) = 0.46		
Detection type	D	N	CV %	D	N	CV %
'Tracks' & 'events'	3.67	69	63	7.94	149	70
(n = 12)	(1.16-11.62)	(22-218)		(2.28-27.68)	(43-520)	
'Tracks' only	1.16	22	75	2.50	47	80
(n = 5)	(0.31-4.36)	(6-82)		(0.62-10.16)	(12-191)	

Discussion

Although no porpoises were seen during the survey of the Hoburgs Bank och Midsjöbankarna Natura 2000 site, there were at least 12 individuals detected acoustically. Of these, five detections were classified as 'tracks' as they contained 3 or more clicks (these may be considered 'probable' detections); seven detections were classified as 'events' as they consisted of only two clicks ('possible' porpoise detections). Typically, porpoise click trains detected by a towed array can consist of dozens of clicks, and according to MCR's standard click classification approach, the 2022 detections would be classified as 'possible' or' probable', rather than 'definite' (e.g. Gillespie et al., 2005; Cucknell et al., 2017; Boisseau et al., 2021). The inverter on board the vessel used for this survey introduced electrical noise into the recording system and included a harmonic tone at 140 kHz. As this lay within the typical frequency range of porpoise clicks (i.e. 120-140 kHz), it had the potential to mask the detection of clicks impinging on the hydrophone array with lower received levels, thus shortening the perceived length of several of the click trains in PAMGuard. Target Motion Analysis is typically more reliable with multiple bearing lines, and thus an event with only two bearing lines is unlikely to provide reliable slant ranges. Although an analysis was performed that incorporated both ‘events’ and ‘tracks’, it is likely that density estimation using ‘tracks’ only will provide more meaningful results. As such, an uncorrected abundance estimate of 22 porpoises (95 % CI 6-82) was derived using the detections classified as ‘tracks’ only. This rose to 47 porpoises (95 % CI 12-191) when correcting for availability bias. The coefficients of variation for these estimates were high (> 70 %), and this deviation led to the wide confidence intervals in the estimates.

According to the Standard Data Form of the Hoburgs bank och Midsjöbankarna Natura 2000 site (https://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=SE0330308 accessed on 31 October 2022), the porpoise population is listed as being 100 individuals. However, it is not clear how these numbers were derived. The SAMBAH study of 2011-13 identified two high density clusters evident in the Baltic Sea in summer months (May-October); the larger cluster was largely confined to the Belt Sea and the other cluster was centred around the offshore banks in a region broadly analogous to the Hoburgs bank och Midsjöbankarna Natura 2000 site (Carlén et al., 2018). A summer abundance of 491 porpoises was estimated for the Baltic Proper (95% CI 71-1105, CV = 68 %), dropping to 243 porpoises in the winter (95% CI 94-560, CV = 54 %; Amundin et al., 2021). If using the 20th lower percentile as a precautionary minimum abundance estimate (Wade, 1998), the summer estimate was 138 individuals. Assuming 50 % of individuals were mature (Taylor et al., 2007), the mature group was estimated to be 36–553 individuals, with a 20th lower percentile of 69 individuals. If using the same methodological approach for the 2022 data, the corrected confidence interval is 6–96 mature Baltic Proper harbour porpoises with a 20th lower percentile estimate of 13 individuals. As noted by Hammond et al. (2016), HELCOM (2013) and Amundin et al. (2021), these low numbers suggest harbour porpoises face a high risk of extinction in the Baltic Proper.

The abundance estimates in the present study are noticeably lower than the Amundin et al. (2021) study. However, the SAMBAH study considered the entire Baltic Proper, including the waters of Sweden, Germany, Poland, Lithuania, Latvia, Estonia and Finland, whereas the present study only considered the relatively small Hoburgs Bank och Midsjöbankarna site. Although most summer detections in the SAMBAH study occurred over Hoburg’s Bank and northern and southern mid sea banks, it is not what proportion of the estimated 491 porpoises were thought to be in that region, as significant detections were also made to the east of Gotland, northeast of Öland and off the west coast of Latvia. The 2022 survey presented a nine-day snapshot of a relatively small area, as opposed to the two-year duration of the SAMBAH study. Although both studies used acoustic techniques to detect porpoise clicks, the two methodological approaches are quite distinct, and will not necessarily provide directly comparable abundance estimates. For example, there is currently a lack of consensus on which acoustic metrics provide the best index of density for static recorders, and approaches including click-positive seconds per 1000 s of survey effort (used by Amundin et al., 2021), detection positive hours per day (e.g. Thompson et al., 2013), porpoise positive minutes per hour (e.g. Brandt et al. 2011) and 10 minute detection windows (e.g. Dähne et al., 2013) have been presented. Similarly for estimation of acoustic density using towed arrays, as in this study, there is a lack of consensus on how to correct for availability bias, as individuals are known to echolocate at variable rates depending on age, sex, motivational state, etc.; a comparison of visual sightings with acoustic detections from a 2011 survey of the North Sea (Cucknell et al., 2017) was used as a proxy in this study but is not an entirely satisfactory approach.

However, despite these differences in methodology, the 2022 study generated estimates within the same order of magnitude as the SAMBAH study; the 95 % confidence interval for the 2022 survey (12-191 porpoises) has some overlap with that of the SAMBAH study (71-1105 porpoises), suggesting the estimates are unlikely to be significantly different. As mentioned above, the two study areas are not directly comparable, with the survey block in this study being 18,794 km^2 and the SAMBAH northeast area being 132,603 km^2. It is perhaps more appropriate to compare densities. The density estimates for the 2022 survey were 1.16 porpoises 1000 km^{-2} (95 % CI 0.31-4.36) uncorrected, rising to 2.50 porpoises 1000 km^{-2} (95 % CI 0.62-10.16) corrected. Although the point estimate of density for the SAMBAH survey was higher (3.70 porpoises 1000 km^{-2}), the 95 % confidence interval of 0.54-8.33 was closely aligned with that of the 2022 survey corrected estimate.

The MCR team have derived density estimates for harbour porpoises in other regions in Europe using the same survey protocols. The corrected acoustic density for the central North Sea in winter, a region noted for providing habitat for a large number of porpoises, was 630 porpoise 1000 km^{-2} (95% CI 270-1520; Cucknell et al., 2017). In the North Aegean Sea, Greece, a region considered to have extremely low numbers of porpoise, uncorrected density estimates were estimated as 8.2 porpoises 1000 km^{-2} (95 % CI 4-19) in 2013 and 12.1 porpoises 1000 km^{-2} (95 % CI 4-36) in 2021 (Boisseau et al., 2021). It can be seen that the density of porpoises over Hoburg's Bank and northern and southern mid sea banks is much lower than other regions studied using similar techniques. Although the 2022 survey was limited in duration, repeated surveys would improve the confidence of these initial estimates and could also be used to monitor changes in local porpoise density over time. Regular, repeated and rigorous monitoring is a key requirement for the conservation of this critically endangered population, particularly in light of the potential for development and/or disturbance in these waters in the future.

The SAMBAH study found greatly elevated detection probabilities for porpoises during the night in the Great Belt off Denmark (Amundin et al., 2021), presumably in response to increased foraging activity at night. That study, however, did not seem to establish such elevated detection probabilities in the Baltic Proper, with acoustic detection rates being 2.1 times higher at night, 1.2 at dusk, and 1.4 at dawn when compared to daytime rates. Although the total number of detections in the current study is rather limited, there seemed to be slight peaks of porpoise detections at dawn and dusk. These peaks seemed more in keeping with the Baltic Proper values reported by Amundin et al. (2021) than the Great Belt values and suggest vocal activity may increase at dawn and dusk in relation to daylight hours. Other more detailed studies have found the diel and seasonal patterns of porpoise echolocation in the Baltic Sea is complex; for example, Schaffeld et al. (2016) found almost all recorded foraging in winter and spring months took place at night, whereas foraging was recorded frequently at night and in the daytime in summer and autumn months. The small sample size in this study (n = 12) does not allow clear inferences to be made regarding diel behaviour.

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