Relative abundance of harbour porpoises (*Phocoena phocoena*) from acoustic and visual surveys of the Baltic Sea and adjacent waters during 2001 and 2002

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ABSTRACT

Boat-based acoustic and visual surveys for harbour porpoises (*Phocoena phocoena*) were conducted during the summers of 2001 and 2002 in order to investigate their distribution and relative abundance in the Baltic Sea, and to compare the results with the adjacent Kiel and Mecklenburg Bights and the Little Belt. Harbour porpoises are subject to year-round bycatch in gillnets and other fishing gear in these waters. This is of particular concern in the Baltic Sea where a survey carried out in 1995 indicated that the population is low and current levels of anthropogenic mortality are believed to be unsustainable. Polish coastal waters were not included in the 1995 survey and it has been hypothesised that these unsurveyed waters may contain a significant uncounted part of the Baltic Sea population. Results show that the porpoise detection rate was two orders of magnitude lower in the Baltic Sea than in other waters surveyed. No evidence was found that Polish waters contain a significant, previously uncounted part of the Baltic Sea population. The results confirm the endangered status of the Baltic Sea population, and stress the urgency of preventing future anthropogenic mortalities that threaten the survival of the population.

KEYWORDS: HARBOUR PORPOISE; SURVEY–ACOUSTIC; INDEX OF ABUNDANCE; CONSERVATION; EUROPE; BALTIC SEA; ACOUSTICS

INTRODUCTION

Harbour porpoises (*Phocoena phocoena*) are subject to bycatch in gillnets and other fishing gear throughout their distribution range in the Northern Hemisphere. This has led to increased concern over the population of this species in recent years (e.g. Berggren, 1994; Perrin *et al.*, 1994; HELCOM, 1996; ICES, 1997; ASCOBANS, 2000; IWC, 2000). Several studies in European waters have shown that bycatch levels in gillnet fisheries may not be sustainable, e.g. in the Celtic Sea (Tregenza *et al.*, 1997), the central North Sea (Vinther, 1999), the Skagerrak and Kattegat Seas (Harwood *et al.*, 1999; Carlström, 2003) and the Baltic Sea (Berggren *et al.*, 2002).

This issue is of particular concern in the Baltic Sea[1], where action is urgently needed to reduce bycatch to conserve Europe's most threatened population of harbour porpoises (ASCOBANS, 2000; 2002). No independent, scientific observer programmes on board fishing-vessels to estimate bycatch have been conducted in the Baltic Sea, but estimated levels cannot be sustained indefinitely by the population (Berggren *et al.*, 2002). It is further known that bycatch in the Baltic Sea occurs year-round (Berggren, 1994).

Porpoises are believed to have been common in parts of the Baltic up until the late 19th and early 20th centuries, and were distributed all the way up into the Bothnian Sea (Berggren, 1995; Berggren and Arrhenius, 1995b; Berggren and Arrhenius, 1995a; Koschinski, 2002). However, in Swedish waters of the Baltic Sea, harbour porpoise abundance appears to have declined drastically between the 1960s and 1980s (Berggren and Arrhenius, 1995b) with no subsequent recovery (Berggren and Arrhenius, 1995a). Porpoises have also become less common during recent decades in other areas of the Baltic Sea, including Danish (Andersen, S.H., 1982) and Polish (Skora *et al.*, 1988) waters. Very occasional sightings and bycaught porpoises have been recorded in Finnish and Estonian waters (Määttänen, 1990; Mattsson, 1995).

Studies of skull morphology, mitochondrial DNA and contaminants show that the Baltic Sea population should be regarded as a separate management unit. Population-level differences have been found between harbour porpoises from the Baltic Sea, the Kiel and Mecklenburger Bights, and the North Sea (Andersen, L.W., 1993; Tiedemann *et al.*, 1996; Huggenberger *et al.*, 2002). In addition, differences have been found among the Baltic Sea, the Skagerrak/Kattegat Seas and the west coast of Norway (Börjesson and Berggren, 1997; Wang and Berggren, 1997; Berggren *et al.*, 1999) and between the Kattegat/Danish Belt Seas and the Skagerrak Sea (Kinze, 1985; 1990; Andersen, L. *et al.*, 2001).

Current information on the number of porpoises in Danish, German, Swedish and international waters of the Baltic Sea (ICES – International Council for the Exploration of the Seas —rectangles 24 and 25) derives from an aerial survey conducted in 1995 (Hiby and Lovell, 1996). The abundance estimate for the area surveyed was 599 (CV=0.57) animals. Polish coastal waters were not included in the survey and it has been hypothesised that these waters may contain a significant uncounted part of the Baltic Sea population. This is based on information from incidental sightings and bycatch that has indicated that Puck Bay in the east of Poland may have a relatively high density of

[1] By the Baltic Sea, we specifically refer to waters East of the Dars Sill. A bank running between Gedser, Denmark and Darsser Ort, Germany (Blocks 4 and 5 in Fig. 1).

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porpoises (ICES, 1997; Kuklik and Skóra, 2003). The Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS) Baltic Discussion Group (ASCOBANS, 2001) accepted the 1995 survey estimate, but noted that this was:

(a) downwardly biased, because it did not cover an area of Polish waters where harbour porpoises are known to occur; and
(b) an estimate with poor precision, due to low numbers of detected animals in the survey.

Further surveys were recommended to address these issues.

This paper presents the results of boat-based acoustic and visual surveys for porpoises carried out during the summers of 2001 and 2002. The primary aim of these surveys was to further investigate the distribution and relative abundance of porpoises in the Baltic, and particularly in 2001, to examine the hypothesis of a 'reservoir' of porpoises off the Polish coast. For these purposes acoustic and visual detection rates were compared between several survey blocks in the Baltic Sea and adjacent waters.

METHODS

Survey design

Five survey blocks were defined and covered during 2001 and 2002 (Fig. 1; Table 1). In 2001, survey transects were laid out only in Polish coastal waters (block 5). In 2002, the survey was expanded to include waters north up to the Swedish coast (block 4). Additionally in 2002, adjacent German and Danish waters to the west (the Little Belt and the Kiel and Mecklenburg Bights, blocks 1-3) were surveyed, in order to obtain data on relative abundance in areas suspected to have higher population densities of porpoises (Hammond *et al.*, 2002). To aid future data comparisons, these blocks corresponded to those used by other researchers conducting aerial surveys for harbour porpoises in 2002 (Scheidat *et al.*, 2004; Berggren *et al.*, 2004), with the exception that the most westerly aerial survey block was split into two (Little Belt and Kiel Bight). The reason for this was that the original aerial survey tracks frequently crossed land and would have been inefficient for boat-based surveying.

Survey lines (transects) were laid out systematically with random starting points, to provide non-zero, approximately even coverage within each block. The boat followed the planned transects as closely as possible, given the constraints of navigational safety and the need for at least 10m of water for the deployment of the hydrophone. Data collection continued even when the vessel was off track, but unless explicitly stated, only data collected on track are presented here. In 2002, survey effort alternated between blocks over the period of the survey in order to reduce any effects from seasonal changes in distribution. Individual transects were not surveyed in any particular order but were selected based on the requirements of port visits for crew changes and the weather conditions on any particular date.

Table 1

Dates of survey by block. Dates represent only the first and last day of data collection within each block. Survey effort alternated between blocks to avoid the risk of biasing the result due to seasonal movement between blocks. The actual survey effort within each block is given in Table 2.

Survey block	Start date	End date
Polish coast	19 Aug. 2001	15 Sept. 2001
Little Belt	8 Jun. 2002	7 Aug. 2002
Kiel Bight	10 Jun. 2002	6 Aug. 2002
Mecklenberg Bight	15 Jun. 2002	4 Aug. 2002
Baltic Sea	26 Jun. 2002	3 Aug. 2002

Data collection

The surveys were conducted from the 14m auxiliary powered sailing vessel *Song of the Whale*. The vessel was operated under engine power in low wind conditions and when visual surveys were taking place (to maintain an approximately constant survey speed and so that sails did not obstruct the forward view of the observers). When not surveying visually, the vessel was sailed whenever the desired course could be maintained at a survey speed of approximately six knots. Global positioning system (GPS) data (position, speed, course over ground) were logged automatically to a database every 10 seconds. Environmental data (wind speed and direction, water temperature and depth) were logged automatically every minute. Other data, which could not be collected automatically, were entered manually into the database every 30 minutes (wave height, sea state, weather, visibility), or whenever they changed (engine on/off).

The vessel was equipped with an automatic porpoise detection system (Gillespie and Chappell, 2002), which was developed to detect the high frequency sounds produced by

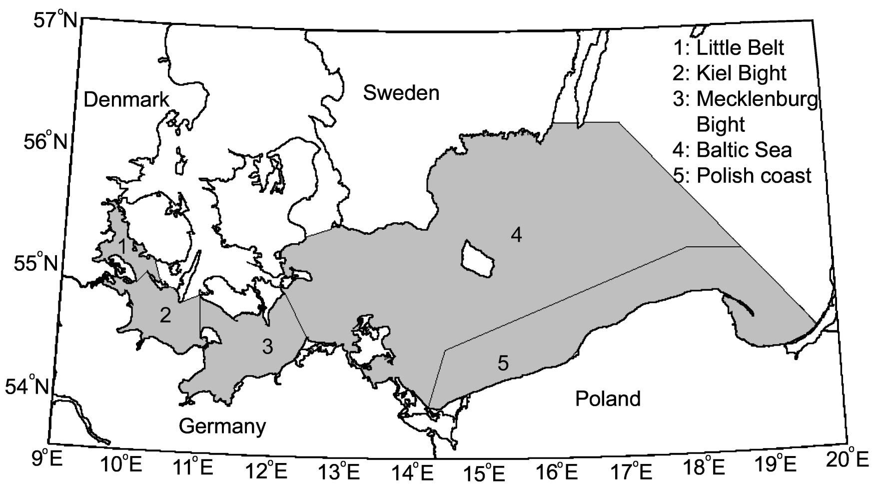

Fig. 1. Map showing the five survey blocks. Blocks 1-4 were surveyed in 2002, and block 5 in 2001. Note that block 4 extends right to the Polish coast and so block 5 is a sub-area of block 4.

harbour porpoises. It consisted of a two-element hydrophone towed 100m astern of the survey vessel. Analogue electronics modules split the signals from the hydrophones into different frequency bands and carried out envelope tracing to reduce the signal frequency. The signal envelopes were then digitised and analysed in real time for porpoise-like clicks using software running on a computer onboard the survey vessel.

During daylight hours (06:00 to 20:00) in clear weather with sea states of Beaufort two or less, two observers were stationed on an A-frame observation platform. This provided them with a clear view ahead, with an eye height of approximately 5.3m above sea level. The port side observer scanned from 270° to 15° and the starboard observer from 345° to 90° relative to the vessel's direction. Although observers only searched for porpoises ahead of the vessel, once spotted, they were tracked as far astern as possible to assist with linking sightings and acoustic detections in possible future dual visual-acoustic data analysis. Observers scanned with the naked eye and estimated ranges to sightings visually. Angle boards were used to measure bearings to sightings. Sightings were recorded on paper by a third person (so that the observers did not need to avert their eyes). Sightings data were transcribed into the database and automatically cross-referenced to the vessel's GPS co-ordinates.

Acoustic data analysis

A fully automatic algorithm to assign clicks to individual porpoises would be desirable but has not yet been developed. The acoustic data were therefore scanned by an analyst for trains of porpoise-like clicks, using the software described in Gillespie and Chappell (2002). The software has a screen display of the data showing amplitude, waveform envelopes and bearing information of the clicks over time. Sequences of clicks can also be played back through headphones. Individual clicks were classified as 'porpoise' if they had a minimum amplitude of 105dB re. 1μPa, and a signal strength in the 115-145kHz 'porpoise' band at least 25dB above the mean signal strength measured at two lower control frequencies. Click classification errors are discussed in Gillespie and Chappell (2002). The chosen analysis settings give a >50% correct classification for porpoise clicks and a low, but >0% false-positive rate.

For this analysis, click train selection was a two-stage process. In the first stage, the operator scanned files for sequences of porpoise clicks which were detected on both hydrophone elements and showed a clear change of bearing going from ahead to astern of the survey vessel. A subjective judgement was made based on the appearance of the track and the sound of the clicks (both porpoise and unclassified clicks) played back over headphones and the click trains labelled as 'likely' or 'possible'.

Porpoise clicks are highly directional (Au *et al.*, 1999) and it has been found that many porpoise events, as well as having a number of clearly identifiable porpoise clicks, also contain 'unclassified' clicks which have a lower amplitude and cannot be clearly identified as porpoise clicks purely from the signal amplitudes in the different frequency bands. These 'unclassified' clicks often lie on a bearing consistent with clicks, and from their regularity (apparent when they are played back through headphones) are clearly part of the porpoise click train.

In the second stage, a more objective classification was applied to the first-pass analysis. It was found that none of the click trains labelled as 'possible' contained more than six porpoise clicks, however, some click trains labelled as 'likely' had fewer than seven porpoise clicks. In order to keep the probability of false detections low, all click trains with fewer than seven porpoise clicks were discarded.

An example of a bearing-time plot for a porpoise detection is shown in Fig. 2. The track of a porpoise passing from ahead to astern of the survey vessel is clearly visible. Random non-porpoise clicks are also shown. The single 'porpoise' click off the main track is a typical false possible classification of a non-porpoise sound.

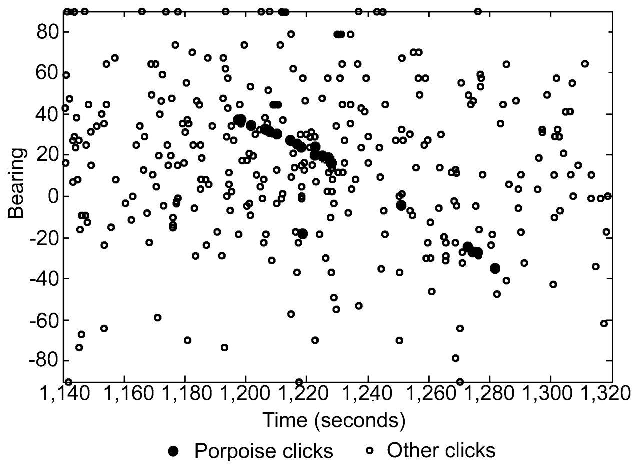

Fig. 2. An example bearing-time plot showing detections from an encounter with a porpoise. Porpoise clicks are characteristically narrowband in the 125-150kHz range while other clicks (open circles) are broadband. The detector found 28 clicks (filled circles) over a period of 80 seconds, as the porpoise passed from approximately 40° ahead to 40° astern. The 'porpoise' click below the main track in the figure is a false classification of another noise.

Statistical analysis

The variances in the number of detections, n, and the detection rate n/100km, were calculated using transects as sampling units (Buckland *et al.*, 2001, pp.78-80). The differences in the detection rates between the Baltic Sea block and the other three blocks to the west were compared using a randomisation test (10,000 re-samples). The standard error (SE) and a variance inflation factor $\hat{b}$ = var(n)/n (Buckland *et al.*, 2001) were also calculated for each block. The factor $\hat{b}$ measures the extent of clustering in the distribution of animals.

RESULTS

The total distance surveyed acoustically and visually in each survey block, the number of detections and detection rates for each block are shown in Table 2.

Fig. 3 shows the survey tracklines, the off-track survey route and the visual and acoustic porpoise detections along the Polish coast in 2001. Only one detection was made on-track in 2001, this was a single porpoise sighted northeast of the Polish port of Swinousjie. However, a single acoustic detection was also made while the vessel was off-track, less than 1km from the Polish coast, approximately 30km east of Swinousjie. These were the only detections in Polish waters during the 2001 and 2002 surveys.

Fig. 4 shows the acoustic survey tracklines and detections for 2002. The highest acoustic detection rate was in Danish waters in the Little Belt (16.8/100km). In broad terms, detection rates decreased from west to east dropping to 0.1/100km in the Baltic Sea. There were only three acoustic

Table 2

On-track survey effort and detections in 2001 and 2002. For acoustic surveys, the number of individuals detected (*n*), the detection rate (*n*/100 km) and the standard error *se* are shown. The symbol $\hat{b}$ denotes the ratio var(*n*)/*n* for the acoustic survey in each block. For visual surveys, the number of groups detected (*n*) and detection rate (*n*/100 km) is shown with number of individuals in parentheses.

			Acoustic survey					Visual survey		
Block	Year	Area (km^2)	km	*n*	*n*/100km	*se* (*n*/100 km)	$\hat{b}$	km	*n*	*n*/100km
Polish coast[1]	2001	17,000	1,692	0	0	0	-	292	1 (1)	0.34 (0.34)
Baltic Sea	2002	56,000	2,946	3	0.1	0.08	1.68	253	0	0
Mecklenburg Bight	2002	6,000	713	23	3.2	0.75	1.30	190	0	0
Kiel Bight	2002	3,200	494	52	10.5	1.96	1.96	97	1 (1)	1.03 (1.03)
Little Belt	2002	1,300	291	49	16.8	3.71	2.70	158	13 (18)	8.2 (11.4)

[1]In addition a single acoustic detection was made during 518km off-track survey route in 2001.

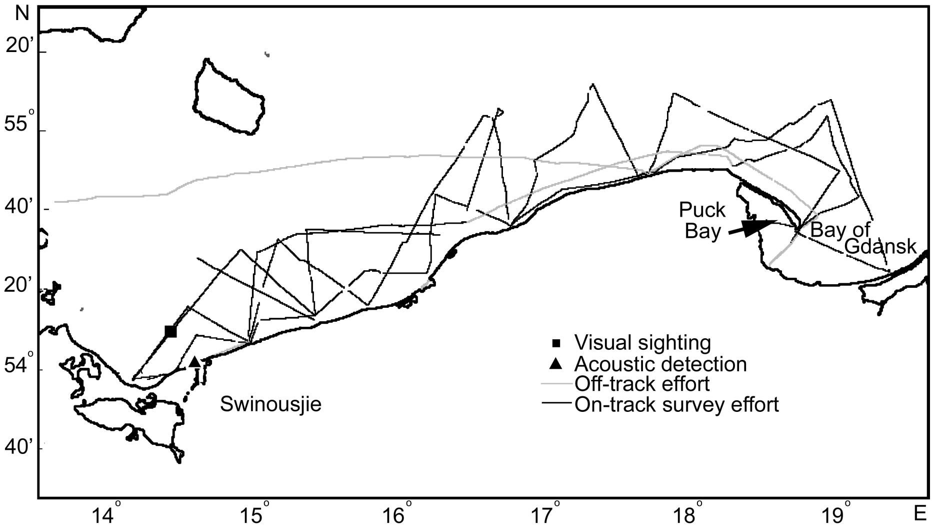

Fig. 3. Survey effort (and off-track effort) along the Polish coast in 2001. A single visual porpoise detection was made northeast of Swinousjie. An acoustic detection made off-effort approximately 1km from the coast is also indicated.

detections in the Baltic Sea block; two of these were close to the western edge of the block while the third was in the far northeast of the survey area in Swedish waters.

The visual on-track survey effort and sightings for 2002 are shown in Fig. 5. All sightings were made in the Little Belt (see Table 2). However, the visual on-track survey effort had limited coverage in all survey blocks limiting any useful comparisons between blocks. Eight single animals and five pairs were observed in the Little Belt, giving an average pod size of 1.4 animals. One of the pairs appeared to be a mother and calf.

The acoustic detection rate in the Baltic Sea block was one or two orders of magnitude lower than in the western blocks (Fig. 6). The vast majority of the visual and acoustic detections were made in the Little Belt and the Kiel and Mecklenburg Bights. Very few porpoises were detected acoustically in the southern part of the Mecklenburg Bight. The factor $\hat{b}$ was greater than one in all four blocks where detections were made while surveying (Table 2), indicating clustering in the distribution of porpoises. The randomisation test gave a probability $P(W>w)=0.0017$, where W is the random variable and w is the observed value. The difference in detection rate between the Baltic Sea and the other three blocks is therefore highly significant.

DISCUSSION

Distribution of porpoises

The pattern of acoustic detections indicates a gradient in the density of porpoises falling from west to east (Table 2, Fig. 4). Only one porpoise was detected while on-track (a sighting) in Polish waters during the survey conducted in 2001 (an additional acoustic detection was made off-track). We therefore conclude that Polish coastal waters do not contain a significant and uncounted part of the Baltic Sea population.

Apart from two porpoises detected at the extreme west of the Baltic Sea block, the only detection in the Baltic Sea in 2002 was in the extreme northeast of that block (see Fig. 4). The low porpoise detection rate in the survey of the entire Baltic Sea block agrees in a broad sense with the low density found in the 1995 aerial survey (599 porpoises in a 43,000km^2 study area; Hiby and Lovell, 1996) in international waters (this survey excluded the Polish coast). Furthermore, Berggren and Arrhenius (1995a) report only a single sighting in a five-year opportunistic Swedish sightings observer programme in the Baltic Sea.

Information from incidental sightings and bycatch (ICES, 1997; Kuklik and Skóra, 2003) has indicated that Puck Bay in the east of Poland (Fig. 3) may contain a relatively high

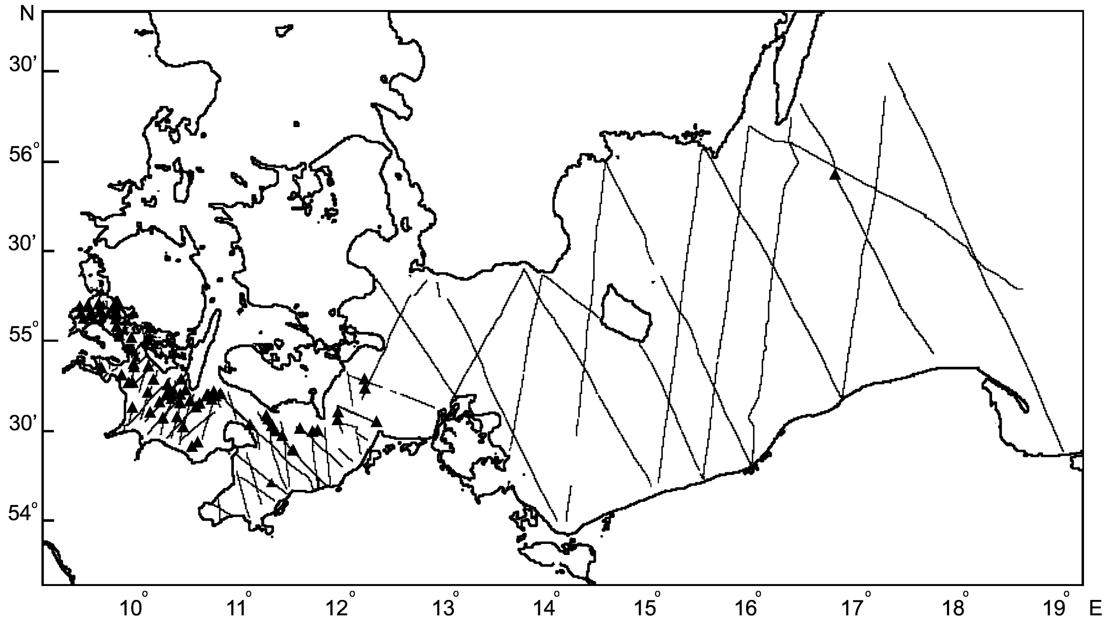

Fig. 4. Acoustic survey effort and detections (▲) in 2002. A total of 124 detections were made in the western blocks 1-3. There were only three detections in block 4 (Baltic Sea), two of which were in the extreme west and one in the northeast.

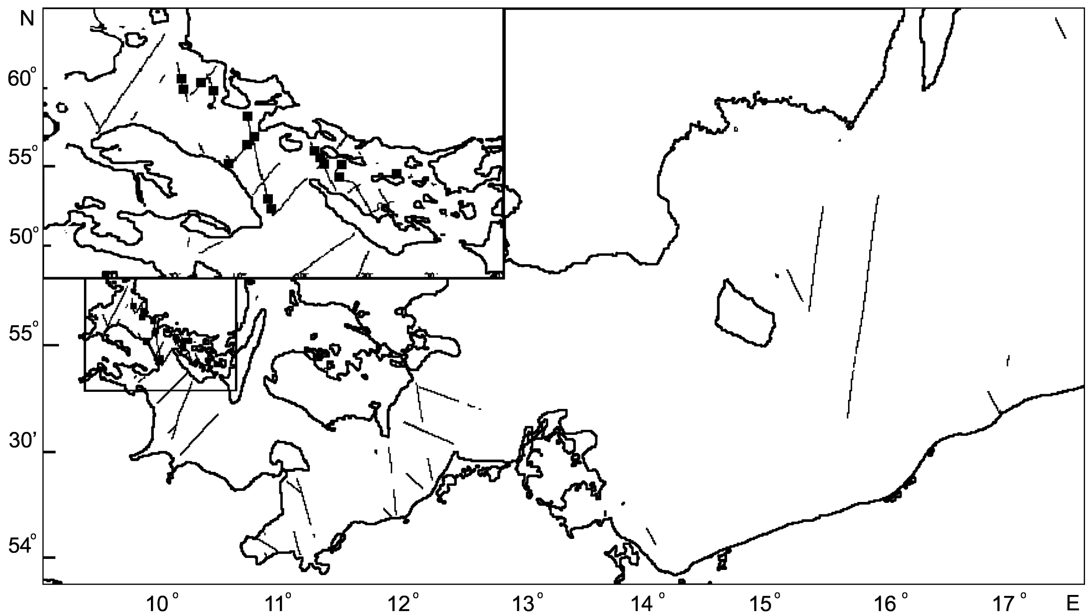

Fig. 5. Visual on-track survey effort and on-track sightings (|) in 2002. The inset is an enlarged view of the Little Belt region, where all sightings were made.

density of porpoises. However, it is possible that the relatively high occurrence of porpoise bycatch in Puck Bay is an effect of a very intense gillnet fishery in this area, rather than a higher density of porpoises. It is suggested that further research be carried out to clarify the cause of the high occurrence of bycatch in this area. Most bycatch is known to occur between December and April, although it has been reported in all other months except June (Kuklik and Skóra, 2003). Since this and other surveys (e.g. Hiby and Lovell, 1996) took place during the summer, we cannot rule out the possibility that there is seasonal movement in and out of the Baltic Sea.

Validity of survey results

An important assumption for a valid measure of relative abundance is that detectability is constant across the survey area (Pollock *et al.*, 2002). Acoustic detectability is a function of various measurable external variables or covariates (in particular ambient noise), and the vocal behaviour of porpoises. Noise level measurements recorded every second by the porpoise detection equipment showed that mean noise levels in the different blocks varied by less than 0.2dB. Acoustic cues from the survey vessel (sounds from the engines, propellers or depth sounder) could alert a porpoise to its presence, leading to changes in movement or vocal behaviour. The depth sounder was run continuously throughout the survey. The percentages of on-track survey effort with engine on were: Little Belt (83%), Kiel Bight (65%), Mecklenburg Bight (83%), Baltic Sea (50%). How engine noise affects porpoise behaviour is not known, but if detectability falls with engine use, due to directed motion of porpoises away from the survey vessel, then in this study the detection rate in the Baltic would have been positively biased. Conversely, if porpoises were attracted to the engine

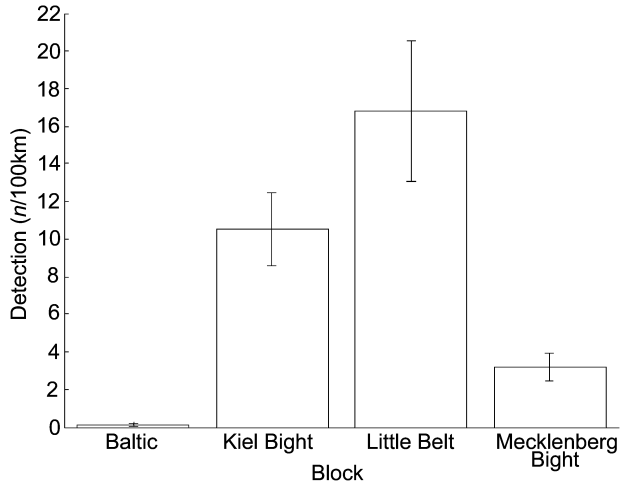

Fig. 6. Detection rates (n/100km) and their standard errors by survey block.

noise, the detection rate in the Baltic would have been negatively biased.

Another important underlying assumption for a measure of relative abundance is that the false detection rate is low, if not zero, compared to the detection rate. In this study, conditions were placed on click trains that would eliminate most false detections, but as a consequence some true porpoise detections may have been discarded. Ideally, both efficiency and false detection rates should be measured. Measuring efficiency is not possible with free ranging animals since even if it were known exactly how many animals were in the vicinity, their vocalisation rate would be unknown. Similarly, it is never possible to be sure that a detection is a false-positive, since it is impossible to be sure that no porpoise was there. This rate could potentially be measured by proxy using data collected in an area with similar levels of background noise, but known to be free of porpoises. No areas were visited during the study that met this requirement. However, the consistently low detection rate across the Baltic Sea block, and the similar measures of background noise between blocks indicates that the false detection rate was low.

Future work: estimation of absolute abundance

If acoustic detections are to be used for absolute abundance estimation, two major issues to consider are the estimation of $g(0)$ and the effects of responsive movement. Borchers (1999) described double-platform methods which, using the type of dual visual-acoustic data collected in this study, may allow the estimation of $g(0)$ when it is less than one. Furthermore, he outlined the use of the Buckland-Turnock approach (Buckland and Turnock, 1992), which is robust to responsive movement, using an observer team looking far enough ahead of the vessel to make visual detections before animals react.

Analysis of the dual visual-acoustic data from this study is underway and the effects of responsive movement are a major concern. Some data were collected using a second platform of observers searching ahead of the vessel from a crows nest at an eye height of approximately 10m above sea level. Unfortunately only eight of the crows nest sightings were at distances greater than 200m forward of the beam. The number of crows nest sightings is insufficient for a Buckland-Turnock analysis, and in any case the threshold distance, beyond which porpoises do not react to the survey vessel, is not known. Any comprehensive analysis of the data from this survey will therefore need to further consider the effects of responsive movement.

Conservation action

The results from this study confirm the limited occurrence and very low relative abundance of harbour porpoises in the Baltic Sea reported in the 1995 aerial survey. Further, the results do not support the existence of a porpoise ‘reservoir’ in Polish coastal waters. This further emphasises the endangered status of this population. Although it would be useful to conduct further surveys, priority should be given to reducing further anthropogenic mortalities, and hence to prevent extinction of the Baltic Sea population (e.g. see ASCOBANS, 2002). A number of factors may have contributed to the decline of the Baltic Sea population, including hunting, severe winters, pollutants and bycatch in fishing gear (ASCOBANS, 2002; Koschinski, 2002). Reducing bycatch in this region should be given high priority, because any is significant, relative to the low estimated abundance in the Baltic Sea, and bycatch is a form of anthropogenic mortality that can be mitigated immediately.

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