ICES Journal of Marine Science, 59: 816–824. 2002
doi:10.1006/jmsc.2002.1214, available online at http://www.idealibrary.com on IDEAL®

A field experiment using acoustic alarms (pingers) to reduce harbour porpoise by-catch in bottom-set gillnets

Julia Carlström, Per Berggren, Felicia Dinnétz, and Patrik Börjesson

Carlström, J., Berggren P., Dinnétz, F., and Börjesson, P. 2002. A field experiment using acoustic alarms (pingers) to reduce harbour porpoise by-catch in bottom-set gillnets. – ICES Journal of Marine Science, 59: 816–824.

A field experiment with Dukane NetMark™ 1000 pingers was conducted in the bottom-set gillnet fishery for cod in the Swedish Skagerrak Sea between March and April 1997. The aim of the experiment was to evaluate (i) the effectiveness of pingers to reduce by-catch rate of harbour porpoises, and (ii) the effects of pingers on the catches of the target species in the fishery. The design of the study was based on a statistical power analysis and the results from observer programmes conducted 1995–1996 in the same area, fishery and time of year.

The catches of cod, pollack and other fish species were not affected by the sound of the pingers in the active strings. No harbour porpoise was caught in any control or active string, which was a significantly lower by-catch rate than in the two previous years. This could not be explained by a reduction in fishing effort *per se*, a difference in the total catch of fish for consumption or a shift in the spatial distribution of the sets between the observer programmes and the pinger experiment. However, the spatial analyses demonstrated that the experimental strings were set parallel to the coast and along the 50 m isobath, and that the audible range of the active pingers on average covered 16% of the longitudinal length and 5% of the surface area of the experimental fishing area. A compilation of herring landings by Swedish fishermen operating in the Skagerrak Sea 1995–1997 suggests that herring were more abundant in 1997 than in 1995. Good access to food in other parts of the porpoises' distribution range and an aversive reaction to the ensonification could have caused their displacement in the fishing area.

A displacement effect by pingers is likely to be more prominent in coastal waters where access to bodies of water is limited and the consequence may be serious if the area is critical to the survival of the porpoise population.

Key words: deterrent, displacement, incidental take, *Phocoena phocoena*, Skagerrak Sea.

Received 10 September 2001; accepted 11 March 2002.

J. Carlström, P. Berggren, F. Dinnétz and P. Börjesson: Department of Zoology, Stockholm University, SE-106 91 Stockholm, Sweden. Correspondence to J. Carlström: tel: +46-8164024; fax: +46-8167715; e-mail: julia@zoologi.su.se

Introduction

Harbour porpoises (*Phocoena phocoena* L.) are caught incidentally in gillnets and other fishing gear throughout their distribution range in the northern hemisphere (Perrin *et al.*, 1994). In Swedish waters by-catch of porpoises occurs year-round in the Baltic, Kattegat and Skagerrak Seas in various gillnet and trawl fisheries (Berggren, 1994). More than 90% of the reported porpoise by-catch in Sweden comes from the Kattegat and Skagerrak Seas and 80% are taken in bottom-set gillnets (Berggren, 1994). Observer programmes operating in the bottom-set gillnet fishery for cod (*Gadus morhua*) and pollack (*Pollachius pollachius*) in 1995 and 1996 have shown that porpoise by-catches in the Swedish Skagerrak Seas exceed 2% of the estimated number of animals in the area (Carlström and Berggren, 1996, 1998; Harwood *et al.*, 1999). This is the level above which by-catch of porpoises is considered biologically unsustainable (IWC, 1996). Even minimum levels of by-catches of harbour porpoises in the Baltic region have been found to exceed potential limits to anthropogenic mortality (Berggren *et al.*, 2002). These mortality limits were calculated following the conservation objective set by the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS, 1997).

Trials with acoustic alarms or "pingers" have shown that these can reduce the occurrence of by-catches at least in the short-term (Kraus *et al.*, 1997; Larsen, 1997; Gearin *et al.*, 2000). It is currently not fully understood how pingers work, i.e. whether they alert or deter porpoises or deter the porpoises' prey. It has been suggested that pingers deter clupeoid fish such as herring (*Clupea harengus*) (Kraus *et al.*, 1997). Clupeoid fish are acoustically sensitive at the fundamental frequency of the Dukane NetMark™ 1000 pinger (Dukane Corp., Seacom Division, 2900 Dukane Drive, IL 60174, USA; Enger, 1967; Mann *et al.*, 1997) and the family comprises the main prey species of harbour porpoises in Scandinavian and temperate Atlantic waters (Recchia and Read, 1989; Aarefjord *et al.*, 1995). However, recently more support has been given to the hypothesis that pingers deter porpoises directly (Kastelein *et al.*, 1995; Cox *et al.*, 2001; Gearin *et al.*, 2000; Culik *et al.*, 2001).

In order to test (i) if pingers could be an efficient way to reduce by-catch of harbour porpoises in the Swedish bottom-set gillnet fishery and (ii) if they affect the catches of cod and pollack, a field experiment was conducted in the bottom-set gillnet fishery in March and April 1997 in the Skagerrak Sea.

Materials and methods

The pinger experiment was conducted during March and April 1997 in the southern Skagerrak Sea off the Swedish west coast (Figure 1). The design of the experiment was based on the results of observer programmes monitoring the bottom-set gillnets for cod and pollack in the same area and during the same time of the year in 1995 and 1996 (Carlström and Berggren, 1996, 1998). Bottom-set gillnets for cod and pollack are similar in configuration and employment and were therefore treated together in the observer programmes. All fishermen participating in the pinger experiment had also taken part in the observer programmes.

Fishing effort and by-catches in previous years

Between the 1995 and 1996 observer programmes no significant difference could be found in string length, soak time or effort per set (Mann–Whitney U-test; length: $U_{314;195}=27\,725$, $p=0.07$; time: $U_{314;195}=30\,359$, $p=0.87$; effort: $U_{314;195}=29\,545.5$, $p=0.51$). Average string length for the whole data set was 467 m (s.d.=264, n=509) and average soak time 23 h 3 min (s.d.=13 h 26 min, n=509).

The harbour porpoise by-catch events in 1995 and 1996 consisted of a single animal on all but one occasion. To compare the by-catch frequency between years the possible outcome of a haul was considered to be either by-catch or no by-catch, i.e. a by-catch event was independent of the number of animals caught. The by-catch frequencies in both 1995 and 1996 followed Poisson distributions (G-test; 1995: $G=0.32$, d.f.=1, $p=0.62$; 1996: $G=0.33$, d.f.=1, $p=0.61$). No difference was found between the distributions of the two years (replicated G-test; $G=0.35$, d.f.=2, $p=0.85$) and hence the data were pooled. The combined by-catch rate was one by-catch event per 28 hauls. The coefficient of dispersion of the pooled by-catch distribution was 0.97, indicating a good fit to the Poisson distribution.

Design of the pinger experiment

Prior to initiating the pinger experiment the statistical power to detect a significant reduction in the number of by-catch events was analysed. In these analyses different values of by-catch rate, string length and the number of sets and hauls were simulated, while the statistically significant level (α) was set at 5%. Several outlines to detect a 75% reduction in by-catch with statistical power of 80% or more were identified and the final design was decided in collaboration with the participating fishermen.

All strings used in the experiment were identical bottom-set gillnets for cod. They were 500 m long, 5 m high and made of 4-twine mesh with a stretched size of 130 mm. The number of meshes was 2000 per 100 m, the buoyancy of the float line 3.3 kg per 100 m and the weight of the lead line 15 kg per 100 m. Every 100 m a Dukane NetMark™ 1000 pinger was attached to the float line, resulting in 6 pingers per string. When a string was set it was either "active" or "control", with all pingers on any one string either emitting sound or silent. The sequence of when a string would carry active or control pingers was randomized prior to the start of the experiment. The fishermen did not know in advance which type of pingers a string would carry and they did not change their decision on where to set when they were informed of the pinger status. The pingers were specified to emit a broadband signal with a fundamental frequency of 10 kHz and a source level of 130 dB (re 1 μPa at 1 m). The emitted signal was repeated every 4 s and lasted for about 300 ms. When a string served as control, the battery packs in the pingers were reversed.

Based on the theoretical dispersal and attenuation of sound the strength of a pinger signal decreases with the distance according to the function

$$S(D)=SL-20*\log(D)+A*D$$

where S(D) is the signal strength at distance D, SL is the sound source level and A is the attenuation rate. At the distances considered here the attenuation rate is

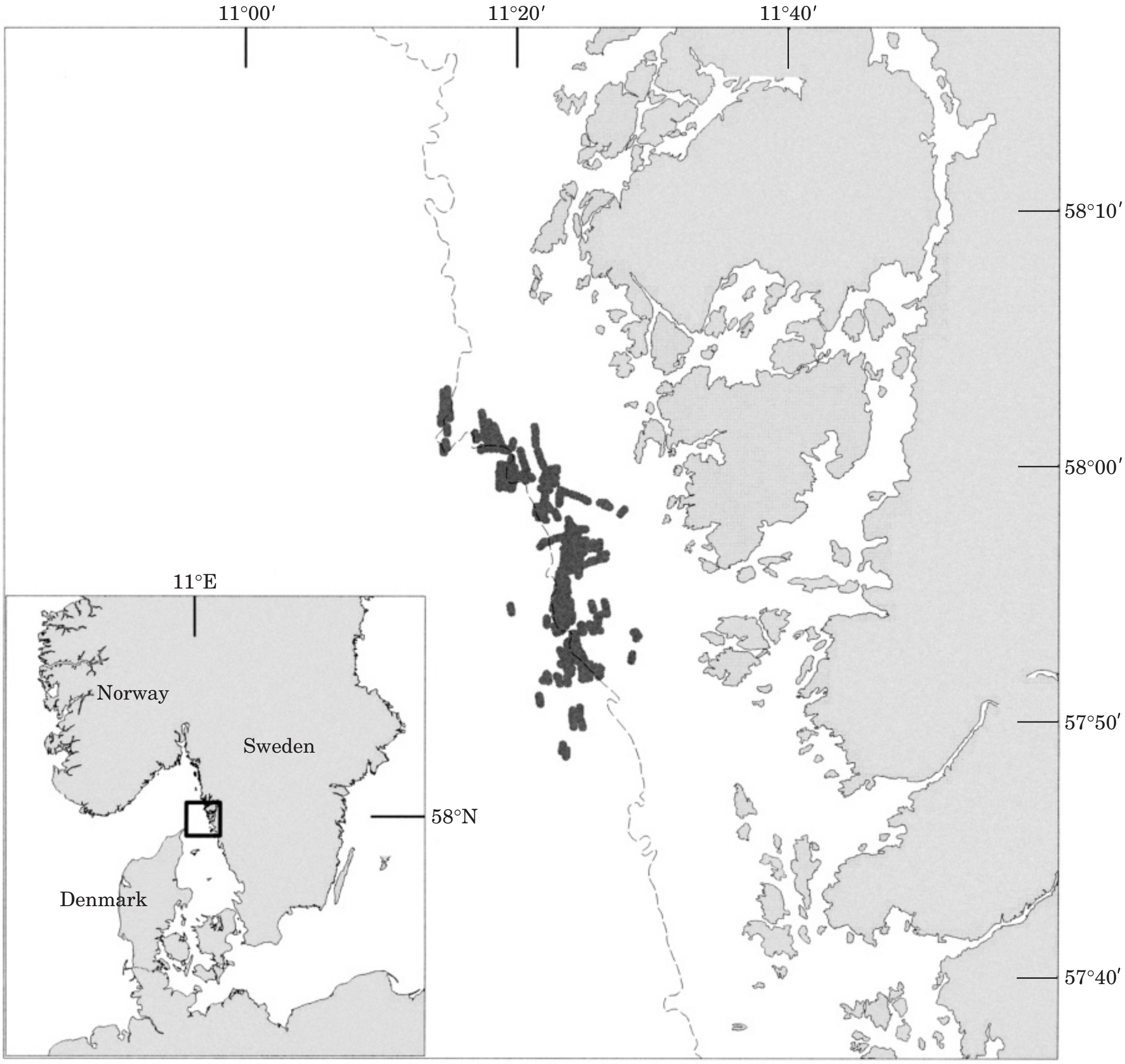

Figure 1. The location of the 1997 pinger experiment. The fishing area is indicated by the shaded zones and the 50 m isobath is marked by the dashed line.

negligible: 0.0007 dB/m of a 10 kHz signal in seawater at 4.7°C (s.d.=0.9, n=150; average water temperature at 20–80 m depth in ICES rectangle 4456 March–April 1994–1997. The temperature data was provided by the Swedish Meteorological and Hydrological Institute while the calculation follows the equation given by Fisher and Simmons, 1977). To perceive a signal the signal strength has to be above the animal's hearing threshold and for a harbour porpoise this is approximately 50 dB re 1 μPa at 1 m at 10 kHz (Andersen, 1970). Furthermore, based on data from human studies (Hirsch, 1952) Trippel *et al.* (1999b) suggested that the signal also has to be about 20 dB above ambient noise level in order to be discernible. The ambient noise level in water varies with sea state (Knudsen *et al.*, 1948), which in turn strongly influences the range of the pinger signal. In very calm conditions a Dukane pinger can theoretically be detected by a porpoise at a distance of approximately 500–600 m, while the distance is decreased to 40–50 m in wind speeds around 10 m s^{-1}. As 10 m s^{-1} represents the upper limit for fishing operations with bottom-set gillnets for cod, 300 m was considered as a representative audible range of pingers for porpoises in the present experiment. This range was used both as the minimum distance experimental strings were allowed to be set in relation to one another, and to define the experimental fishing area (see Results, Distribution of strings and by-catches).

Table 1. The average catch of fish for consumption per string in the 1997 pinger experiment presented with standard deviations ($n_{control}=181$, $n_{active}=188$).

Species	Weight (kg) Control	Active	p	Number Control	Active	p
Cod	27.6 ± 25.0	31.8 ± 29.6	0.33	14.0 ± 12.7	16.5 ± 14.0	0.10
Pollack	8.3 ± 28.3	7.1 ± 21.1	0.92	3.8 ± 13.5	2.8 ± 7.4	0.93
Other species	9.4 ± 8.0	8.7 ± 6.9	0.78	8.1 ± 6.8	8.0 ± 7.0	0.79
All species	45.3 ± 42.1	47.5 ± 44.5	0.58	25.9 ± 22.0	27.3 ± 19.7	0.25

Five fishermen were contracted to fish with a total of 25 strings (2–8 per fisherman). Each fisherman was accompanied by an independent observer and the expected number of days-at-sea during the two-month period was 26. This would result in a total of 650 sets and, with an average soak time of 23 h, the total fishing effort would have been 7475 km net*h of fishing (3737 km net*h of fishing with control and active strings respectively). On this assumption, the power to detect a 75% reduction in the active strings was 0.86 (0.71 for 6 by-catch events and 0.97 for 21).

Statistical and spatial analyses

Prior to all comparisons except those of fish catch, Cochran's test was used to test for homogeneity of variance. A parametric test was chosen for testing for differences between samples with homogenous variances, and non-parametric tests between samples with heterogeneous variances. Non-parametric tests were also used for analyses of fish catches, since cod, pollack and herring are schooling fish and therefore are likely to have clumped distributions. In repeated comparisons the critical alpha was adjusted by the equation $\alpha'=1-(1-\alpha)^{1/k}$, where $\alpha=0.05$ and k is the number of repeated tests. Statistical analyses followed Sokal and Rohlf (1995) and were performed in STATISTICA 5.5 (StatSoft Inc., 1999). Spatial analyses were performed in MapInfo 3.0 (MapInfo Corp., 1994).

Results

Fishing effort

The fishing effort obtained during the experiment was 184 sets or 2053 km net*h of fishing with control strings, and 189 sets or 2122 km net*h of fishing with active strings. The obtained effort was 57% of the anticipated effort due to unfavourable weather conditions in combination with the implementation of new fishing regulations. It covers all effort with bottom-set gillnets for cod reported to the Swedish National Board of Fisheries from the area (ICES rectangle 4456) during the time of the experiment.

No significant difference was found in soak time, and hence not in effort, between sets of control and active strings (ANOVA, $F=0.034$, d.f.$=(1;\ 371)$, $p=0.85$). Neither did the soak time differ significantly between 1995, 1996 and 1997 (Kruskal–Wallis rank ANOVA, $H_{2;882}=2.82$, $p=0.24$). Slightly longer strings in 1997 (average length 33 m longer than in the two previous years) resulted in higher effort per set (Kruskal–Wallis rank ANOVA, $H_{2;882}=43.73$, $p<0.01$).

Catch of porpoises

No porpoises were caught in either the control or the active strings. With an unchanged by-catch rate from the observer programmes the expected number of by-catch events in the obtained control sets would have been 7 (95% CI=3–14) and the power to detect a 75% reduction in the obtained active sets 0.73 (0.53 for 3 events and 0.92 for 14 events).

Catch of fish

In total 31 species of fish were caught but only cod and pollack each contributed more than 5% of the total number of fish caught. There was no significant difference in catch of fish for consumption between the control and active strings in 1997 (see Table 1) or between 1995, 1996 and 1997; the latter calculated as "total catch of fish for consumption" per effort and trip; Kruskal–Wallis rank ANOVA, $H_{2882}=3.92$, $p=0.14$. The fishery was selective with an average number of 3.9 (s.d.=5.8, n=181) and 4.0 (s.d.=6.0, n=188) discarded fish per string in the control and active strings, respectively.

Herring were rarely caught both in the pinger experiment and in the observer programmes. In 1997 one herring was caught in a control string and nine in four active strings. In 1995 eight herring were taken in a total of 314 strings and in 1996 nine herring in 213 strings.

To investigate the availability of herring during the time of the experiment, herring landings from fishing gear targeting this species were considered. In the Skagerrak Sea herring was targeted by Swedish fishermen using bottom trawls, mid-water trawls, pair trawls

Table 2. The landings of herring per fishing effort by Swedish fishermen using herring gears in the Skagerrak Sea in March and April 1995–1997. "n" is the number of fishing operations and the average landings/effort are presented with standard deviations. The last column shows the periods when the landings per effort are significantly different (p<adjusted α).

Herring gear	Year	n	Landings/effort (kg/h)	Significantly different from
Bottom trawl	1995	39	1 008 ± 1 003	1997
	1996	35	732 ± 1 142	1997
	1997	30	2 945 ± 2 343	1995, 1996
Mid-water trawl	1995	8	1 569 ± 456	1996, 1997
	1996	17	3 741 ± 1 934	1995
	1997	5	4 398 ± 3 295	1995
Pair trawl	1995	0	No effort	—
	1996	13	11 725 ± 13 805	n.s.
	1997	9	5 363 ± 2 641	n.s.
Bottom-set gillnet	1995	11	29 ± 38	n.s.
	1996	25	13 ± 14	n.s.
	1997	21	105 ± 147	n.s.

and bottom-set gillnets in March and April 1995–1997 with the exception that pair trawls were not used in 1995 (data from the Swedish National Board of Fisheries). Each of the trawl types contributed 11–72% of the total weight of the herring landings during these months, while 1–3% came from the bottom-set gillnets. The landings-per-effort (kg per fishing hour) were compared between years for each gear type separately. A general comparison including all gear types was not applicable as the gears differ in configuration and employment. Significant differences were found for two of the four gear types. For herring bottom trawls landings-per-effort were higher in 1997 than in 1995 and 1996 while for herring mid-water trawls landings-per-effort was higher in 1996 and 1997 than in 1995 (p-values<adjusted α; Table 2). This indicates that the availability of herring was higher in 1997 than in 1995.

Distribution of strings and by-catches

In the fishing area, the strings were generally set parallel to the coast and along the 50 m isobath (Figure 1). Based on the calculated maximum ensonification coverage of the pingers, the 1997 experimental fishing area was conservatively defined as the combined area of 300 m buffer zones plotted around all sets, control as well as active. The total longitudinal distance of this area was 27.2 km and the surface area was 63.3 km^2. In average per fishing day, 16% (s.d.=10, n=33) of the longitudinal distance and 5% (s.d.=3, n=33) of the surface area were covered by 300 m buffer zones around active strings. An example of the coverage on a fishing day is given in Figure 3. The day is 12 March 1997 and the ensonified zones covered 20% of the longitudinal distance and 4% of the surface area.

A spatial comparison between the pinger experiment and the previous observer programmes show that 62% of all sets and 67% of all by-catches in 1995 and 1996 had occurred within the 1997 experimental fishing area (Figure 2).

Discussion

The by-catch rate in the pinger experiment was significantly reduced in comparison to the pooled by-catch rate in the observer programmes conducted in the two previous years. This reduction could not be explained by a reduction in fishing effort *per se*, a change in catch of cod or pollack, or a spatial shift in fishing area in comparison to the two previous years.

The only modification of the experimental strings was that they carried pingers, which theoretically could work as passive reflectors allowing porpoises to detect more easily both control and active strings and thereby avoid entanglement. Initial findings on passive reflectors have indicated that they might reduce the by-catch rate of small cetaceans, but to date no field study has demonstrated an unequivocal reduction (e.g. Hembree and Harwood, 1987; Hatakeyama *et al.*, 1994; Silber *et al.*, 1994; Koschinski and Culik, 1997; Trippel *et al.*, 1999a; see also review by Dawson, 1994). Considering these results and that the distance between the pingers in the present experiment was 20–33 times longer than that typically used for passive devices, it is not likely that the reduction in by-catch rate was caused by pingers functioning as passive reflectors.

Nonetheless, the drastic reduction in by-catch rate in 1997 may have resulted from a combination of factors. Landing statistics suggest that herring were more abundant in the Swedish Skagerrak Sea in 1997

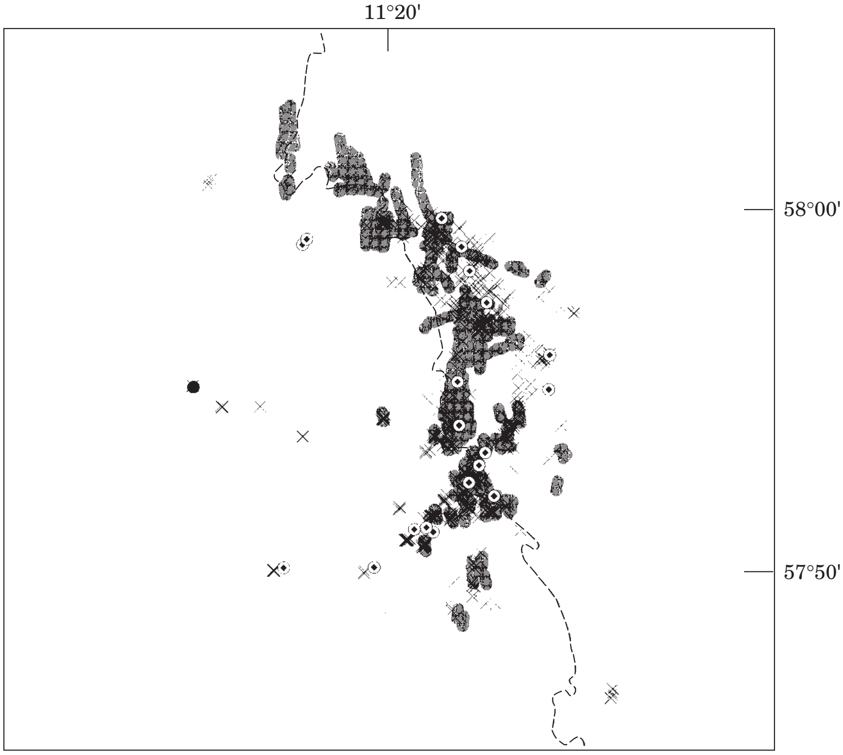

Figure 2. The central positions of the strings set in the 1995 and 1996 observer programmes (×), the positions of monitored harbour porpoise by-catches in 1995 and 1996 (⊙), and the position of the reported by-catch in 1997 (●). The 1997 fishing area is indicated by the shaded zones and the 50 m isobath is marked by the dashed line.

than in 1995 and the spatial analysis shows that the strings in the pinger experiment were set parallel to the coastline along the 50 m depth contour. Good access to food in other parts of the porpoises' distribution range and the ensonification in the experimental fishing area could have provoked a displacement of porpoises from this part of the coast. Furthermore, the audible range of the pingers was calculated at the upper limit of the wind speed for fishing operations with bottom-set gillnets for cod. Theoretically this means that the pingers were discernible to porpoises at longer distances during all times when the wind was less than this upper limit and the sea was calmer. A larger audible range of the pingers would have a twofold effect on the displacement of porpoises:

(i) the coverage of the longitudinal length and surface of the fishing area would have been larger, resulting in a lower accessibility of this part of the coast, and
(ii) sections of the control strings would have been within the ensonified zones, resulting in a lower expected by-catch rate in the control strings.

Apart from the effort by the onboard observers only opportunistic data were collected on live sightings, strandings and by-catches of porpoises in Swedish waters during the time of the experiment. No reports of sightings or strandings were obtained from other areas, although two animals were taken as by-catch in a bottom-set gillnet for pollack that was set approximately 14 km west of the experimental fishing area by one of the fishermen who participated in the experiment (Figure 2). The reported effort with this fishing gear in ICES area 4456 during March and April 1997 was 9% of the effort with bottom-set gillnets for cod covered in the pinger experiment (data from the Swedish National Board of Fisheries). The by-catch event in the pollack net shows that there were harbour porpoises present in the Swedish Skagerrak Sea during the time of the experiment, although no observations were made in the fishing area.

Yet another possible explanation of the zero by-catch in the control strings could be variations in other environmental factors than those investigated here. However, a compilation of data on by-catches of harbour porpoises from the observer programmes (Carlström and Berggren, 1996, 1998; Harwood *et al.*, 1999), an earlier scheme attempting to collect all stranded animals and those occurring as by-catch (Berggren, 1994) and other opportunistic submissions

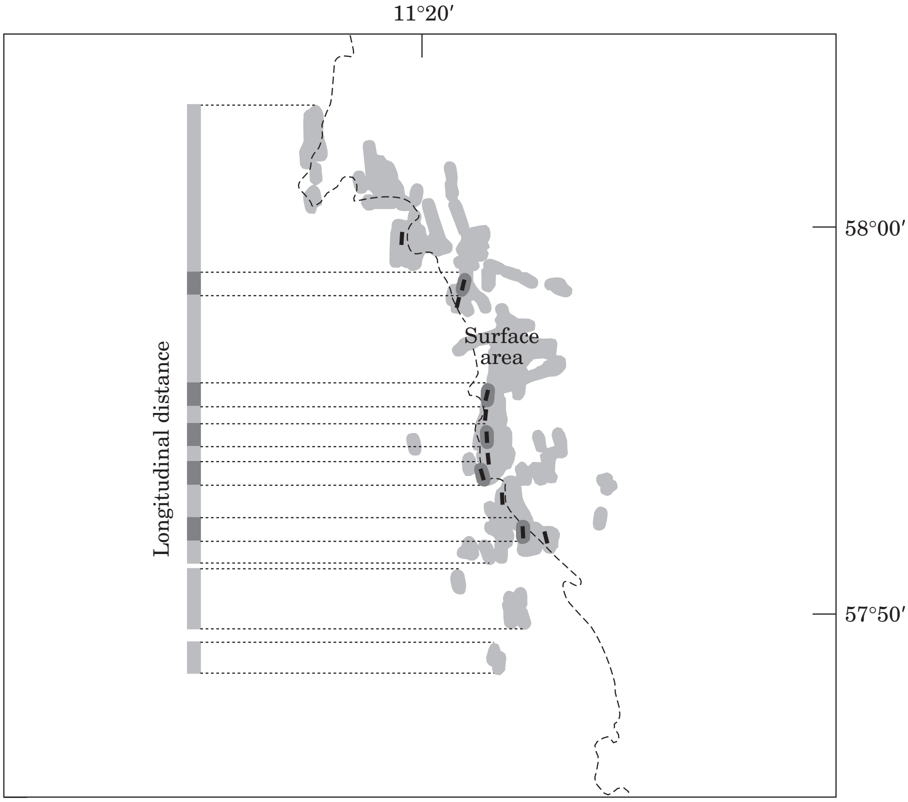

Figure 3. The longitudinal and surface coverage of the ensonified zones on 12 March 1997. Both the control and the active strings set then are marked with black bars, the ensonified zones around the active strings are shaded with dark grey, the total 1997 fishing area is shaded with lighter grey and the 50 m isobath is indicated by the dashed line.

and reports of animals figuring in by-catch (data from Swedish Museums of Natural History; G. Gunnesson, Klädesholmen, Sweden, pers. comm.), show that by-catches of porpoises have occurred not only in the experimental fishing area every year since 1979 during the same season but also in the same fishing gear as in the present study. This suggests that environmental changes resulting in an absence of porpoises in this part of the Skagerrak Sea during this time of the year are not a frequently recurring phenomenon.

The non-significant differences in the catch rates of cod and pollack between control and active strings are consistent with findings on herring, cod and saithe (*Pollachius virens*) in other field experiments using the Dukane NetMark™ 1000 pingers (Trippel *et al.*, 1999b; Culik *et al.*, 2001). It has been concluded, as a result, that the observed reductions in by-catch rates have not been mediated by a redistribution of the porpoises' prey. Neither has behavioural field studies given support to the hypothesis that pingers function by alerting porpoises and trigger them, as it were, to increase their own echolocation. In the presence of active alarms recorded echolocation rates and echolocation occurrence have been shown to decrease (Cox *et al.*, 2001; Culik *et al.*, 2001). Instead it has been proposed that the sound of porpoises affects porpoises directly. Aversive reactions and an increased "distance of closest approach" to an active pinger have been observed (Kastelein *et al.*, 1995; Laake *et al.*, 1998; Cox *et al.*, 2001; Culik *et al.*, 2001). The displacement area has been found to be similar to the audible range of the pinger (Gearin *et al.*, 2000; Cox *et al.*, 2001; Culik *et al.*, 2001), irrespective of the type of alarm used in the study. Gearin *et al.* (2000) noted that many porpoises were sighted within the general area but outside the ensonification zone, indicating that the animals were not displaced far away from the alarms. This is contrary to the hypothesis of a more general displacement in the present study. If porpoises had been displaced only a short distance in this case, an increased by-catch rate would have been expected in the control strings set in non-ensonified water next to the active strings. The observations by Gearin *et al.* (2000) may reflect that that site represented a more critical habitat to the porpoises at the time of the study, or that the porpoises reacted differently to that type of acoustic alarm.

The effectiveness of pingers as a means of safeguarding harbour porpoises is contradictive *per se*. If pingers displace porpoises, the displacement zone caused by the combination of their audible range, their spatial distribution on the net and the time interval between the "pings", must be large enough to prevent porpoises from approaching the net within the distance that they risk entanglement. However, if pingers are too efficient porpoises will be deterred from larger areas than necessary to avoid by-catch. This effect will be even more pronounced in coastal areas where access to bodies of water, such as in archipelagos and sounds, is limited. For a porpoise or a porpoise population decreased access to the areas where fishing nets are set is expected to have a relatively larger impact than the size of the displacement area divided by the total distribution range. The fishing areas are likely to have high concentrations of Clupeoids, which are important prey species both for cod (Curry-Lindahl, 1985) and porpoises (Recchia and Read, 1989; Aarefjord *et al.*, 1995). To assess the relative importance of fishing areas for porpoise populations more information is needed on their distribution and habitat use. Little is known to date but information on e.g. relative distribution, migration routes and detailed diving behaviour can be obtained by new and improved technology. Porpoise-click detectors and animal-carried data loggers and transmitters have been used to study echolocation behaviour (Cox *et al.*, 2001), diving patterns and movements (e.g. Westgate *et al.*, 1995; Read and Westgate, 1997; Otani *et al.*, 1998; Teilmann, 2000).

In conclusion, a combination of relatively high prey availability and an aversive response to pingers may have caused the displacement of porpoises from the fishing area in the present experiment. A potential problem with displacement could be that the ensonified areas may represent habitats critical to the survival of porpoises. A displacement effect is likely to be more prominent in coastal waters where access to sections of the coastline or an archipelago may become more limited. In order to evaluate the effects of an extensive use of pingers on a porpoises more information is needed on distribution, migration and habitat use of porpoise populations.

Acknowledgements

We are grateful to the fishermen for their co-operation in the project and to the onboard observers for their dedicated effort. We would also like to thank Dr Ron Kastelein and Dr Nick Tregenza for contructive comments on the manuscript. The study was jointly funded by the Swedish National Board of Fisheries and the World Wide Fund for Nature (WWF-Sweden).

References

Aarefjord, H., Bjørge, A. J., Kinze, C. C., and Lindstedt, I. 1995. Diet of the harbour porpoise (*Phocoena phocoena*) in Scandinavian waters. Report of the International Whaling Commission, special issue 16: 211–222.

Andersen, S. 1970. Auditory sensitivity of the harbour porpoise, *Phocoena phocoena*. *In* Investigations on Cetacea, 3, pp. 255–259. Ed. by G. Pilleri. Brain Anatomy Institute, University of Berne, Switzerland.

ASCOBANS (Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas) 1997. Report of the Second Meeting of Parties to ASCOBANS. 17–19 November, Bonn, Germany. 67 pp.

Berggren, P. 1994. By-catches of the harbour porpoise (*Phocoena phocoena*) in the Swedish Skagerrak, Kattegat and Baltic Seas 1973–1993. Report of the International Whaling Commission, special issue 15: 211–215.

Berggren, P., Wade, P. R., Carlström, J., and Read, A. 2002. Potential limits to anthropogenic mortality for harbour porpoises in the Baltic region. Biological Conservation, 103: 313–322.

Carlström, J., and Berggren, P. 1996. By-catch estimates of harbour porpoises (*Phocoena phocoena*) in the Swedish Skagerrak Sea obtained from independent observer data. IWC SC/48/SM25, 6 pp.

Carlström, J., and Berggren, P. 1998. By-catch removal rate of harbour porpoise in the Swedish Skagerrak Sea. Abstract, World Marine Mammal Science Conference/12th Biennial Conference on the Biology of Marine Mammals, Monaco, January 20–24.

Cox, T. M., Read, A. J., Solow, A., and Tregenza, N. 2001. Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? Journal of Cetacean Research and Management, 3(1): 81–86.

Culik, B., Koschinski, S., Tregenza, N., and Ellis, G. M. 2001. Reactions of harbour porpoises *Phocoena phocoena* and herring *Clupea harengus* to acoustic alarms. Marine Ecology Progress Series, 211: 255–260.

Curry-Lindahl, K. 1985. Våra fiskar. Havs- och sötvattensfiskar i Norden och övriga Europa. P.A. Nordstedt & Söners Förlag, Stockholm, Sweden. 528 pp. (In Swedish).

Dawson, S.M. 1994. The potential for reducing entanglement of dolphins and porpoises with acoustic modifications to gillnets. Report of the International Whaling Commission, special issue 15: 573–578.

Enger, P. S. 1967. Hearing in herring. Comparative Biochemistry and Physiology, 22: 527–538.

Fisher, F. H., and Simmons, V. P. 1977. Sound absorption in sea water. Journal of Acoustical Society of America, 62: 558–564.

Gearin, P. J., Gosho, M. E., Laake, J. L., Cooke, L., DeLong, R. L., and Hughes, K. M. 2000. Experimental testing of acoustic alarms (pingers) to reduce by-catch of harbour porpoise, *Phocoena phocoena*, in the state of Washington. Journal of Cetacean Research and Management, 2: 1–9.

Harwood, J., Andersen, L. W., Berggren, P., Carlström, J., Kinze, C. C., McGlade, J., Metuzals, K., Larsen, F., Lockyer, C. H., Northridge, S., Rogan, E., Walton, M., and Vinther, M. 1999. Assessment and reduction of the by-catch of small cetaceans (BY-CARE). Final Report FAIR-CT05-0523 to EU. 27 pp.

Hatakeyama, Y., Ishii, K., Akamatsu, T., Soeda, H., Shimamura, T., and Takahito, K. 1994. A review of studies on attempts to reduce the entanglement of the Dall's porpoise, *Phocoenoides dalli*, in the Japanese salmon gillnet fishery. Report of the International Whaling Commission, special issue 15: 549–571.

Hembree, D., and Harwood, M. B. 1987. Pelagic gillnet modification trials in northern Australian Seas. Reports of the International Whaling Commission, 37: 369–373.

Hirsch, I. J. 1952. The measurement of hearing. McGraw-Hill Inc., Toronto, Ontario.
IWC (International Whaling Commission) 1996. Report of the sub-committee of small cetaceans, Annex H. Reports of the International Whaling Commission, 46: 160–179.
Kastelein, R. A., Goodson, A. D., Lien, J., and de Haan, D. 1995. The effects of acoustic alarms on Harbour porpoise (*Phocoena phocoena*) behaviour. *In* Harbour porpoises: laboratory studies to reduce by-catch, pp. 157–167. Ed. by P. E. Nachtigall, J. Lien, W. W. L. Au, and A. J. Read. A.J. De Spiel Publishers, Woerden, The Netherlands. 167 pp.
Knudsen, V. O., Alford, R. S., and Emling, J. W. 1948. Underwater ambient noise. Journal of Marine Research, 7: 410–429.
Koschinski, S., and Culik, B. 1997. Deterring harbour porpoises (*Phocoena phocoena*) from gillnets: observed reactions to passive reflectors and pingers. Reports of the International Whaling Commission, 47: 659–668.
Kraus, S. D., Read, A. J., Solow, A., Baldwin, K., Spradlin, T., Anderson, E., and Williamson, J. 1997. Acoustic alarms reduce porpoise mortality. Nature, 388: 525.
Laake, J., Rugh, D., and Baraff, L. 1998. Observations of harbor porpoise in the vicinity of acoustic alarms on a set gill net. NOAA Technical Memorandum NMFS-AFSC-84, U.S. Department of Commerce. 40 pp.
Larsen, F. 1997. Effekten af akustiske alarmer på bifangst av marsvin i garn. Report 44–97, Danish Institute for Fisheries Research. 10 pp. (In Danish).
Mann, D. A., Lu, Z., and Popper, A. N. 1997. A clupeid fish can detect ultrasound. Nature, 388: 341.
MapInfo Corp 1994. MapInfo 3.0 for Windows. Computer program manual. MapInfo Corp., Troy, NY.
Otani, S., Naito, Y., Kawamura, A., Kawasaki, M., Nishiwaki, S., and Kato, A. 1998. Diving behavior and performance of harbor porpoises, *Phocoena phocoena*, in Funka Bay, Hokkaido, Japan. Marine Mammal Science, 14: 209–220.
Perrin, W. F., Donovan, G. P., and Barlow, J. 1994. Report of the workshop on mortality of cetaceans in passive fishing nets and traps. Report of the International Whaling Commission, special issue 15: 6–57.
Read, A. J., and Westgate, A. J. 1997. Monitoring the movements of harbour porpoises (*Phocoena phocoena*) with satellite telemetry. Marine Biology, 130: 315.
Recchia, A. C., and Read, A. J. 1989. Stomach contents of harbour porpoises, *Phocoena phocoena* (L.) from the Bay of Fundy. Canadian Journal of Zoology, 67: 2140–2146.
Silber, G. K., Waples, K. A., and Nelson, P. A. 1994. Response of free-ranging harbour porpoises to potential gillnet modifications. Report of the International Whaling Commission, special issue 15: 579–584.
Sokal, R. R., and Rohlf, F. J. 1995. Biometry: the principles and practice of statistics in biological research, 3rd edn. W.H. Freeman and Company, New York. 850 pp.
Statsoft Inc. 1999. STATISTICA 5.5 for Windows. Computer program manual. StatSoft Inc., Tulsa, OK.
Teilmann, J. 2000. The behaviour and sensory abilities of Harbour Porpoises (*Phocoena phocoena*) in relation to by-catch in gillnet fishery. Ph.D. thesis, Center for Sound Communication, Institute of Biology, University of Southern Denmark, Odense, Denmark. 219 pp.
Trippel, E. A., Conway, J. D., Palka, D., Potter, D. C., Merrick, R., Laurie, A., and King, D. 1999a. Testing of acoustically reflective gillnets as an alternative tool to reduce incidental mortalities of harbour porpoise in gillnet fisheries. Abstract, 13th Biennial Conference on the Biology of Marine Mammals, Wailea, Hawaii, 28 November–3 December.
Trippel, E. A., Strong, M. B., Terhune, J. M., and Conway, J. D. 1999b. Mitigation of harbour porpoise (*Phocoena phocoena*) by-catch in the gillnet fishery in the lower Bay of Fundy. Canadian Journal of Fisheries and Aquatic Science, 56: 113–123.
Westgate, A. J., Read, A. J., Berggren, P., Koopman, H. N., and Gaskin, D. E. 1995. Diving behaviour of harbour porpoises, *Phocoena phocoena*. Canadian Journal of Fisheries and Aquatic Sciences, 52: 1064–1073.