Effect of pingers on harbour porpoise (*Phocoena phocoena*) bycatch in the US Northeast gillnet fishery

DEBRA L. PALKA*, MARJORIE C. ROSSMAN*, AMY S. VANATTEN* AND CHRISTOPHER D. ORPHANIDES+

Contact e-mail: Debra.Palka@noaa.gov

ABSTRACT

Harbour porpoise (*Phocoena phocoena*) bycatch in the US Northeast gillnet fishery is managed under the Harbour Porpoise Take Reduction Plan (HPTRP), which was implemented on 1 January 1999. The HPTRP divides this fishery into management areas that are either completely closed to all gillnets or closed only to gillnets that do not use pingers. Questions about pingers that have arisen include: (1) would pingers be as effective in an operational fishery as in controlled scientific experiments; (2) would the fishery comply with these regulations; and (3) would harbour porpoises habituate to pingers? To investigate these questions, data from over 25,000 gillnet hauls observed by the Northeast Fisheries Observer Program after the implementation of the HPTRP, 1999-2007, were examined. In a 1994 controlled scientific experiment conducted in part of this fishery that used 15cm mesh gillnets, the bycatch rate in pingered nets was 92% less than that in nets without pingers. In contrast, in the operational fishery, the bycatch reduction in pingered nets was 50-70%, depending on the time, area and mesh size. In particular, there was no observed bycatch in pingered nets that used the same mesh size as used in the experiment. Thus, it seem that the apparent decrease in pinger effectiveness in the operational fishery was partially due to the type of gillnet used and lack of compliance. Pinger usage started out high in 1999 (the first year required), dropped substantially during 2003-05 and perhaps due to outreach activities increased beginning in 2006. During years of high pinger usage, 87% of the tested pingers were functional, while only 36% of the tested pingers were functional during years of low pinger usage. In general, as expected, observed bycatch rates in hauls without pingers were greater than bycatch rates in hauls with the required number of pingers. Unexpectedly, bycatch rates of observed hauls with an incomplete set of pingers were higher that in observed hauls without pingers. Confounding factors that could partially explain this apparently contrary result are discussed. There was no evidence for temporal trends in the bycatch rates, suggesting that harbour porpoises had not habituated to the pingers. In conclusion, in the US Northeast gillnet fishery, harbour porpoises do not appear to have habituated to pingers, and pingers appear to have reduced the bycatch rate, particularly when the required number of pingers were used and in nets using mesh sizes of 15cm or less.

KEYWORDS: NOISE; GILLNETS; INCIDENTAL CATCHES; CONSERVATION; CATCH PER UNIT EFFORT; MONITORING; ATLANTIC OCEAN; NORTH AMERICA; SHORT-TERM CHANGE; MANAGEMENT REGULATIONS; SAMPLING TECHNIQUES

INTRODUCTION

During the Kraus *et al*. (1997) controlled scientific experiment, a 92% reduction in bycatch of harbour porpoises (*Phocoena phocoena*) was documented in gillnets that used a 15cm (6in) stretched mesh size, within the US Northeast Atlantic Mid-Coast management area, in autumn (October to December) 1994 (0.0591 harbour porpoises per haul in control nets versus 0.0048 harbour porpoises per haul in pingered nets). Based on the success of this experiment, the US National Marine Fisheries Service developed the Harbour Porpoise Take Reduction Plan (HPTRP)[1] to use pingers as one of the mitigation tools for reducing harbour porpoise bycatch in gillnet fisheries in the US portion of the Northwest Atlantic Ocean. The HPTRP was implemented on 1 January 1999 (NOAA, 1998).

The Northeast gillnet fishery is prosecuted in US waters east of 72°W and north of 40°N (Fig. 1) and targets Atlantic cod (*Gadus morhua*), monkfish (*Lophius americanus*), pollock (*Pollachius virens*) and various flounder species. The HPTRP divides this region into management areas (MA) that are either completely closed to all gillnets or closed only to gillnets that do not use pingers (Table 1). The HPTRP specifies that, when pingers are required, an operating and functional pinger must be attached at the end of each gillnet string and at the bridle of each net within that string, where a net is usually 92m (300ft) long. Thus, 11 pingers are required on a 10 net string. The HPTRP defined a pinger as an instrument which, when immersed in water, broadcasts a 10kHz (±2kHz) sound at 132dB (±4dB) re 1μPa at 1m, lasting 300ms (±15ms), and repeating every 4s (±2s).

Several concerns about pingers were raised during the development of the HPTRP and during an IWC review of pingers (IWC, 2000); namely, effectiveness, compliance and habituation. There was some concern expressed that pingers may not consistently reduce the bycatch of harbour porpoises, particularly to the levels demonstrated in experiments such as in Kraus *et al*. (1997) i.e. that harbour porpoise bycatch rates in operational fisheries might not be as low as in controlled scientific experiments. Other concerns centred over issues that (1) pingers might not be used properly (e.g. not the required number and/or no replacement of broken pingers or used batteries) with the result that in operational fisheries harbour porpoise bycatch might increase due to declining compliance; and (2) concern that harbour porpoises might become habituated to the sounds made by the pingers with the result that in operational fisheries harbour porpoise bycatch rates might increase with time, as shown elsewhere by Cox *et al*. (2001) and Carlström *et al*. (2009). To investigate these concerns, this paper examines data collected by the Northeast Fisheries Observer Program (NEFOP) to document patterns in harbour porpoise bycatch rates, levels of compliance to the pinger regulations and possible indications of habituation.

[1] *http://www.nero.noaa.gov/prot_res/porptrp*

* *Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543, USA.*
+ *Northeast Fisheries Science Center, 28 Tarzwell Dr., Narragansett, RI 02882, USA.*

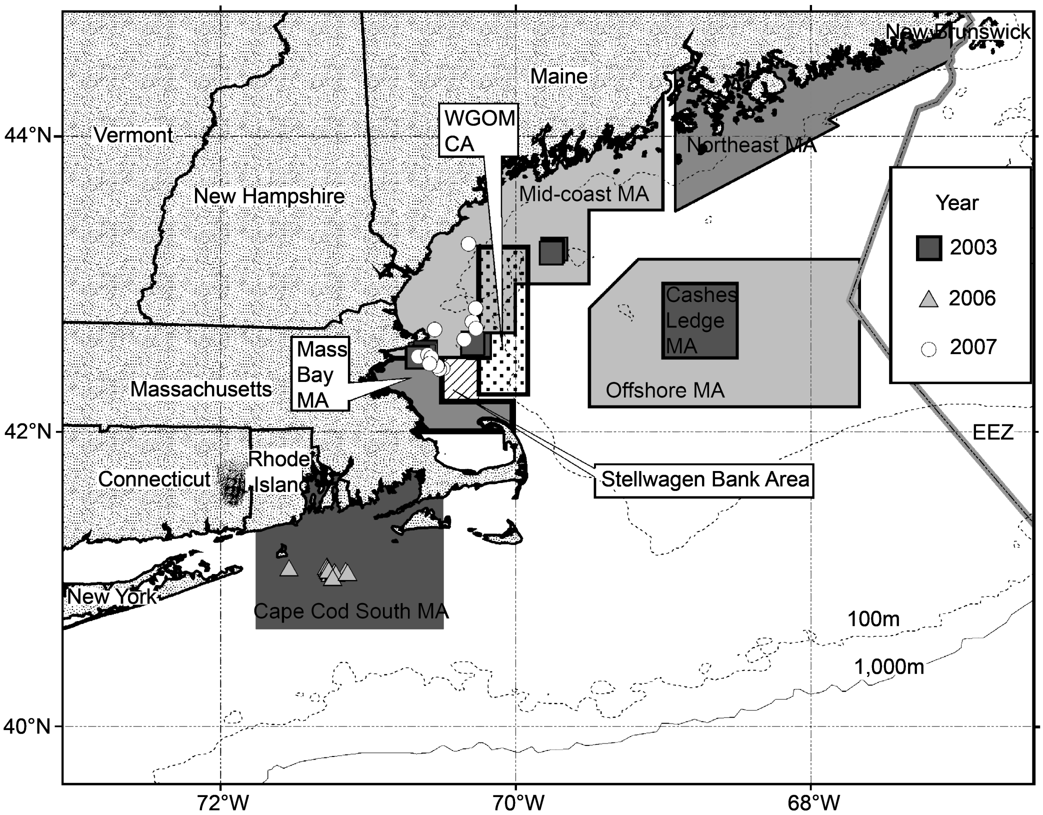

Fig. 1. Locations of the US Northeast gillnet fishery management areas (MA), closed area (CA) and other areas of interest. In addition, the locations of trips that had pinger performance tested are shown.

Table 1

Times and areas in the US Northeast gillnet fishery that are either closed to all gillnets (Closed) or else closed to all gillnets that do not use pingers (Closed – pingers allowed).

Area	Dates	Status of gillnets[1]
Northeast	15 Aug. – 13 Sep.	Closed
Mid-coast	15 Sep. – 31 May	Closed – pingers allowed
Massachusetts Bay	1 Dec. – 28/29 Feb.	Closed – pingers allowed
	1-31 Mar.	Closed
	1 Apr. – 31 May	Closed – pingers allowed
Offshore	1 Nov. – 31 May	Closed – pingers allowed
Cashes Ledge	1-28/29 Feb.	Closed
Western Gulf of Maine	All year round	Closed
Cape Cod South	1 Dec. – 28/29 Feb.	Closed – pingers allowed
	1-31 Mar.	Closed
	1 Apr.– 31 May	Closed – pingers allowed

[1]A pinger is defined as an acoustic deterrent device which, when immersed in water, broadcasts a 10kHz (±2kHz) sound at 132dB (±4dB) re 1 μPa at 1m, lasting 300ms (±15ms), and repeating every 4s (±2s).

DATA

Observers from the NEFOP collect data on characteristics of the trip, haul, gear, economic factors, catch and incidental bycatch. Trip characteristics include: vessel name and number; date sailed; date landed; home port; port fish landed; steam time; and number of crew. Haul characteristics include: weather conditions; wind speed and direction; wave height; depth range; latitude; longitude; time of the beginning and ending of the haul; soak duration; species targeted on each haul; presence and quantity of fish kept and discarded; and the number of incidental bycatch of cetaceans, seals, turtles and birds. Gear characteristics for gillnets include: mesh size; twine size; length of string; height of net; hang ratio; number of floats and weights; and length of tie downs. Economic factors related to the trip include: tons of ice used; fuel used; price of water, food, oil and bait; and damage costs. Observers identify both kept and discarded catch, and, on some trips, record the amount caught of each species. When an incidental bycatch occurs, information recorded includes: species identification; number of each species; condition of the body; body length; sex; tag number (if body is returned to the sea); and types of samples taken (body parts or whole animal). Only bycatches of harbour porpoises and observed hauls that have complete latitude-longitude information that were observed during 1 January 1999 to 31 May 2007 were used in this paper.

As interest arose on the use of pingers to deter marine mammal bycatch, the NEFOP modified their data collection protocols, logs, gear and training to include: whether active marine mammal deterrent devices (i.e. pingers) were used; how many were on the gear when set; frequency in kilohertz; whether it was salt-water activated; brand name of the pingers; number of pingers hauled back on the gear; and number of pingers lost as reported by the captain.

In addition to collecting the pinger information for all observed hauls, the NEFOP implemented a Pinger Tester Program in October 2003. NEFOP staff drafted a pinger tester datasheet, developed a tester and trained observers in the field to test whether or not pingers were functioning during observed trips. A dozen pinger testers were issued to observers during times and places where pingers were required to be used.

There are two types of sampling protocols that an observer may follow while on a gillnet trip, 'Limited' and 'Complete'. During a 'Complete' trip observers are more focused on fish sampling and discards whereas during a 'Limited' trip observers are focused exclusively on marine mammal incidental takes and pinger testing. If a gillnet trip within an area requiring pingers is a 'Limited' trip and the observer is equipped with a pinger tester, then the observer tests the performance of each pinger as the net is hauled on board by evaluating if a pinger is: (1) audible; (2) inaudible and tested; or (3) inaudible and not tested. If a gillnet trip is a 'Complete' trip, the observer primarily performs the fish sampling requirements; however, if a marine mammal take occurs, and the observer is equipped with a pinger tester, then the remaining pingers on that string are tested as they are hauled on board. In this paper, only the 'Limited' trips were used to investigate pinger performance. Both types of trips were used to investigate pinger usage, pinger effectiveness and habituation.

METHODS

Compliance

To document compliance with HPTRP complete closure regulations, the numbers of observed hauls within totally closed times and areas were summarised.

Pinger usage

To document compliance with the pinger usage regulations, percentages of observed hauls that used various quantities of pingers were summarised by year and management area. Pinger usage was grouped into four categories:

(1) all of the required number of pingers (given the number of nets per string);
(2) more than 50% but less than all of the required number of pingers;
(3) some pingers but less than or equal to 50% of the required number of pingers; and
(4) no pingers on a string.

The choice of categories (2) and (3) was to allow some investigation of the effect of various levels of incomplete pinger use whilst retaining sufficient sample sizes by category.

Pinger performance

To document compliance with the functional pinger regulation, pinger performance data that were collected by the NEFOP Pinger Tester Program (during 2003, 2006 and 2007) were evaluated by summarising the percentage of pingers that were audible and inaudible.

Pinger effectiveness

To document the effectiveness of pingers, in the times and areas where pingers were required, bycatch rates of harbour porpoises were estimated from hauls that used no pingers, some pingers and the required number of pingers. The bycatch rate was defined as the sum of observed dead harbour porpoises divided by the sum of the fishing effort on the observed hauls, where three proxies of fishing effort were investigated: metric tons (mtons) landed; hauls; and volume-soaked (the product of net length, net height and soak duration, in the units of km^2-days). Since the unit of effort required when estimating bycatch for the entire fishery (e.g. Belden, 2007; Belden and Orphanides, 2007) is mtons landed (Orphanides and Palka[2]), this unit of effort is the primary unit of effort presented in this paper, although the other units were also investigated.

The coefficient of variation (CV) of the bycatch rates were estimated using 1,000 bootstrapped iterations. First, for each iteration, the observer dataset was resampled by haul with replacement to result in a dataset with the same number of hauls as in the original dataset. Second, the bycatch rate from the new dataset was calculated. Finally, the CV was defined as the standard deviation of the 1,000 bycatch rates divided by the actual bycatch rate.

Reduction in bycatch rates of hauls with no pingers versus hauls with the required number of pingers was tested with a non-parametric one-tailed Mann-Whitney-Wilcoxon (MWW) two sample rank-sum test. The differences between bycatch rates of hauls with none, some and all of the required number of pingers were tested using the Kruskal-Wallis rank-sum test.

Habituation

To determine if habituation to pingers may have occurred in times and areas where pingers were required, the observer data were used to monitor bycatch rate trends. Long-term trends were defined as trends in the annual rates over the years since the implementation of the HPTRP. Short-term trends were defined as trends in the monthly rates within the time period that pingers were required within a management area. To determine if bycatch rates increased over time on a short- or long-term basis, bycatch rates were summarised and modelled using generalised linear and additive models (GLMs and GAMs), where the numbers of harbour porpoise takes in a haul were regressed against the year (or month), percentage of pinger usage, and an offset of the effort (mtons landed), using a quasi-Poisson model.

RESULTS

Since the implementation of the HPTRP (1 January 1999 to 31 May 2007), about 25,400 gillnet hauls have been observed in the Northeast gillnet fishery, of which about 20,750 hauls were in the Gulf of Maine and about 4,650 were south of Cape Cod (Table 2A). The Mid-Coast MA, Massachusetts Bay (Mass Bay) MA and the area outside all GOM management areas had the most observed hauls. The Cashes Ledge MA and Western Gulf of Maine (WGOM) Closed Area, both officially closed to fishing for specified

[2] Though all three of the above units of effort are available for the observed hauls, mtons landed is the only reliable unit of effort available to expand the sample bycatch rate to the entire fishery. Mtons landed may be considered a non-standard measure of fishing effort, though in the case of harbour porpoise bycatch in the previously observed gillnet fishery, mtons landed is a valid unit of effort when using ratio estimation methods because the underlying assumptions of the methodology are valid. That is, as the mtons landed increases so does the number of observed dead harbour porpoises. For more details refer to: *Orphanides, C. and Palka, D. 2007. Landings: the unit of effort for bycatch rates in gillnet fishing gear. Presented to the Harbour Porpoise Take Reduction Team in December 2007. Available from the author.*

Table 2

By month and management area (MA): (A) number of harbour porpoise takes and observed hauls and (B) resulting bycatch rates (harbour porpoises per mtons landed). In addition, for each MA, the resulting bycatch rates using three different units of effort (C). Data used from 1 January 1999 to 31 May 2007. Dark shaded cells indicate the times/areas when pingers are required. Light shaded cells with bold numbers indicate the times/areas that are closed to all gillnets.

Month	Cashes Ledge	Mass Bay	Mid-coast	Offshore	WGOM	Stellwagen Bank	Outside GOM MAs	TOTAL GOM	CC South MA	Outside CC South MA	TOTAL south of Cape Cod
A. Number of observed takes (Number of observed hauls)											
1999 to 2007											
Jan.	0 (0)	0 (273)	1 (139)	0 (55)	**1 (67)**	3 (377)	0 (433)	5 (1,344)	2 (197)	1 (60)	3 (257)
Feb.	**0 (21)**	0 (193)	0 (177)	0 (79)	**2 (98)**	7 (396)	0 (281)	9 (1,245)	11 (179)	6 (111)	17 (290)
Mar.	0 (13)	**1 (61)**	3 (199)	0 (95)	**1 (153)**	2 (499)	1 (370)	8 (1,390)	**0 (3)**	7 (155)	7 (158)
Apr.	0 (13)	0 (0)	0 (30)	0 (145)	**0 (0)**	0 (0)	5 (649)	5 (837)	1 (270)	33 (303)	34 (573)
May	0 (0)	0 (326)	0 (5)	0 (77)	**0 (22)**	0 (200)	1 (614)	1 (1,244)	9 (739)	16 (452)	25 (1,191)
1999 to 2006											
Jun.	2 (24)	0 (721)	1 (195)	0 (124)	**0 (29)**	0 (286)	0 (639)	3 (2,018)	0 (0)	0 (335)	0 (335)
Jul.	0 (0)	0 (397)	2 (944)	0 (127)	**0 (60)**	0 (210)	0 (630)	2 (2,368)	0 (0)	0 (266)	0 (266)
Aug.	0 (30)	0 (488)	1 (888)	0 (82)	**0 (67)**	0 (214)	0 (746)	1 (2,515)	0 (0)	0 (158)	0 (158)
Sep.	0 (36)	2 (496)	4 (728)	0 (46)	**0 (67)**	0 (252)	0 (806)	6 (2,431)	0 (0)	0 (190)	0 (190)
Oct.	0 (53)	0 (38)	11 (790)	0 (150)	**0 (60)**	0 (5)	0 (722)	11 (1,818)	0 (0)	0 (357)	0 (357)
Nov.	0 (18)	2 (95)	26 (925)	0 (83)	**5 (74)**	0 (5)	1 (681)	34 (1,881)	0 (0)	0 (508)	0 (508)
Dec.	0 (13)	3 (466)	7 (325)	0 (76)	**1 (31)**	6 (280)	2 (476)	19 (1,667)	1 (277)	0 (85)	1 (362)
TOTAL	2 (221)	8 (3,554)	56 (5,345)	0 (1,139)	10 (728)	18 (2,724)	10 (7,047)	104 (20,758)	24 (1,665)	63 (2,980)	87 (4,645)
B. Bycatch rate (number of observed takes/observed mtons of landing)											
1999 to 2007											
Jan.	0	0	0.045	0	**0.082**	0.047	0	0.022	0.047	0.038	0.044
Feb.	**0**	0	0	0	**0.192**	0.192	0	0.056	0.558	0.069	0.16
Mar.	0	**0.267**	0.156	0	**0.047**	0.037	0.017	0.038	**0**	0.068	0.065
Apr.	0	0	0	0	**0**	0	0.069	0.04	0.025	0.170	0.145
May	0	0	0	0	**0**	0	0.01	0.005	0.051	0.084	0.068
1999 to 2006											
Jun.	0.332	0	0.032	0	**0**	0	0	0.007	0	0	0
Jul.	0	0	0.01	0	**0**	0	0	0.003	0	0	0
Aug.	0	0	0.006	0	**0**	0	0	0.002	0	0	0
Sep.	0	0.023	0.028	0	**0**	0	0	0.01	0	0	0
Oct.	0	0	0.066	0	**0**	0	0	0.023	0	0	0
Nov.	0	0.052	0.121	0	**0.145**	0	0.005	0.066	0	0	0
Dec.	0	0.043	0.071	0	**0.095**	0.079	0.018	0.044	0.013	0	0.010
TOTAL	0.023	0.016	0.052	0	0.056	0.04	0.005	0.022	0.066	0.041	0.062
C. Bycatch rates using different units of effort for entire time period											
Mtons landed	0.023	0.016	0.052	0	0.056	0.040	0.005	0.022	0.066	0.041	0.062
Hauls	0.009	0.002	0.010	0	0.014	0.007	0.001	0.005	0.014	0.021	0.019
Volume-soaked (km^2-days)	0.641	0.527	2.024	0	2.317	1.134	0.256	0.911	1.837	1.090	1.953

time periods, had the lowest number of observed hauls. There were no hauls observed in the Northeast MA at any time in the year because fishing in this area has nearly stopped; thus further discussions do not include the Northeast MA.

Compliance

Few hauls were observed (Table 2A) in the times and areas that were totally closed to gillnets due to the implementation of the HPTRP (Table 1). However, within the WGOM Closed Area (closed all year round for fish conservation reasons) there was observed gillnet fishing during nearly every month; observed hauls were usually very close to a border, in particular the western inshore border (Fig. 2); and harbour porpoise bycatch was observed from November through March (Table 2A).

Pinger usage

Pinger usage dropped substantially in 2003 and started increasing again in 2006 (Fig. 3). This pattern occurred in all management areas (Fig. 4). To allow for the situations where one pinger may have died or accidently fallen off during the time the net was under water, compliance in Fig. 4 was expressed as observed hauls with more than 90% of the required number of pingers, which is the result of the commonly used 10-net string missing one pinger.

Pinger performance

Of the 42 observers trained to use the pinger tester, eight actually collected data on pinger performance. Sixty-nine gillnet strings, with a total of 813 pingers, were tested (Fig. 1). Most of these trips were since 2006: 12 trips were in 2003; 15 trips in 2006; and 42 in 2007. Of the 813 pingers examined, 346 (43%) were audible by ear and thus not tested; 109 (13%) were not audible by ear and were not tested; 307 (38%) were not audible by ear, were tested and determined to be working properly; and 51 (6%) were not audible by ear, were tested and determined to be not working.

Thus, over all years at least 80% of the tested pingers were working and perhaps as many as 93% were working (as estimated by including only those pingers that were tested or audible by ear). During 2003, a year with low pinger usage (Figs 3 and 4), 113 pingers were investigated

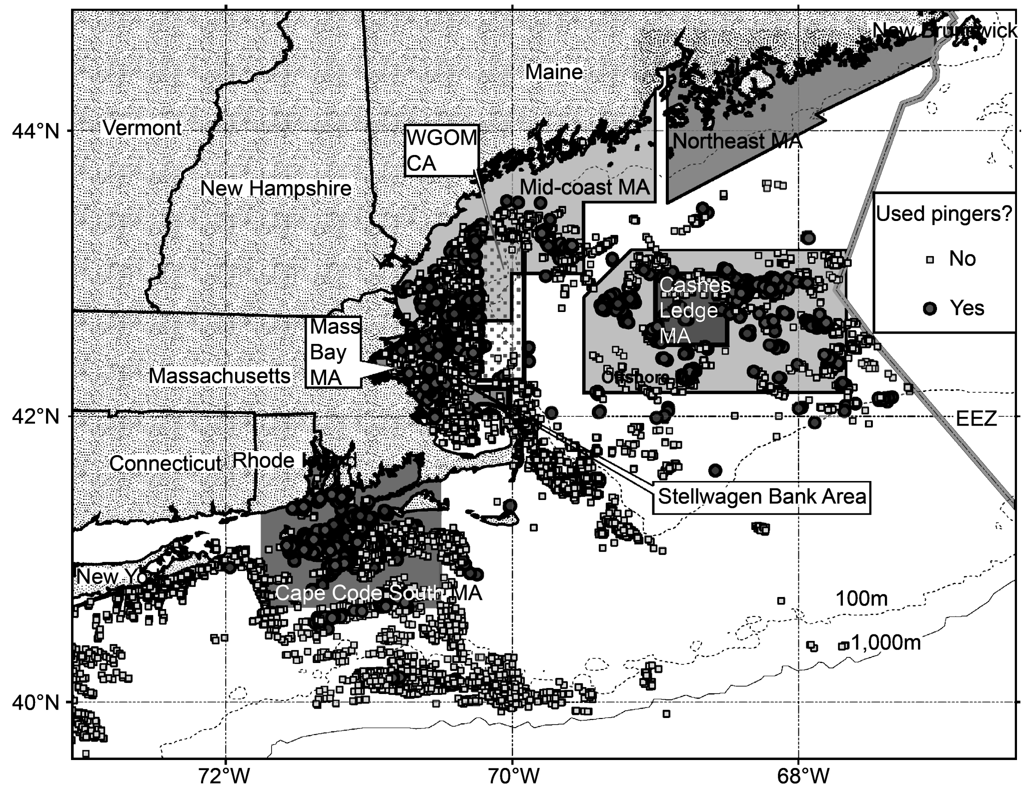

Fig. 2. Location of hauls that did not use pingers (small light squares) and hauls that did use pingers (large dark circles) from 1 January 1999 through 31 May 2007.

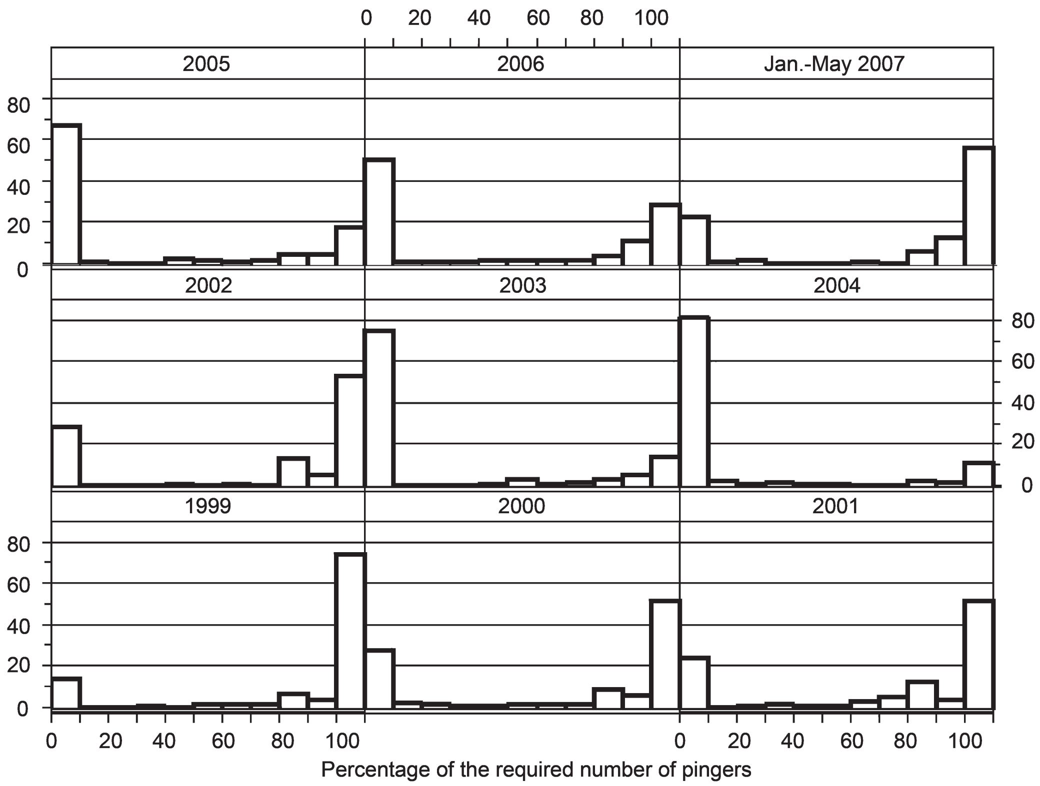

Fig. 3. The distribution, by year, of the number of pingers used per string in the US Northeast gillnet fishery during times and areas that pingers were required (1 January 1999 to 31 May 2007), where the number of pingers used was normalised by the number of pingers required for the length of that string. For example, the regulations state that if a gillnet string consists of 10 nets then 11 pingers are required. If that 10-net string was an observed haul and there were 11 pingers on the string, then it had 100% of the required number of pingers, while if that string did not have any pingers, then it had 0% of the required number of pingers.

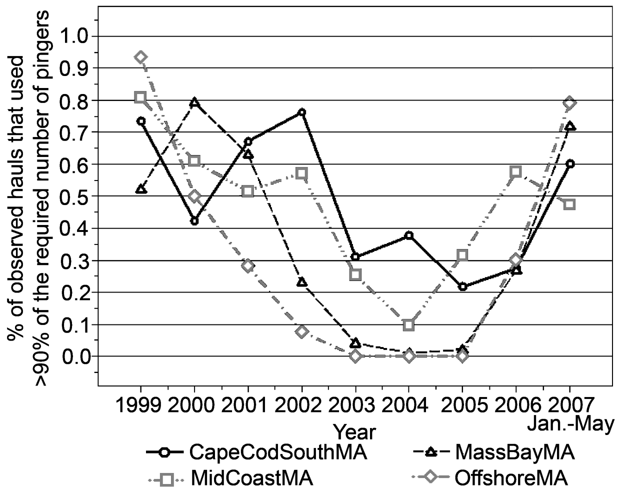

Fig. 4. During 1 January 1999 to 31 May 2007, by management area, the percentage of observed hauls that used more than 90% of the required number of pingers, during times pingers were required.

and only 36% were working. In contrast, in 2006-07 when pinger usage was high, 700 pingers were investigated and 87% were working.

Pinger effectiveness

Since the implementation of the HPTRP, harbour porpoise bycatch rates (Table 2B and 2C) differed by area. The highest bycatch rates (no matter which unit of effort was used in the definition of the bycatch rate) were in the Cape Cod South (CCSouth) MA, WGOM Closed Area and Mid-Coast MA. The next highest bycatch rates were within the Stellwagen Bank Area and the area south of Cape Cod but outside the CCSouth MA.

Pooling over all years and management areas since the implementation of the HPTRP for those times and areas for which pingers were required, the bycatch rate (harbour porpoises per mtons landed) of hauls without pingers was about two to three times the rate of hauls with the required number of pingers (Table 3A); this was a significant difference (p-value=0.0048). Significant differences were also observed (Table 3B) when the bycatch rate was defined as harbour porpoises per haul (p-value=0.0054) and harbour porpoises per volume-soaked (km^2-days; p-value=0.0052). A similar pattern was evident within each area when pooled over years (Fig. 5), and within most individual years when pooled over areas (Fig. 6).

Harbour porpoise bycatch rates of hauls with an incomplete set of pingers were usually two to three times the bycatch rates of hauls without pingers, for each area pooled over years (Fig. 5) and for each year pooled over areas (Fig. 6). These differences were significant for each area (Table 3A), except for the WGOM Closed Area (where pingers are not required), according to the MWW test. These differences were also significant when the bycatch rate was defined as harbour porpoises per haul or as harbour porpoises per volume-soaked (Table 3B) and when comparing the three levels using the Kruskal-Wallis rank-sum test.

To gain further insight about the characteristics of hauls with an incomplete set of pingers, the percent of required pingers, spatial distribution, and mesh size were explored. In nearly every year, bycatch rates of hauls with some pingers, but less than or equal to 50% of the required number of pingers, was greater than or equal to the bycatch rate of hauls with more than 50% but less than 100% of the required number of pingers (Fig. 6). Bycatch rates of hauls with an incomplete set of pingers was high in all areas when the data were pooled over the entire time period (Fig. 5), but the location of these hauls were not spatially clustered, even when looking at each year individually (figures not shown). That is, the locations of hauls with none or some pingers were not spatially aggregated. In 15cm mesh gillnets that were in the operational fishery (661 observed hauls), which is the same size mesh used in the Kraus *et al*. (1997) controlled scientific experiment, there was no observed harbour porpoise bycatch. The general pattern observed in the operational fishery was, as mesh size increased so did the bycatch rate, no matter how many pingers were on the gillnet; although bycatch rates in nets with pingers were still

Table 3

Comparison of bycatch rates (harbour porpoises per mtons landed) and number of observed hauls (n haul) with no pingers, some pingers and the required number of pingers for various areas in the US Northeast gillnet fishery after the implementation of the HPTRP (A). For all MAs, comparison of bycatch rates that are defined with three units of effort for hauls with no pingers, some pingers, and the required number of pingers (B).

A. Bycatch (Byc) rates using mtons landed as the unit of effort

	No pingers			Some pingers			Required number of pingers		
Area	Byc rate	%CV	n hauls	Byc rate	%CV	n hauls	Byc rate	%CV	n hauls
all MAs	0.053*	19.9	3,157	0.120+	20.9	1,065	0.024	35.1	2,407
Mid-coast MA	0.084*	25.6	1,287	0.130+	23.1	670	0.041	40.1	1,057
Mass Bay MA	0.009*	101.4	927	0.524+	63.7	39	0	0	353
CC South MA	0.075*	29.4	660	0.139+	53.4	262	0.023	71.9	743
Offshore MA	0	0	269	0	0	92	0	0	249
Cashes Ledge MA	0	0	14	0	0	2	0	0	5
Stellwagen Bank	0.074*	26.7	1,371	0.238+	72	68	0	0	118
WGOM CA	0.099	49.9	212	0.131+	42	149	0.034	1.0	122

B. Bycatch rates pooled over all MAs using different units of effort

	No pingers		Some pingers		Required number of pingers	
Unit of effort	Byc rate	% CV	Byc rate	% CV	Byc rate	% CV
Mtons landed	0.053*	19.9	0.120+	20.9	0.024	35.1
Number of hauls	0.0114*	19.7	0.0301+	21.5	0.0046	34.3
Volume soaked (km^2-day)	0.00016*	19.6	0.00041+	21.1	0.00008	34.8

*When comparing no pingers versus required number of pingers p-value < 0.05. +When comparing no pingers versus some pingers p-value < 0.05.

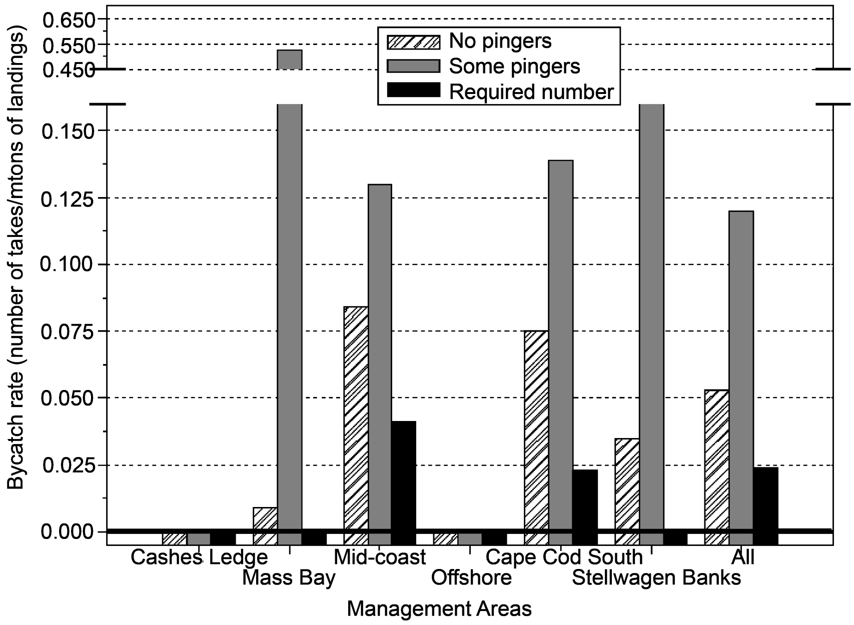

Fig. 5. Within each management area, pooled over all years, bycatch rates (harbour porpoises per mtons landed) of hauls that had no pingers (0%), some pingers (1-99%) and the required number of pingers (100%).

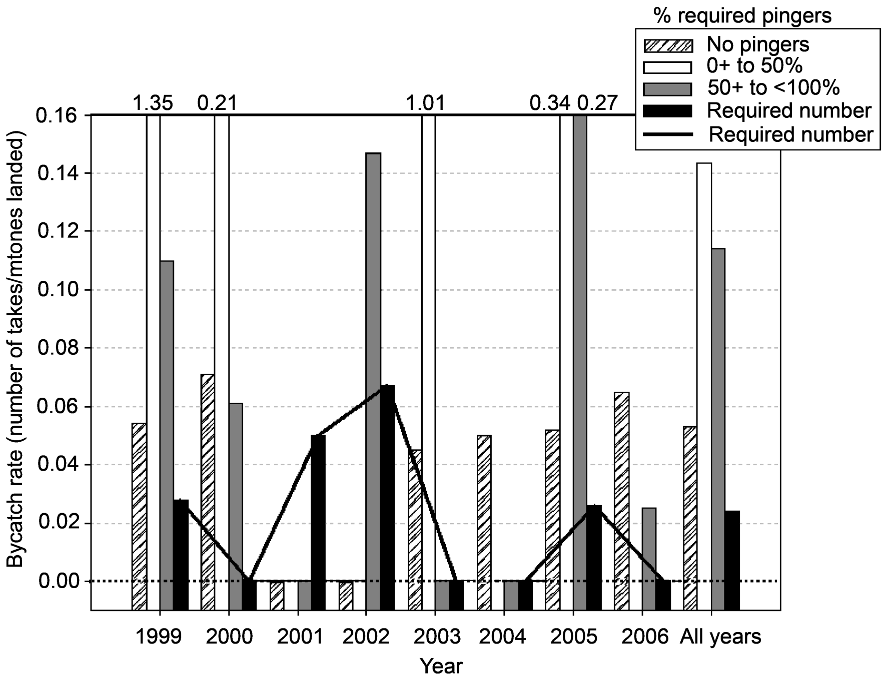

Fig. 6. For each year, pooled over all managed times and areas in the US Northeast gillnet fishery, bycatch rates (harbour porpoises per mtons landed) of hauls that had no pingers (0%), less than half of the required number of pingers (0+ to 50%), more than half of the required number of pingers (50+ to <100%) and the required number of pingers (100%). The black line connects the bycatch rates of hauls with the required number of pingers for each year.

less then that in nets without pingers, no matter what mesh size (Table 4 which uses the unit of effort (hauls) in the bycatch rate as reported in Kraus *et al.,* 1997).

Habituation

Harbour porpoise bycatch rates of hauls with pingers fluctuated from year to year in each management area (Fig. 5). There was no evidence of a long-term trend over years (line in Fig. 6) or a short-term trend over months (Fig. 7), using either landings or hauls as the unit of effort. When the bycatch rates were modelled with a GLM that included the percentage of required number of pingers as a covariate, there was no evidence of a significant slope over years (slope=0.064, SE=0.068, *t*-value=0.943) or over months (slope=-0.065, SE=0.065, *t*-value=-1.008). This same conclusion resulted when modelling just the hauls with all the required number of pingers or when using GAMs to model the bycatch rates.

Table 4

Comparison of bycatch rates (harbour porpoises per haul) and number of observed hauls (n haul) with no pingers, some pingers and the required number of pingers for gillnets with different mesh sizes.

	No pingers			Some pingers			Required number of pingers		
Mesh size (inches)	Byc rate	% CV	n hauls	Byc rate	% CV	n hauls	Byc rate	% CV	n hauls
3+ thru 6#	0	0	98	0	0	168	0	0	431
6+ thru 7	0.005*	35.2	1648	0.032+	24.8	508	0.003	49.9	1187
7+ thru 10	0.007*	51.6	733	0.047+	43.4	148	0	0	276
10+ thru 14	0.034*	26.1	678	0.037	52.9	241	0.014	47.3	512

Of the 697 observed hauls in the 3+ thru 6 mesh size category, 8 observed hauls used 3in, 7 used 5in, 3 used 5.25in, 18 used 5.5in and 661 observed hauls used 6in. *When comparing no pingers versus required number of pingers p-value < 0.05. +When comparing no pingers versus some pingers p-value < 0.05.

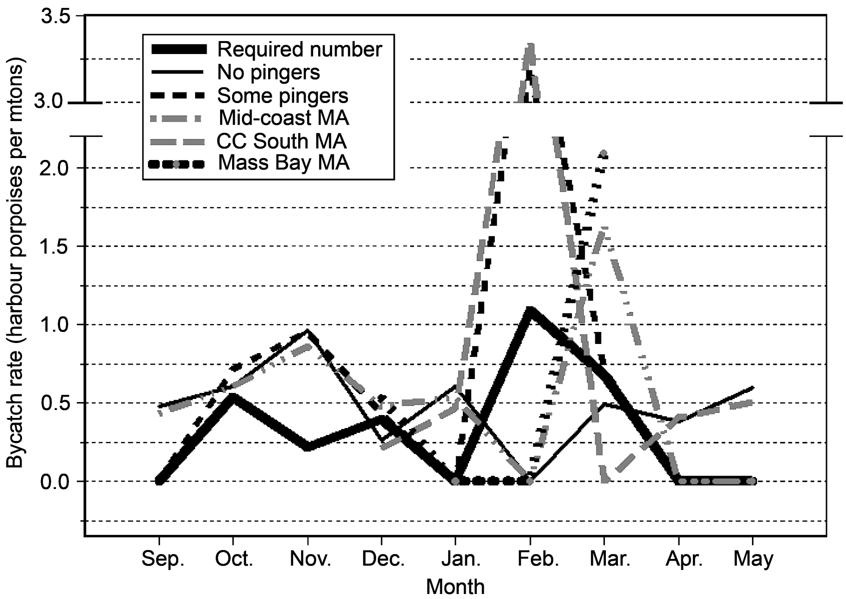

Fig. 7. Bycatch rates (harbour porpoises per mtons landed) during the times pingers were required by month for different percentages of pingers (all the required number of pingers; some pingers; and no pingers) and for the Mid-Coast MA, Cape Cod South MA and Mass Bay MA.

DISCUSSION

Compliance

Pinger usage

Pinger usage varied greatly from year to year. Perhaps one of the reasons why the pinger usage increased in 2006 and 2007 was that during October 2006 to January 2007 NOAA Fisheries Northeast Regional Office conducted an outreach program where they presented outreach materials in ports from New Jersey to Maine to remind industry of the HPTRP requirements and educate them on bycatch and pinger maintenance. When comparing the percentage of pinger usage by season, the overall fall rate of usage doubled from 20% in autumn (September to December) 2005 (before the outreach project) to 40% usage in autumn 2006 (after the outreach project); and the overall winter rate of usage jumped from 3% in winter (January to May) 2006 (before the outreach project) to 58% in winter 2007 (after the outreach project).

Pinger performance

Pinger tester data collection was sporadic because of challenges in implementing the Pinger Tester Program. At the beginning of the program, in 2003, many of the observers with testers were on fishing trips that did not use pingers, although pingers were required. During the development of the program, observers encountered the challenge of testing saltwater activated pingers that were not immersed in enough water to activate the signal. So, a field was added to the datasheet to specify whether or not the pingers were saltwater activated, and the observers were instructed to ensure that the pingers were wet when tested. In addition, the testers were not sufficiently robust under field conditions and often were non-functional when the observer had an opportunity to use it. In response, the carrying case for the tester was weather-proofed, observers were supplied with ample replacement batteries, and provided with a live pinger that they could use to determine if the tester was functioning properly. In subsequent versions of the tester, engineers added more padding to the internal wiring, which slightly improved the durability. After attempting to design more durable testers, four new testers are presently being used in the field. These modifications should provide more data on the performance of pingers from a variety of ports and seasons, thus providing a more representative sample of the fishery.

If pingers were tested on a random, representative sample of the fishery, it should be possible to estimate bycatch rates of hauls that had various percentages of functional pingers. This information could then be used to improve the bycatch estimates and might be used to determine an optimal number of pingers to reduce bycatch and minimise the overhead costs to the fishery.

Pinger effectiveness

Field studies worldwide concluded that pingers and 'acoustic harassment devices' (AHDs) can reduce bycatch of harbour porpoises and other small cetaceans (Barlow and Cameron, 2003; Culik *et al*., 2001; Gearin *et al*., 2000; Johnston, 2002; Johnston and Woodley, 1998; Kraus *et al*., 1997; Laake *et al*., 1998; Larsen and Krog, 2007; Lien *et al*., 1995; Morton and Symonds, 2002; Olesiuk *et al*., 2002; Trippel *et al*., 1999). The present paper provides additional support that pingers can reduce harbour porpoise bycatch, even in an operational fishery.

Since the implementation of the HPTRP, there were no observed takes in gillnets with mesh sizes of 15cm, the size used in the controlled scientific experiment. All of the observed bycatch was in nets using >15cm mesh sizes. Thus, the bycatch reduction documented in the controlled scientific experiment appears to also be true for the operational fishery. However, in the operational fishery, a variety of average mesh sizes are normally used, 13.3-35.5cm (5.25-14in) and the bycatch rates appear to depend on the mesh size. Thus, it appears that additional factors not tested in the controlled experiment also influence the bycatch rate. To lend further support to this conclusion, Palka *et al*. (In press) documented that the bycatch rate in the Gulf of Maine since the implementation of the HPTRP can be modelled using a quasi-Poisson distribution by the following variables: management area, sea surface temperature (SST), North Atlantic Oscillation (NAO) value, mesh size and lead line weight. That is, environmental factors and mesh size appear to influence the bycatch rate, in addition to the use of pingers.

Harbour porpoise bycatch rates in hauls with an incomplete set of pingers had a much higher bycatch rate than hauls without pingers or hauls with the required number of pingers, no matter what the mesh size, area or year. One possible reason for this pattern is that gillnets with an incomplete set of pingers may also have had more non-functioning pingers, but this information was not previously collected. However, this still would not fully explain why the rate in strings with some pingers was higher than the rate of hauls without any pingers. Two other possible reasons for this pattern, that are explored below, are gaps between the functional pingers and other gear/environmental factors.

The first hypothesis is that harbour porpoises may 'interpret' a gap in pingers to be a gap in the net, and thus try to swim into this 'gap' but rather become entangled in an unpingered portion of the gillnet. However Larsen and Krog (2007) found that harbour porpoise bycatch reduction was still evident when pingers were 455m and 585m apart in the Danish hake gillnet fishery, where the pingers had an harmonic energy bandwidth from 20-160kHz and a source level of 136-145dB re. 1μPa @ 1m. Although the wide spacings in the Danish fishery may perhaps mimic missing or non-functional pingers in the US Northeast fishery, the quite different pinger specifications in the US Northeast fishery (10kHz, no harmonics, 132dB and about 92m apart) preclude the application of the Danish results to the US Northeast fishery. In order to investigate this hypothesis in the US Northeast fishery, more detailed information must be collected on the functionality of pingers on nets surrounding a take and the distance between operational pingers. This type of information is now being collected by the NEFOP and can be explored in the future.

The second hypothesis is that, perhaps by chance, the hauls with an incomplete set of pingers may have different environmental/gear characteristics to those with none or all the required pingers. As stated earlier, Palka *et al*. (In press) illustrated that the bycatch rate in the Gulf of Maine since the implementation of the HPTRP can be modelled by the management area, SST, NAO value, mesh size and lead line weight. The bycatch rates of hauls with characteristics that relate to higher than average bycatch rates (Mid-Coast MA, ≤12.5°C SST, ≤0.15 NAO value and mesh sizes ≥ 17.8cm (7in)) were 0.0602 harbour porpoises per haul (from 216 hauls) in nets with no pingers, 0.0506 harbour porpoises per haul (from 178 hauls) in nets with some pingers and 0.0101 harbour porpoises per haul (from 199 hauls) in nets with the required number of pingers. The same pattern of bycatch rates occurred if the unit of effort in the bycatch rate was defined as mtons landed or volume soaked. So, for this subset of hauls with similar environmental/gear characteristics, there was an 83% bycatch rate reduction due to use of the required number of pingers, and the bycatch rate of hauls with some pingers was intermediate between the bycatch rate of hauls with no pingers and with all of the required number of pingers. Thus, it appears that the reason(s) for the bycatch rate reduction may not be fully understood until the mechanisms as to how pingers reduce bycatch and the relationship between bycatch rates and environmental/gear characteristics are more completely understood.

Habituation

The pattern of bycatch rates over months in management areas where pingers are required did not show an increasing trend, as would be expected if habituation occurred. Instead monthly bycatch rates appear to track the migration of the harbour porpoises, i.e. a northerly direction in the spring and a southerly direction in autumn.

In addition, there was no evidence of an increase in the annual bycatch rates since the implementation of pinger use, as would be expected had habituation occurred. This may reflect the fact that harbour porpoises in the area are not continuously exposed to pingers for the following reasons: (1) pingers are not used continuously in any one area (Table 1); (2) pingers do not emit sounds into a large region around each pinger; (3) during some times of the year harbour porpoises inhabit areas without pingers; and (4) even within a season, porpoises migrate through all these management areas, and move considerably within the Gulf of Maine and Canadian Bay of Fundy as shown by tracked animals (Read and Westgate, 1997).

However, it should be recognised that the NEFOP data do not provide a direct method to study habituation. A better approach may be to conduct a long-term study of the behaviour of animals around a pingered gillnet (Carlström *et al*., 2009; Cox *et al*., 2003; Culik *et al*., 2001; Laake *et al*., 1998) or around a single pinger (e.g. Cox *et al*., 2001), but such studies have not yet occurred in the US Northeast fishery. However, the NEFOP data do provide an indication that habituation has not occurred on a level that affects the bycatch estimate for an operational fishery.

ACKNOWLEDGEMENTS

We are grateful to the many NEFOP observers who went on the commercial fishing vessels to collect these data and to the captains and crews of the many fishing vessels that have been observed. In addition we thank Drs. Richard Merrick and Fred Serchuk (Northeast Fisheries Science Center, Woods Hole, MA) and two anonymous reviews for their useful comments on previous drafts of this manuscript.

REFERENCES

Barlow, J. and Cameron, G.A. 2003. Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. *Mar. Mammal Sci.* 19(2): 265-83.

Belden, D. 2007. Estimates of cetacean and pinniped bycatch in the 2005 northeast sink gillnet and mid-Atlantic coastal gillnet fisheries. *NEFSC Lab. Ref. Doc.* 07-08: 16pp. [Available from: *http://www.nefsc.noaa.gov/publications/crd/crd0708*].

Belden, D. and Orphanides, C.D. 2007. Estimates of cetacean and pinniped bycatch in the 2006 northeast sink gillnet and mid-Atlantic coastal gillnet fisheries. *NEFSC Lab. Ref. Doc.* 07-20: 18pp. [Available from: *http://www.nefsc.noaa.gov/publications/crd/crd0720*].

Carlström, J., Berggren, P. and Tregenza, N.J.C. 2009. Spatial and temporal impact of pingers on porpoises. *Can. J. Fish. Aquat. Sci.* 66: 72-82.

Cox, T.M., Read, A.J., Solow, A. and Tregenza, N. 2001. Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? *J. Cetacean Res. Manage.* 3(1): 81-86.

Cox, T.M., Read, A.J., Swanner, D., Urian, K. and Waples, D. 2003. Behavioural responses of bottlenose dolphins, *Tursiops truncatus*, to gillnets and acoustic alarms. *Biol. Conserv.* 115: 203-12.

Culik, B.M., Koschinski, S., Tregenza, N. and Ellis, G.M. 2001. Reactions of harbour porpoises (*Phocoena phocoena*) and herring (*Clupea harengus*) to acoustic alarms. *Mar. Ecol. Prog. Ser.* 211: 255-60.

Gearin, P.J., Gosho, M.E., Laake, J., Cooke, L., Delong, R.L. and Hughes, K.M. 2000. Experimental testing of acoustic alarms (pingers) to reduce bycatch of harbour porpoise, *Phocoena phocoena*, in the state of Washington. *J. Cetacean Res. Manage.* 2(1): 1-10.

International Whaling Commission 2000. Report of the Scientific Committee. Annex I. Report of the Sub-Committee on Small Cetaceans. *J. Cetacean Res. Manage. (Suppl.)* 2:235-57.

Johnston, D.W. 2002. The effect of acoustic harassment devices on harbour porpoises (*Phocoena phocoena*) in the Bay of Fundy, Canada. *Biol. Conserv.* 108: 113-18.

Johnston, D.W. and Woodley, T.H. 1998. A survey of acoustic harassment device (AHD) use in the Bay of Fundy, NB, Canada. *Aquat. Mamm.* 24: 51-61.

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 Tech. Mem. NMFS-AFSC-* 84: 40.

Larsen, F. and Krog, C. 2007. Fishery trials with increased pinger spacing. Paper SC/59/SM2 presented to the IWC Scientific Committee, May 2007, Anchorage, USA (unpublished). 8pp. [Paper available from the Office of this Journal].

Lien, J., Hood, C., Pittman, D., Ruel, P., Borggaard, D., Chisholm, C., Wiesner, L., Mahon, T. and Mitchell, D. 1995. Field tests of acoustic devices on groundfish gillnets: assessment of effectiveness in reducing harbour porpoise bycatch. pp.1-22. *In*: Kastelein, R.A., Thomas, J.A. and Nachtigall, P.E. (eds). *Sensory Systems of Aquatic Mammals*. De Spil Publishers, Woerden.

Morton, A.B. and Symonds, H.K. 2002. Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. *ICES J. Mar. Sci.* 59: 71-80.

NOAA. 1998. Taking of marine mammals incidental to commercial fishing operations; Harbor porpoise take reduction plan regulations. *Federal Register Notice* 63(231): 464-90. [Department of Commerce, National Oceanic and Atmospheric Administration 50CFR Part 229].

Olesiuk, P.F., Nichol, L.M. and Ford, J.K.B. 2002. Effect of the sound generated by an acoustic harassment device on the relative abundance and distribution of harbour porpoises (*Phocoena phocoena*) in Retreat Passage, British Columbia. *Mar. Mammal Sci.* 18(4): 843-62.

Palka, D.L., Orphanides, C.D. and Warden, M.L. In press. Summary of harbor porpoise bycatch, covariates and levels of compliance in the northeast and mid-Atlantic gillnet fisheres after the implementation of the Take Reduction Plan: January 1 1999 through May 31 2007. *NOAA Technical Memorandum NMFS*. [Will be available at *http://www.nefsc.noaa.gov/nefsc/publications/tm/tmlist.htm*].

Read, A.J. and Westgate, A.J. 1997. Monitoring the movements of harbour porpoises (*Phocoena phocoena*) with satellite telemetry. *Mar. Biol.* 130: 315-22.

Trippel, E.A., Strong, M.B., Terhune, J.M. and Conway, J.D. 1999. Mitigation of harbour porpoise (*Phocoena phocoena*) by-catch in the gillnet fishery in the lower Bay of Fundy. *Can. J. Fish. Aquat. Sci.* 56: 113-23.

Date received: September 2008
Date accepted: April 2009