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Reduction of harbour porpoise by-catch in the North Sea by high-density gillnets

by

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Abstract

Reduction of harbour porpoise by-catch by use of high-density gillnets was tested in sea trials in the Danish North Sea bottom set gillnet fishery in September-October 2000. The sea trials were conducted as a controlled experiment with conventional gillnets as the control group. Eight porpoises were caught in the control nets and none in the high-density nets. Analyses of porpoise catch rate show that this reduction is highly significant (ANOVA, P=0.002). Of the four fish species analysed only catch rate for cod was significantly different between the two groups of nets, with CPUE in the high-density nets being c. 30% percent lower than in the control nets.

Subsequent investigations conducted in seawater tanks under controlled conditions revealed that there was no difference in acoustic target strength of the two net types, and that the nets behaved similarly under various conditions.

We conclude that the mechanical properties of the high-density nets, primarily the increased stiffness, are the main reasons for the differences in catch rates for cod and for porpoises.

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Introduction

The documentation of high by-catches of small odontocete cetaceans in various gillnet fisheries in the last decade has led to the development of different types of acoustic alarm (pingers) whose function is to keep the cetaceans well away from the nets, thereby reducing by-catch. A number of trials in commercial fisheries have shown that pingers can indeed reduce by-catch considerably (Kraus *et al.,* 1997; Larsen, 1999; Barlow & Cameron, 1999). However, pingers are active electronic devices, and as such they have a number of disadvantages, including requirement of a continuous source of energy and being sensitive to physical impacts. In addition concern has been expressed about the effects on target as well as non-target species of widespread pinger deployment and about the potential for the cetaceans to habituate to the alarm signals (IWC, 2000; Cox *et al*., 2001). Despite this, large sums have gone into developing and testing pingers, and pingers are now routinely used in a number of fisheries (Rossman, 2000; Larsen *et al*., 2002).

Comparatively little effort has been invested in modifying the acoustic properties of conventional nets, to increase their detectability to echolocating odontocetes. A number of trials were conducted in the 1980es, but they were largely unsuccessful. Either they failed to take the acoustic abilities of the odontocetes in question into account or the acoustic detectability enhancement had severe side effects of reduced catches of the fish target species (Perrin *et al.,* 1994). Acoustic enhancement has a number of advantages relative to pingers, of which the most important are: a) habituation is not possible; b) no noise pollution; and c) no need for an energy source. However, reducing by-catch by increasing the detectability of nets rests heavily on the unproven assumption that odontocetes are entangled because they fail to detect the nets, or if they detect them, that they don't perceive them as a hazard. There are several possible reasons for an animal to fail in detecting nets: i) the animals don't use their sonar to scan for obstacles sufficiently often (or fail to pay attention, even though echolocating); ii) animals orient themselves so the net is out of the sound beam (*e.g.* when bottom feeding vertically) and drift sideways into the net; iii) echoes from the nets are masked by echoes from free swimming or entangled prey in and around the net; or iv) the net itself is not detectable by the odontocetes at a sufficiently large distance to avoid entanglement. In the two former cases enhancing the detectability alone will not reduce by-catch whereas it could have a reducing effect in the two latter situations. Studies of detection distances for porpoises and delphinids suggest that they are capable of detecting regular gillnetting (Au, 1994; Kastelein *et al*., 2000), although the detection distance can be quite short, particularly for porpoises (below 5 meters), depending on factors such as ambient noise level and angle of incidence, as well as the net itself and attached material (floats and lead-lines). If odontocetes are entangled because they don't perceive the nets as a hazard it could be because the echo from the nets is not sufficiently strong, in which case enhancing the detectability again could reduce by-catch. It seems form the above that there are good reasons to develop nets with increased acoustic reflectivity, and that controlled experiments with such nets could help choosing between the competing theories about why odontocetes become entangled in gillnets.

In the late 1990's a private manufacturer designed a high-density monofilament, where use of a metal compound as filler in the polymer was intended to increase the acoustic reflectivity and thus the detectability for echolocating odontocetes. Nets made from such monofilaments were tested in the Bay of Fundy, Canada, in 1998 and 1999, but low by-catches of harbour porpoise (*Phocoena phocoena*) during the trials in both high-density and control nets prevented definitive conclusion about the efficacy of the high-density nets in reducing by-catch of porpoises (Trippel *et al.,* 2000).

In the North Sea, the documentation of high by-catches of harbour porpoises in the Danish bottom set gillnet fisheries (Vinther, 1995; 1997; 1999) led to the formation of the Danish action plan to reduce by-catches of porpoises in the North Sea (Ministry of Environment and Energy, 1998). The action plan recommends pingers as one of the principal mitigations measures, but also recommends that alternative measures be investigated. The high-density gillnets described above appeared to be an interesting alternative to pingers, and a trial was conducted in the commercial fishery for cod in the autumn of 2000. The objective of the trial was to determine if the high-density nets had a significantly lower by-catch of porpoises than conventional nets used in this fishery. Difficulties in interpreting the results of the trial were then attempted resolved in the autumn of 2001 by exploring the behaviour of the nets under controlled conditions in a flume tank, and by measuring the acoustic target strength of the nets. The results of the sea trial as well as of the subsequent studies are described in this document.

Materials and methods

Sea trial

The sea trial was designed as a controlled experiment of comparative fishing, where conventional gill nets were used as the control group. To simplify the interpretation of the results, the high-density nets were to be manufactured to the same specifications as the control nets regarding twine size, stiffness, colour and mesh size. The only expected differences between the nets would be in acoustic reflectivity and in specific gravity. The difference in specific gravity was to be balanced out by an equivalent increase in the buoyancy applied to the high-density nets. However, when the high-density nets arrived from the manufacturer they differed also from the control nets in colour and in stiffness/flexibility. It was decided to go through with the test trials despite these differences, knowing that the interpretation of the results could be somewhat more difficult.

The specifications of the two types of nets used in the trials are given in Table 1. As a measure of twine stiffness we used the E-module, an international standard for measuring stiffness. This parameter proved to be substantially different between the two net types as seen in Table 1.

Table 1 *. Specifications for the two types of nets used in the trials.*

	Control nets	High-density nets
Twine size	0.59 mm	0.58 mm
Twine colour	silvery green	reddish brown
E-module	784 MPa	2617 MPa
Mesh size	156 mm	156 mm
Acoustic reflectivity (1)		+13 dB relative to control nets
Specific gravity (1)		+11% relative to control nets

(1) According to manufacturer

The fishing gear used in the trials consisted of strings of either control or high-density nets. The design specified that comparative hauls should include approximately equal numbers of control and high-density nets fished within in a restricted area in time and space in order to minimize the natural variation in species availability between hauls.

The main objective of the experiment was to determine whether the high-density nets could result in a significant reduction in harbour porpoise by-catch, here understood as a statistically significant reduction of at least 75% determined with a probability of 0.95. Analyses of by-catch rates from previous years suggested that a total effort of around 400 km of nets fished, equally distributed on the high-density group and the control group was necessary. Based on information on the typical effort of a vessel engaged in the selected fishery, it was estimated that one vessel could achieve the necessary total effort in around 60 days at sea.

A commercial fishing vessel typical of the Danish North Sea gillnet fleet was chartered to conduct the experimental fishing. The RI324 ("Ingrid Frich" of Hvide Sande), a 45.39 GRT vessel, was used for all sea trials to eliminate between-vessel variation in the experiment.

An independent observer was on board the vessel for the duration of the experiment. The principal tasks of the observer were collection of information on gear type, fishing effort and by-catch of cetaceans. In addition the observer collected data on the magnitude and species and size distributions of all catches including discard.

Catch per unit effort (CPUE) for porpoises and the four fish species most frequently caught were analysed on a trip basis, with each trip contributing two paired samples from, respectively, high-density and control nets. To take into account potentially large between-trip differences in species availability, the following multiplicative model was used for analysing the variation in the fish CPUEs:

$$CPUE_{g,t} = Gear * Trip * \varepsilon_{g,t}$$

where CPUE is given as number of fish per net kilometres*days, $\varepsilon_{g,t}$ designates the statistical noise in the model and the two indices mark the effect from the gear (control net and high-density net) and the trip for each sample. The model was linearised by log transformation:

$$\ln(CPUE_{g,t}) = Gear + Trip + \ln(\varepsilon_{g,t})$$

before being applied to catch data for the 4 species most frequently caught and subsequently submitted to statistical analysis by the SAS software package.

The statistical analyses of porpoise catch data included testing the difference between the two net types by analyses of variance within and between the two means for each of the two types of net. It was assumed that the porpoise availability was constant between trips.

Flume tank experiments

To clarify whether differences in the behaviour of the two types of gillnets during fishing could induce differences in the catch of target species and porpoises, a series of measurements were made in a seawater flume tank. The experimental design was to submit in turn the two net types (reduced to a length of 34.5 m, a height of 2.5 m and mounted with buoyancy and weight as when fishing) to increasing currents varying from 0 to app. 1 knot and to observe and measure the changes in behaviour of the nets. We were primarily interested in the degree of "collapse" of the nets, *i.e.* the reduction in net height with increasing water velocity. The net height was measured with a fixed camera at water velocity intervals of 0.25 knots, after the nets had stabilized upon changing the velocity. After the measurement at 1 knot the velocity was reduced to 0 knot for a measurement of the "recovery" of the net height.

In addition to the observations of the sensitivities of the two net types to different water velocities, a detailed description of the rigging of the two types of nets was undertaken with respect to *e.g.* buoyancy and hanging ratios.

Target strength measurements

Measurements took place in a seawater filled concrete tank of sufficient size to allow nets to be fully submerged and stretched as they would be if bottom-set for fishing. Nets were stretched as they would be if bottom-set for fishing. Transmitting and receiving hydrophones were placed at mid-water depth on a line perpendicular to the net (0° incidence angle) and at an approximate distance of 0.5 m.

The sound used was a previously recorded harbour porpoise signal (duration 200 µs, peak frequency 140 kHz) stored in a computer and D/A converted at 400 ksamples per second. The signal was transmitted through a Sonar Products HS150 hydrophone. Echoes were measured by a Reson TC4013 hydrophone, amplified (Etec amplifiers) and recorded by the computer (12 bit, 400 ksamples per second).

The results were confirmed in a different set-up, located in a sheltered corner of a harbour (Kerteminde, Denmark). This set-up offered better positioning of transducers due to an increased source level of the transmitted signal. On the other hand it was not possible to position nets in a realistic way, so only a relative comparison between nets could be performed. Nets were hung vertically from a horizontal bar placed just above water level and were dragged down by a lead line. Transmitting and receiving hydrophones were placed approx 2 m from the net, 1 m below the surface. Sounds were 200 μs pulses of 140 kHz sine wave signals and projected by a Reson TC2130 transducer. Echoes were received by a Reson TC4032 hydrophone and monitored on an oscilloscope.

Results

Sea trials

The trials were conducted in ICES subdivision IVb in the North Sea in September-October 2000, and included 6 trips each of approximately 3 days of fishing. The total length of net fished (app. 100 km of each net type) was only half the effort considered necessary to determine whether the high-density nets had a significantly lower by-catch of porpoises than the control nets. This was due to a premature termination of the sea trials following indications that the stiffness of the high-density nets was the reason for the considerably lower catch of the target species (cod, *Gadus morhua*) compared to the controls. If stiffness was the reason for the lower catch, it could also be the reason for the observed lack of by-catch of porpoises in the high-density nets (see Table 2). If so, there were no reason to continue the sea trials, since these would not enable us to determine if the reduced by-catch of porpoises was caused by the increased density of the high-density nets or by their increased stiffness.

During data verification we discovered that the vessel in a number of cases, in addition to the nets involved in the experiment, had set conventional nets only on wrecks, *i.e.* without setting a comparable number of high-density nets on wrecks as well. Because catch rate for cod is considerably higher in wreck sets, these sets were deleted from the present analyses.

Table 2 presents the total effort on a trip basis as net kilometres*soak time, together with the total catch of porpoise and cod. Each of the strings of either high-density or control nets consisted of between 20 and 112 repetitions of 60 m net units and had soak times between 10 and 26 hours. The nets were set at depths between 26 and 154 m, with the majority between 50 and 80 m. In the following, all CPUE values refer to a standardised effort of 1 km and 24 hours soak time.

The CPUE for porpoises and the 4 fish species most frequently caught is given on a trip basis in Table 3.

Table 2. *Effort and total catch (in numbers) of porpoise and cod for each of the six trips (HD = high-density nets).*

	year 2000	Net strings		Kilometer x days		Porpoise by-catch		Cod catch	
Trip	Fishing dates	HD-Nets	Control	HD-Nets	Control	HD-Nets	Control	HD-Nets	Control
1	11 - 12. Sept.	5	5	13	12	0	1	78	91
2	17 - 19. Sept.	5	7	8	9	0	1	96	181
3	24 - 27. Sept.	7	6	14	8	0	1	204	112
4	03 - 04. Oct.	4	4	6	5	0	0	87	149
5	15 - 18. Oct.	8	8	16	15	0	3	159	217
6	23 - 25. Oct.	4	5	11	12	0	2	61	95

Table 3*. CPUE of porpoise and the four most frequent species by trip. CPUE is calculated as the total summed catch divided by the total effort (kilometers of net fished * days soak time).*

	CPUE Porpoise		CPUE Cod		CPUE Saithe		CPUE Haddock		CPUE Plaice	
Trip	HD-Nets	Control	HD-Nets	Control	HD-Nets	Control	HD-Nets	Control	HD-Nets	Control
1	0	0,09	6,1	7,9	0,4	0,4	1,8	1,7	0,7	0,2
2	0	0,12	12,0	21,3	1,5	0,4	2,9	3,8	0,5	0,2
3	0	0,12	14,7	13,5	0,0	0,0	0,3	0,0	5,6	2,4
4	0	0,00	14,3	31,7	0,5	0,4	1,8	3,0	0,2	0,0
5	0	0,20	9,9	14,6	7,3	18,1	1,1	2,2	0,3	0,1
6	0	0,17	5,5	7,9	0,5	0,2	2,0	1,6	0,1	0,2

A total of 8 harbour porpoises were by-caught during the sea trials. They were all caught in the control nets and distributed fairly evenly among trips. Porpoise CPUE for the control nets varied between 0.09 and 0.20 except for trip 4 where no porpoise were by-caught. Average CPUE for high-density and control nets were 0 and 0.12, respectively. They are significantly different (ANOVA, P = 0.002).

The fish CPUEs for the two net types proved to be significantly different only for cod. According to Table 4 the catch rate for cod was 1.43 times higher in the control nets compared to the high-density nets (LSMeans, P = 0.04).

Table 4. *The ratio between catches in control nets and high-density nets as calculated by GLM procedure. P- values are found by least square means.*

	Control nets / high-density nets	Significant	Non - significant
Cod	**1.43**	**p = 0.04**	
Saithe	0.76		p = 0.56
Haddock	1.26		p = 0.26
Plaice	0.48		p = 0.12

Flume tank experiments

The flume tank experiments revealed no obvious differences in the sensitivity of the two net types to water current as judged by visual inspection. Neither did the measurements of the degree of collapse reveal marked differences, but there was a tendency for the height of the high-density nets to be reduced more by the water flow compared to the control nets (Table 5).

Table 5. *Measurements of changes in net heights during exposure to currents in the flume tank. The last entry is the "recovery" measurements.*

	Net height in cm	
Water velocity (knots)	**Control net**	**High-density net**
0.00	245	245
0.25	245	221
0.50	190	190
0.75	150	130
1.00	105	100
0.00	180	205

There were no differences in the hanging ratios between the two types of nets. As intended, the high-density net had 14% higher buoyancy than the control net, which should balance out the 11% increased specific gravity of the high-density net.

Target strength measurements

Target strength for the control net was –53.5 dB ± 2.4 dB (SD) and –57.0 dB ± 1.3 dB (SD) for the high-density net, both measured at 0° incidence. The difference between nets was not significant (Mann-Whitney, P>0.05).

Discussion

Fish catches

The decision to terminate the sea trials prematurely was primarily based on two factors. The first was that reports from the observer suggested that target species catches in the high-density nest were as much as 30-50% lower than catches in the control nets. The second was that there were indications from the observer's preliminary report that fish caught in the high-density nets were generally smaller than in the control nets, and that fewer fish in the high-density nets were tangled than gilled compared to fish in the control nets. This information led us to suspect that the reason for the reduced catches in the high-density nets was the stiffness of these nets. If stiffness was the reason for the lower catch, it could also be the reason for the observed lack of by-catch of porpoises in the high-density nets.

The analyses presented here show that, after deleting the wreck sets from the data, the difference in CPUE for cod, the target species, is reduced to around 30%, whereas the difference in catch rate for harbour porpoise is 100%. For the other fish species analysed, the variability in CPUE between trips is too large to detect a significant difference.

We assumed that the reduced cod catches in the high-density nets were related to either the physical properties of the nets, the behaviour of the nets in the water or consistent differences in fish abundance in the areas where the two types of nets were used.

The physical properties that we believe could influence fish catches are twine size, colour, specific gravity and stiffness as well as mesh size. The data in Table 1 shows that there was no difference in mesh size and only a very minor difference in twine size. The difference in specific gravity is compensated by increased flotation, and should not influence the catching efficiency of the nets. The reddish brown colour of the high-density nets makes them very visible compared to the silvery green of the control nets, but fishing was conducted primarily over night and at depths where there is very little light, so we don't believe colour is the primary reason for the different catch rates. There is a clear difference in stiffness, and we believe this could influence catch rates. Fish will not get so easily tangled in nets with an increased stiffness, and since tangled fish tend to be larger than gilled fish, catch rates will be reduced in the stiffer nets. As mentioned above, the observer reported that fish caught in the high-density nets were generally smaller than in the control nets, and that fewer fish in the high-density nets were tangled than gilled compared to fish in the control nets. A planned, detailed analysis of the size distributions of the fish caught will throw more light on this question.

With respect to the behaviour of the nets in the water, the factors most important for the catching efficiency are the hanging ratio and the buoyancy. Hanging ratios were the same for the two types of nets, whereas the buoyancy was 14% higher for the high-density nets to compensate for the increase in specific gravity. The test conducted in the flume tank shows little difference between the two types of nets, although there was a tendency for the high-density nets to be more affected by water currents. The reason for this is probably the added number of floats creating more hydrodynamic drag on the float line of the high-density nets. However, we don't believe this difference is important for the catching efficiency of the nets.

With respect to the effect of differences in local fish abundance, we are confident that, after deleting the wreck net data, the experiment was fairly well balanced, *i.e.* that the high-density nets were not consistently used in areas with lower fish abundance.

So, in conclusion, we believe that the most likely explanation for the different catch rates for cod is the difference in stiffness, but also colour could play a role here.

Porpoise catches

From the outset we had expected that the observed difference in catch rates for harbour porpoise could be explained by the expected increased acoustic reflectivity of the high-density nets.

However, no significant difference in target strength could be found between the two nets. They both have target strengths that correspond well to measurements on a comparable net (0.57 mm diameter nylon monofilament, 140 mm mesh size), also measured using harbour porpoise signals (Kastelein *et al*., 2000). They report a target strength of –54.7 dB ± 3.3 dB. Target strength of an object is determined by a number of components such as size, geometry, material and angle of incidence. The material of the high-density nets were manipulated by the manufacturer in order to increase target strength, relying on the fact that more dense materials in general create stronger echoes than does less dense materials (for materials more dense than water; if lighter than water the reverse is generally true). The fact that the more dense experimental nets did not create significantly stronger echoes than did the controls can be for two reasons: i) the increased density (11% relative to the control, according to manufacturers information) is not sufficient to produce a measurable effect, or ii) the effect of an increased density is counteracted by a parallel change in compressibility, which also affects target strength (Urick, 1983, p. 299). Compressibility of the nets was not measured, so this possibility cannot be thoroughly evaluated. The mechanical properties of the two net materials are nevertheless clearly different, as evidenced by the difference in stiffness/flexibility.

If porpoises and other odontocetes do in fact get entangled because of failure to detect nets in time to evade, then increasing the target strength of the nets seems a viable strategy. Two problems are eminent, however. First of all, it is not known whether failure to detect the nets is the fundamental problem for the animals, or at least a major part of the problem. Laboratory studies have indicated that detection may not be the problem per se, but rather the attention of the animal is the key. In the studies of Kastelein *et al.* (1995) porpoises kept well clear of a suspended gill net in their pool for a long time, but eventually they were all entangled, perhaps due to lack of attention or distraction from the net. The second problem in manipulating target strengths of the nets, assuming it is indeed an answer to the problem, is that fairly large increases are needed in order to produce significant effects. According to the calculations of Kastelein *et al.* (2000), an increase in target strength of 10 dB (from –55 dB to –45 dB) is needed to increase 90% net detection distance from 4 m to 7 m for porpoises. Such a large increase in target strength cannot be obtained without substantial changes in either material properties (density and compressibility) or dimensions of twine. This is likely to change other mechanical properties of the net and thus possibly affect also catch of target species and/or ease of handling for the fisherman. From an immediate inspection, it seems more worthy to explore other strategies for increasing target strength than manipulation of the net material itself. This could be in the form of a limited number of added reflectors of a reasonable size to create strong echoes or a larger number of smaller reflectors, such as glass or metal beads in all or some of the knots of the net.

From the present it cannot be concluded what caused the substantial reduction in porpoise by-catch in the experimental, high-density nets. It does not, however, seem to be related to acoustic properties of the net, as the two types did not differ. Also the general behaviour of the nets when set for fishing can probably be ruled out, as the two nets behaved in a similar way in the flume tank. There were other differences between the nets, however, most notably the colour and the mechanical properties of the twine, both of which could potentially influence by-catch.

As for the cods, the possibility that the reddish-brown high-density nets were more visible to the porpoises than the silvery green control nets is clearly present. Although vision has not been studied in details in harbour porpoises, there is little reason to believe that they should not posess good visual capabilities, as does the well-studied bottlenosed dolphin. However, as most fishing occurred during night, as mentioned above, the colour is unlikely to be the main explanation for the elimination of by-catch in the high-density nets.

Although the exact circumstances of entanglement of porpoises in the wild are unknown, studies on animals in captivity indicate that entanglement occurs if tail fluke, flipper or dorsal fin touches the net (Kastelein et al. 1995). The entanglement is apparently facilitated by the tubercles often present on the leading edge of all the fins, which effectively catch the net at the slightest touch. It is imaginable that the increased stiffness of the high-density net could make it more difficult for the net to hang onto the fins of the animal and perhaps make it easier for the animal to escape if caught in the first place. This possibility can potentially be investigated by deliberate entanglement of captive animals under closely controlled conditions, using different types of nets or twine.

In the clear light of hindsight, it seems obvious that we should have conducted the experiments in the opposite order of what we actually did. However, in that case, with the lack of difference in target strength between the high-density nets and the control nets, we would probably not have conducted the sea trials and thus not have found that the high-density nets, despite being similar to the control nets in target strength, have a significantly reduced by-catch of porpoises.

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