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Harbour porpoise (*Phocoena phocoena* L.) by-catch in set gillnets in the Celtic Sea

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A programme to assess the cetacean by-catch in the Irish and UK set gillnet fisheries in the Celtic Sea was conducted from August 1992 to March 1994 using volunteer observers. Observers were present for the hauling of over 2500 km of net which caught 43 harbour porpoises and four common dolphins, with one of each alive. The by-catch rate was 7.7 porpoises per 10 000 km · h of net immersion. A negative relationship was found between porpoise by-catch and tidal speed but no other relationships were found with operational or environmental variables. Spatial and temporal stratification of the by-catch rate and effort data had a small effect on estimated total by-catch, which was therefore estimated from pooled data. The estimated total annual by-catch of 2200 porpoises (95% C.I. 900–3500) is 6.2% of the estimated number of porpoises in the Celtic Sea and there is serious cause for concern about the ability of the population to which they belong to sustain this level of by-catch.

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Introduction

During recent years, concern has grown over the impact on harbour porpoise (*Phocoena phocoena*) populations of incidental catches in fisheries, especially those using set gillnets in the western North Atlantic (Smith *et al.*, 1983; Gaskin, 1984; Read and Gaskin, 1988; Read *et al.*, 1993). In the eastern North Atlantic the data needed to conduct even a simplistic assessment of the impact of these by-catches have been unavailable. Three studies have now begun to provide some information in European waters. This paper presents the results of an observer programme to collect data on cetacean by-catch in set gillnets in the Celtic Sea. An observer programme on Danish groundfish gillnetters has collected data from which preliminary estimates of annual porpoise by-catch have been reported (Lowry and Teilmann, 1994; Vinther, 1994), and a major sightings survey was conducted in summer 1994 to estimate the abundance of harbour porpoises and other small cetaceans in the North Sea and adjacent waters (Hammond *et al.*, 1995).

In the winter of 1991–1992, 110 common dolphins (*Delphinus delphis*) were stranded in SW England, mainly along the south coast of Cornwall. Speculation over the cause of death resulted in the local gillnet fleet that fished for hake (*Merluccius merluccius*) agreeing to take observers to sea to verify that their fishery did not catch common dolphins. The observer programme was funded by the European Commission and extended to include a similar observer study of the Irish hake fishery. The primary objectives of the study were to assess the rates of incidental cetacean capture by the hake fisheries and to use these to estimate total annual by-catch. The UK study also collected data to investigate the relationship between by-catch rates and environmental factors, while the Irish study assessed elasmobranch by-catch (Berrow, 1994).

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Methods

The fishery

The fishery studied uses boats of around 20 m in length, working from Newlyn (Cornwall) in the extreme south-west of England, and from ports between Dunmore East (County Wexford) and Dingle (County Kerry) in the south-west of Ireland. The preferred target species is hake, which has a high market value. Other whitefish caught include pollack (*Pollachius pollachius*) saithe (*Pollachius virens*) ling (*Molva molva*) and cod (*Gadus morhua*). These species often make up most of the catch. Nets are set only during the periods of neap tides as strong tidal currents twist the nets and entangle debris.

Most Irish boats in this size-class change to trawling at times and some Cornish boats change to longline fishing for conger eel (*Conger conger*) and other species. During the last 10 years, the UK fishery has moved further offshore and now overlaps the areas fished by the Irish fleet. A few boats studied did not specifically target hake, but specialised in setting nets over wrecks. Many boats also set one or two nets over wrecks near to their hake fishing site. One boat also set tangle nets for crawfish (*Palinurus vulgaris*).

The fishery is mostly in the Celtic Sea, the area of shelf waters to the south-west of the British Isles bordered by Ireland, Wales, England, and France. For the purposes of this study, the Celtic Sea lies between 48°30′N and 52°N and between 4°W and the 1000 m depth contour at the edge of the continental shelf. This contour lies approximately along the 11°30′W meridian for most of the area.

Net types

The gillnets are made of blue or colourless monofilament nylon and set on the sea bed with anchors at both ends. Three types of net are used:

Hake nets. These have headline floats and a mesh of 100–150 mm between diagonally opposite knots, when stretched, with most being 120 mm. Each net panel is 90 m when rigged and can be 30, 45, or 60 meshes deep. Most of the net is 30 meshes deep allowing it to rise up to 5 m from the bottom. Panels are made up into nets about 1600 m long, but with much variation. Two types of hake net are used. Double footrope nets have vertical ropes 0.5 m long at 2 m intervals between a weighted leadline (20 kg/220 m) and the footrope on the net itself. This saves time by avoiding entanglement of crabs.

Irish boats usually set nets at dawn and start hauling in the early evening. UK boats generally leave their nets in the water overnight and do 90% of hauling between 0600 h and 2100 h.

Wreck nets. These are mostly 150 mm mesh single footrope nets that are set over wrecks. Short lengths of net that have already been damaged nets are often used. The main target species is pollack.

Tangle nets. Large mesh (180–300 mm) nets, usually with no added buoyancy on the headrope that lie close to the bottom to entangle benthic species such as angler fish (*Lophius piscatorius*), rays (*Raja* spp.), and crawfish. These species survive longer after entanglement than hake.

Data collection

The location, length, and type of nets set, and the time of the shooting and hauling of each net were recorded. The fishermen have no record of the changes in length of their nets as pieces are lost or replaced but it was sometimes possible to check lengths set using Global Positioning System data. This showed no bias in the lengths stated by the fishermen.

Observers attempted to watch all net hauling and shooting. All marine mammals seen entangled in the nets were recorded and dead animals were brought into the boat whenever possible to be identified measured, sexed, and examined externally. Observers on UK boats kept a chronological record of viewing conditions, sea state, boat activity, boat speed and cetacean behaviour around boats. Timed watches for cetaceans were carried out from various vantage points, all of which had a restricted view and were close to sea level.

Measurement of fishing effort

The measures used were:

(1) Soak time in kilometre hours (km · h), calculated as the interval between the mid-time of shooting the net and the mid-time of hauling the net multiplied by the length of the net.
(2) Kilometres of net set.
(3) Days at sea and number of trips made. These data are available for the whole fleet.

These measures of fishing effort were chosen to allow a description of by-catch rates in terms of net use, and to allow extrapolation to the whole fleet using available measures of fishing effort. Km of net set, and km · h of net immersion could not be identified as independent sampling units, so no standard error has been calculated for these measures.

Results

Observed fishing effort

Six UK trips were observed in 1992 from August onwards. Between January 1993 and March 1994 observers accompanied 39 trips by UK boats and 40 by

Table 1. Extent and seasonal distribution of observation of UK and Irish boats using gillnets in the Celtic Sea 1992–1994.

	Trips		Days at sea		km · h fishing effort		km · h %
Season	UK	Irish	UK	Irish	UK	Irish	All
Mar–May	10	10	56	31	7838	5366	23.6
Jun–Aug	13	11	58	34	9088	6748	28.4
Sept–Nov	13	10	56	28	11 088	4089	27.2
Dec–Feb	9	9	47	18	7877	3734	20.8
Total	45	40	217	111	35 891	19937	100

Irish boats (Table 1). The fishing boats sampled ranged in size from 14.7 m to 26.2 m. Mean overall registered length of UK boats was 17.5 m (s.d. 3.0) and mean gross registered tonnage 32.3 (range 22–71). Boat and trip selection was opportunistic and relied on the consent of the skipper.

Table 1 shows the distribution of the 328 observed days at sea. The number of days at sea per trip varied from 1 to 11 with a mean of 4.9 days for UK boats and 2.8 days for Irish boats, giving an overall mean of 3.9 days per trip. The observed net hauls on four incompletely observed UK trips equalled an average single trip, giving an effective total of 42 UK trips, which includes two trips which did not fish because of severe weather but which would appear in fishery statistics as days at sea. Table 1 also shows the seasonal distribution of the 2870 km of gillnet which were observed being hauled, 58% by UK boats and 42% by Irish boats. This represents a total of 55 828 km · h of net use, 64% by UK boats and 36% by Irish boats.

Table 2 shows the observed fishing effort by net type. Hake nets comprised 93.2% of the total. The length of net carried ranged from 5–23 km, with a mean of 12.5 km. Boats fishing on wrecks were exceptional, setting 3.6 km or less. Soak time averaged 17.2 h for Irish hake nets and 22.1 h for UK hake nets, 18.9 h for wreck nets, and 53.8 h for tangle nets. All the fishing studied took place between 48°30′ and 53°N and between 3° and 13°W. Figure 1 shows the location of observed hake nets. Observed wreck fishing was mainly in ICES area VII rectangles 30E4 and 27E2. Tangle nets were used in ICES area VII rectangles 28E5, 29E3, 30E1, 30E3, and 29E2. (In this numbering convention a rectangle yEx has its NW corner at $(y/2+36)$°N and $(10-x)$°W.)

Cetacean by-catch

Forty-three porpoises and four common dolphins were recorded caught during the sampled trips. No other marine mammal by-catch was recorded. Forty-two porpoises were caught in hake nets, 28 by UK and 14 by Irish boats. In two cases two porpoises were within 250 m of each other in a net. One porpoise was caught in a tangle net by a UK boat. No by-catches were seen in wreck nets. All porpoises were dead on hauling except for one which was moving weakly and was assumed not to have survived.

Negative binomial distributions gave good fits to porpoise catch per trip and per day with means of 0.53 and 0.13 and variances of 1.4 and 0.2, respectively. The

Table 2. Observed fishing effort by net type used by UK and Irish boats using gillnets in the Celtic Sea 1992–1994.

Fishing effort	Hake		Net type wreck		Tangle	
	UK	Irish	UK	Irish	UK	Irish
km · set	1591* 37†	1105	21	98	19	—
km · h	33 674* 765†	17 599	404	2338	1048	—
% all km · h	61.7	31.5	0.7	4.2	1.9	—

*Double footrope nets.
†Single footrope nets.

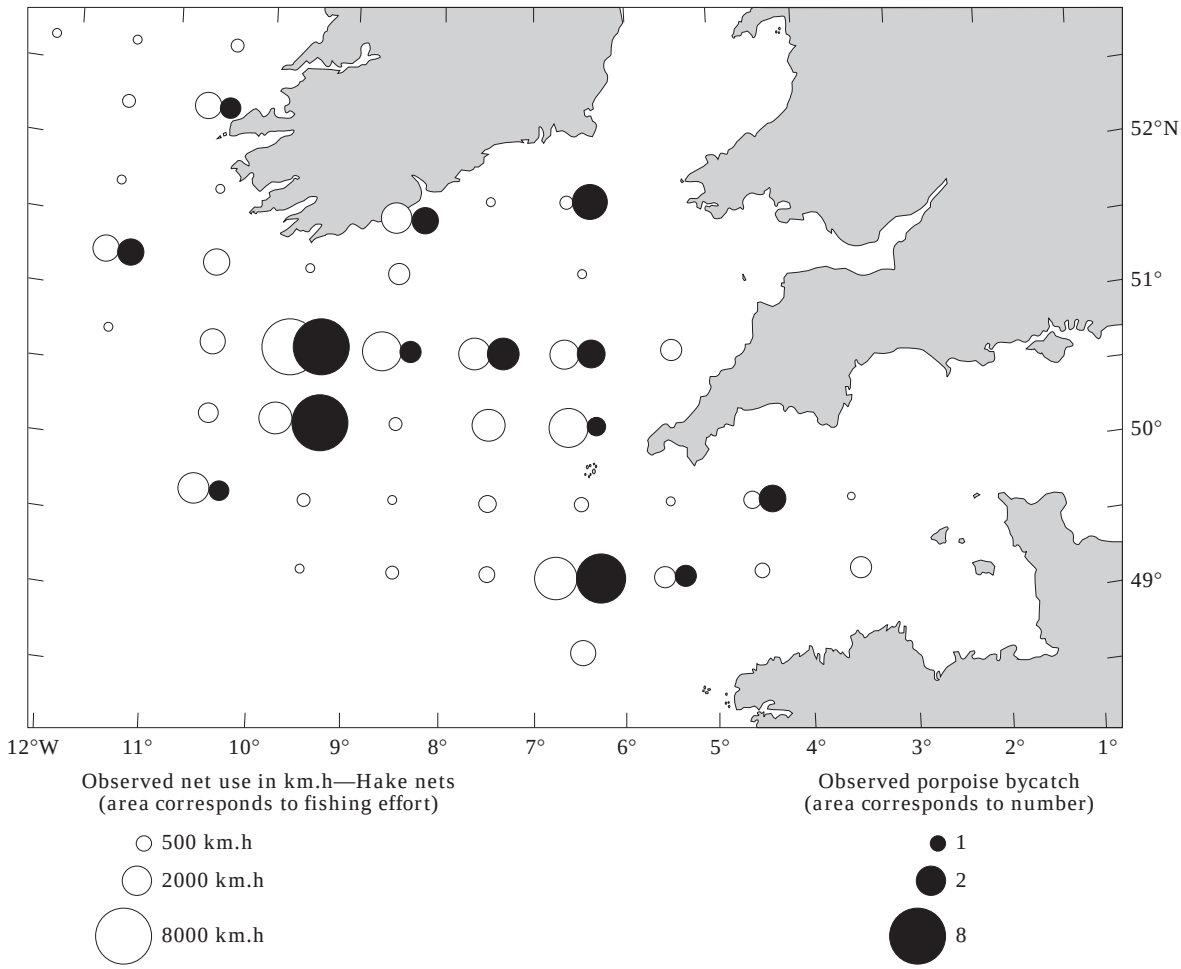

Figure 1. Observed fishing effort and porpoise by-catch by UK and Irish boats 1992–1994 aggregated by ICES rectangles.

Table 3. Seasonal distribution of porpoise by-catch observed in Celtic Sea 1992–1994.

Season	Porpoises caught/ 1000 km · h	n groups caught	p of n or greater (Poisson)
Mar–May	1.29	16	0.04
Jun–Aug	0.44	7	0.82
Sept–Nov	0.72	10	0.44
Dec–Feb	0.69	8	0.35

highest porpoise catch per day was three and per trip was eight. Estimated by-catch rates for all net types combined are given in Table 3. The rate for days at sea includes boats using only wreck nets. No trip rate is given specifically for tangle nets because these were only a part of the net carried by one boat.

Relationship between by-catch rates and other variables

The seasonal distribution of porpoise by-catches is shown in Table 3. In testing for seasonal differences the Bonferroni procedure for multiple tests was applied, which requires the p value for any single season to be <0.0125 to keep the probability of a Type 1 error below 0.05. On the least cautious assumption that capture of porpoise groups of one or more is random in relation to km · h of net use, none of the seasonal catch rates differed significantly from the mean.

The geographical distribution of observed by-catch rates was analysed in 14 areas each consisting of four ICES rectangles, grouped by 1° of latitude and 2° of longitude. The areas south and east of 51°N 10°W, 52°N 8°W, and 50°N 6°W had higher by-catch rates. Applying the Bonferroni procedure as above, none of the stratified rates differed significantly from the overall mean. Because most of the data come from one year, 1993,

Table 4. Observed porpoise by-catch rates in set gillnets in the Celtic Sea 1992–1994.

Measure of fishing effort	Fleet	Observed effort	Porpoise by-catch rates		
			Rate	S.E.	c.v. (%)
10 000 km · h	UK	3.59	8.08		
10 000 km · h	Irish	1.99	7.02		
10 000 km · h	All	5.58	7.70		
1000 km net set	All	2.87	15.0		
100 days at sea	UK	2.17	13.4	3.3	25
100 days at sea	Irish	1.11	12.6	3.4	27
100 days at sea	All	3.28	13.1	2.4	19
Trip	UK	42	0.69	0.24	35
Trip	Irish	40	0.35	0.11	31

annual variability in seasonal or geographical patterns of by-catch cannot be inferred.

Nets were set in water depths of 38 to 327 m, with 90% of fishing effort in 75 to 150 m (Fig. 2). There was no relationship between by-catch rate and water depth. (Product moment correlation -0.1, $df=7$, $p>0.05$). By-catch rates showed no significant differences between hake nets with double or single footropes (8.3 and 7.6 per 10 000 km · h respectively. $\chi^2=0.2$ $p\geqslant 0.05$) but it should be noted that daylight soak time for single footrope nets was longer. Tangle nets were little used, but did catch one porpoise in 1000 km · h of net use.

By-catch in relation to tidal flow rates was assessed using the height of first afternoon high water (Cobh, Ireland) following shooting of the net. Significantly higher by-catch rates occurred during neap tides. (Product moment correlation -0.67, $df=10$, $p<0.05$). Flow rates in the area at mean spring tides are approximately double those at neaps (D'Oliveira and Lees-Spalding, 1993, 1994). By-catch rate was not correlated significantly with sea state during net hauling (Product moment correlation -0.49, $df=4$, $p>0.05$). Porpoise by-catch per trip was not correlated significantly with hake landings (Product moment corelation $=0.18$, $df=40$, $p=0.6$).

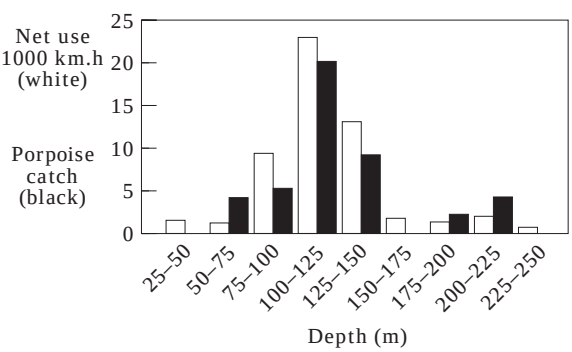

Figure 2. Sea depths of hake net set and porpoises caught in the Celtic Sea 1992–1994.

Detection and characteristics of by-caught porpoises

Sixteen porpoises were seen to drop out of the net spontaneously as they emerged from the water and two were shaken out of the net by the fishermen. Four others were first seen floating within 20 m of the boat during or soon after hauling. We assume these four animals were by-catches. Twenty-two of the 43 porpoises were brought aboard. Sixteen porpoises on UK boats were watched when discarded into the sea; eight sank immediately and eight initially floated.

Sixteen porpoises, eight of each sex, were measured. Lengths ranged from 1.21 m to 1.89 m (Fig. 3). One of the largest had many teeth missing. External injuries were seen on all porpoises. The five most frequent surface lesions recorded, in order of frequency, were:

(1) narrow (1–2 mm), dark, linear marks, especially around the beak, becoming incisions over prominences, and deep incisions on the edges of fins. Four porpoises had encircling net marks, usually around the head;
(2) loss of superficial slices of tissue or broad notches on the edges of fins;
(3) deep linear wounds, 5–10 mm wide, sometimes associated with a bent body position and consistent with powerful impingement of net ropes against the net hauler;
(4) blood or foam discharge from the mouth or foam from the blowhole; and,

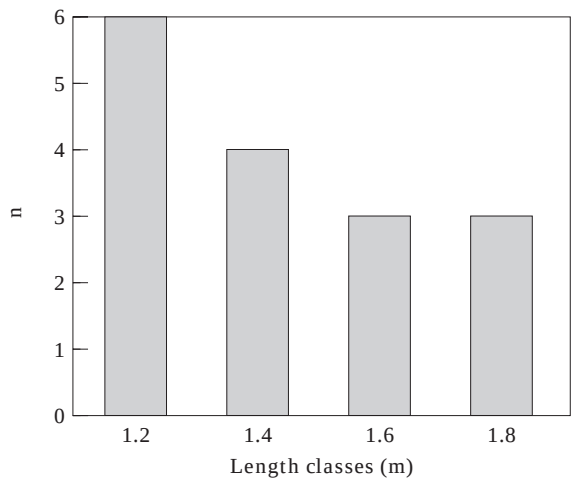

Figure 3. Size of harbour porpoises caught in gillnets in the Celtic Sea 1992–1994.

(5) tissue loss around the eye without penetration of the globe of the eye. Scavenging isopod crustaceans were seen in one such lesion.

Post-mortem examination ashore or four porpoises landed in Ireland and one in the UK showed, in addition, tooth damage and subcutaneous bruising, especially around the pectoral fins and head. All animals were in good nutritive condition with blubber thickness of 10–15 mm.

Estimated total annual porpoise by-catch

UK fleet

Official statistics for UK boats using gillnets in the Celtic Sea in 1993 and 1994 were provided by the Fisheries Research Division of the Ministry of Agriculture, Fisheries and Food (MAFF), giving days at sea by vessel length in three size classes: 10–14.9 m; 15–19.9 m; and $\geq$20 m. No vessels in the 10–14.9 m length class were observed and we have not extrapolated by-catch to this section of the fleet. In this study, 73% of observed days at sea were in the 15–19.9 m length class.

For 1993/1994, the mean total days at sea in the Celtic Sea were 4443 (80%) in the 15–19.9 m length class and 1080 (20%) in the $\geq$20 m length class. These percentages are close to the observed effort in these length classes so the by-catch data were pooled over length class. The by-catch rate of 13.4 porpoises per 100 days at sea (Table 4) gives an estimated annual porpoise by-catch of 740 (S.E. 182, 95% confidence interval 383–1097) for vessels over 15 m. Extrapolations based on effort and rates stratified by season, or by latitude in 1 deg strata, or by longitude in 2 deg strata each vary the total estimated by-catch by less than 10%.

Irish fleet

Total bottom set gillnet fishing effort off the south coast of Ireland by Irish vessels was calculated from official statistics provided by the Irish Department of the Marine. In 1993, 56 vessels between 30 and 110 GRT (approximately 14–22 m in length) from Dunmore East, County Wexford to Dingle, County Kerry were recorded as carrying an average of 9.3 km of gillnet, and 36 vessels between 110 and 150 GRT were recorded as carrying an average of 13 km of gillnet. The fishing effort was concentrated in ICES rectangles VII g, h, j and k.

During 1993, these vessels made a total of 4277 trips. Using the by-catch rate per trip for Irish vessels gives a total estimated porpoise by-catch of 1497 porpoises (S.E. 475, 95% C.I. 566–2428). This figure must be interpreted with caution because it does not allow for differences in trip length by boats of different sizes, and because the average net length reported in the official statistics is less than the average length carried by the boats observed. The spatial and temporal data required for stratification were not available.

The combined estimate, rounded to the nearest 100 animals, of porpoise by-catch in the Celtic Sea for 1993 by the fleets studied is 2200 (95% C.I. 900–3500).

Discussion

Sources of bias

Boats with observers usually fished near other netters and no impression was gained by any observer that fishing practice was being modified in any way to minimise by-catch. Bias up or down may arise where the fraction of effort observed in areas of high or low by-catch was disproportionate to the overall distribution of fishing effort. Extrapolation to the whole fishery using rates stratified by area makes only a slight difference to the estimated overall by-catch, and we do not believe this was a significant problem in this study. Negative bias could arise from missed by-catches. Animals that are shaken out of the net or fall out spontaneously are liable to be missed:

(1) at night, when UK boats hauled 16% of nets;
(2) whenever the observer cannot watch the net coming up. A viewing position may not be available or the observer may be asleep or sick;
(3) when the sea is rough. Three of the four floating animals were seen in sea states Beaufort 0 or 1, which prevailed for only 7.5% of total hauling time recorded by UK boats. Live porpoises are rarely detected in Beaufort 4 or rougher (Heide-Jørgensen

et al., 1993; Hammond *et al.*, 1995) which was the case for 49% of UK daylight hauling time; and,

(4) if rough seas promote disentanglement of porpoises during hauling. Half of the discarded porpoises sank immediately suggesting that all those coming free from the net at depth may sink because gas in the respiratory tract and gut will be compressed, and no opportunity has occurred for water draining from the pharynx etc. to be replaced by air. However, no relationship was found between sea state during hauling and observed by-catch despite a higher proportion of floaters and dropouts being recorded in lower sea states.

Table 5. Days at sea by all UK registered boats reporting tangle net use in the Celtic Sea (Ministry of Agriculture Fisheries and Food data).

	Year		
Boat length	1992	1993	1994
10–14.9 m	26	36	102
15–19.9 m		23	5
20 m and over			91
Total >10 m	26	59	198

Mechanism of porpoise by-catch

During hauling the net rises more or less vertically and any point takes about 6 min to reach the surface. If porpoises are entangled during hauling a substantial proportion should reach the boat alive, but only one out of 43 did so. No attraction of porpoises to boats during setting of nets was observed (in contrast to common dolphins which were attracted). These observations are consistent with porpoise entanglement occurring while the net is on the bottom. Soak time (km · h) is thus a more relevant measure of fishing effort than km set. The comparison between nets with and without a second raised footrope suggests that this does not reduce porpoise by-catch although Au (1994) states that such a rope should substantially increase the acoustic detectability of the net to porpoises. The apparent effect of tidal height on by-catch rates may be because:

(1) faster currents reduce the standing height of the net;
(2) faster currents produce sound from the net (Lien *et al.*, 1990) or make it more detectable to sonar by rolling parts of it up;
(3) porpoises seeking prey may tend to swim into stronger currents. Nets are set in line with tidal currents as far as possible; and,
(4) tidal flow rates may change prey behaviour. For example, some migrating demersal fish exploit favourable currents by rising in the water column.

Comparison with other studies

The by-catch observed contrasts with under 10 cetacean by-catches per year reported voluntarily to MAFF for the whole UK. To compare studies of by-catch an index representing the lethality of the gear can be derived by assuming that by-catch is proportional to the product of fishing effort and porpoise density. This can be expressed as $B = kED$ where B is observed by-catch, k is a factor representing the lethality of the gear to porpoises in the study area, E is observed effort measured in units of 1000 km · h; and D is porpoise density estimated as porpoises km^{-2}.

For the Celtic Sea, an estimate of porpoise density (0.18 porpoises km^{-2}) is available for July 1994 from the SCANS (Small Cetacean Abundance in the North Sea) study (Hammond *et al.*, 1995). In this study k is estimated as $42/(52 \times 0.18) = 4.5$ porpoises per 1000 km · h of hake net immersion per porpoise per km^2.

This statistic is of potential interest in understanding differences between studies of porpoise by-catch in gillnets. Lower values of k may be expected, for example, where porpoises spend more time in pursuit of pelagic fish. Combining data from a study of porpoise by-catch rates in the Kattegat set gillnet fishery for cod in March and April 1995 (Berggren, 1995) with a porpoise density estimate for that area (Hammond *et al.*, 1995), gives a very similar value for k of 4.7.

Estimates of annual by-catch

The by-catch estimate presented excludes several categories of gillnetting:

(1) UK gillnetters of 10–15 m. They make shorter trips than larger boats, and no systematic data exist for their net use. Tangle net use for ''monkfish'' or crayfish predominates in the summer with boats setting 15–20 km (maximum 26 km) of 350 mm tangle net. ''Cod nets'' of 30 or less meshes deep with stretched mesh lengths of 150 mm are used more often in winter. Boats may be able to carry and work six times as much tangle net as hake net which is much bulkier. Official statistics show an average of 3816 days at sea per year for 1993/1994 for these vessels;
(2) UK boats declaring their main fishing gear to be tangle nets or turbot nets (Table 5). Where all gillnet types were once recorded as ''gillnets'', they are increasingly being differentiated, with a consequent apparent growth in ''tangle'' and similar ''turbot'' net use to 2% of days at sea in 1994;

(3) UK and Irish boats under 10 m. Many such boats set nets close inshore;
(4) Gillnetting used in the southern part of the Celtic Sea by French boats. IFREMER (Morizur *et al.*, 1992) reported about 160 boats using large mesh tangle or trammel (three layered) nets and 270 using hake nets from north Brittany. In this area porpoise strandings and sightings are few but gillnet by-catches have been identified (Collet and Mison, 1995; Hammond *et al.*, 1995).

Assessment of impact

Assessment of the maximum potential annual growth rate of porpoise populations has been based on data from other large mammals that have single offspring and are well studied. Barlow and Boveng (1991) arrived at 10% per annum based on humans as a model. Woodley and Read (1991) found a 4% maximum based on the Himalayan Thar (*Hemitragus jemlahicus*). Palka (1994) and Caswell *et al.* (1995) concluded that the best estimate was probably 4% to 5% with rates above 10% being unlikely. The by-catch estimated here for 1993 is 6.2% of the porpoise abundance of 36 280 (c.v. = 0.57) in the Celtic Sea in July 1994 estimated by Hammond *et al.* (1995). The Scientific Committee of the International Whaling Commission at its Annual Meeting in 1995 (Anon., 1996) considered a by-catch of 1% to be a threshold for concern for harbour porpoise populations.

Analyses of genetic relationships (Walton, 1997) among porpoises in waters around the British Isles suggest that more than one stock exists, but are unable to define their ranges. At present the northerly extent of the population of porpoises which lives in the Celtic Sea is unknown. To the east and south, the Celtic Sea borders areas of low porpoise density (Hammond *et al.*, 1995). Unfortunately, although anecdotal reports suggest higher densities, there are no estimates of the number of porpoises to the north, where the Celtic Sea adjoins the Irish Sea and the waters west of Ireland, except for an estimate by Leopold *et al.* (1992) of 19 200 (c.v. = 0.34) obtained from a single day's survey of shelf waters off south-west Ireland. By-catches have been recorded in the Irish Sea in bottom set gillnets and in fixed nets in the intertidal zone by Thomas (1992). By-catches are also known to occur to the west of Ireland.

In conclusion, although currently we cannot accurately quantify the impact of the set gillnet fishery in the Celtic Sea on harbour porpoises, there is serious cause for concern about the ability of the population to which these animals belong to sustain an annual by-catch of the magnitude indicated by this study.

Acknowledgements

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