Sea Mammal Research Unit

University of St Andrews

Bycatch of Vulnerable Species: Understanding the Process and Mitigating the Impacts.

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Executive Summary.

The accidental capture or bycatch of vulnerable and protected species has become an increasingly important aspect of fisheries management. This project was established to examine various aspects of this issue in UK fisheries and to develop and test mitigation measures, specifically for dolphins and porpoises, to help the fishing industry minimise the wider impacts of fishing. This project is linked to another Defra/Scottish Government funded project – a monitoring programme that collects bycatch data through onboard fishery observers. Data from the monitoring programme also helps inform our understanding of the processes that lead to bycatch occurring for particular groups of species.

Among the marine mammals, harbour porpoises and common dolphins are most frequently bycaught in certain static net fisheries, while common dolphins are also bycaught in some pelagic trawl fisheries. Seals are bycaught in both of these broad gear types. Our observations to date suggest that the greatest numbers of seabirds are probably taken in smaller meshed static net fisheries (mainly guillemots) and longline fisheries (mainly fulmars). Shark bycatch has been recorded from both static and mobile gears and at least 4 species of large shark and at least 10 other elasmobranch species have been recorded. Tope is the most frequently recorded of the larger sharks, and is taken mainly in large meshed static nets in the North Sea. Other protected fish recorded include allis and twaite shads which are reported most frequently, albeit sporadically, from some gill net fisheries in the North Sea.

The most recent abundance estimates for cetacean populations around the UK are collated and compared with accepted bycatch reference limits and our current best estimates of cetacean bycatch levels in UK fisheries. Limited or non-existent information from neighbouring European Member States regarding bycatch rates on shared cetacean populations makes it impossible at this point in time to assess the likely conservation threat posed by total bycatch levels. However, our estimates of bycatch levels from UK fisheries alone do not exceed the recommended bycatch reference limits.

Extrapolations from observed hauls to the entire fleet have not been made for non-cetacean species because there is considerable evidence of clumped bycatches which will likely result in statistically biased estimates. Further data analyses and more data collection will be required before we can produce robust total bycatch estimates for other vulnerable species or groups.

Cetacean bycatch is addressed by EU Council Regulation 812/2004, which mandates the use of acoustic deterrent devices (pingers) for all >12 metre (m) vessels using static nets in ICES Divisions VIIdefghj (Celtic Sea and the English Channel), as well as in some more specific fisheries in the North Sea (Subarea IV). Trials conducted by Seafish in 2004 and 2005 found that all the recommended pinger models had relatively high failure rates during field tests and were also potentially dangerous to deploy. As a result of these trials the fishing industry concluded that the commercially available devices listed in Regulation 812/2004 were impractical for use in the harsh conditions of offshore netting, and in particular in those fisheries where long (>500 m) fleets of nets are used. The industry was also concerned about the financial implications of equipping tens of kilometres (km) of netting with a pinger every 100 m or 200 m. To address these financial and operational concerns, the industry made two suggestions: 1. using louder

pingers so that fewer would be needed, and 2. deploying them on the end ropes of the fleet rather than on the actual nets, so that they would be less prone to damage.

The Sea Mammal Research Unit (SMRU) sourced a louder recently available device from an Italian manufacturer (STM) called the Dolphin Dissuasive Device (DDD). This device was originally designed to deter dolphins from depredating on nets in the Mediterranean. Since 2008 we have conducted a trial in close collaboration with the industry in the Southwest, during which we have learned how best to deploy the devices in the offshore gill net and tangle/trammel net fisheries in the Celtic Sea and Western Channel. We have contacted almost all of the 20 or so vessels that are currently required to use pingers under Regulation 812/2004, and the majority of these have now tried and tested these devices over the course of at least one trip. Several of these vessels have been successfully working long fleets of nets with DDDs (model DDD-03L) attached on a regular basis for over two years.

During the trial we also recorded instances of dolphin and porpoise bycatch on a haul by haul basis. Not all fleets set during individual trips had DDDs attached. A minority of fleets were left as 'controls' (without DDDs), as this is the most effective way to determine if the devices are having the desired effect. We have records of 23 porpoises that were bycaught in over 1900 fishing operations. Seven of these occurred in 'test' fleets (with DDDs), while 19 were taken in 'control' fleets. Furthermore, none of the seven animals taken in test fleets was closer than 1.2 km from a DDD, and most were over 2 km from the nearest DDD. The difference in bycatch rates between fleets with and without DDDs is statistically significant, as is the fact that most animals caught in nets using DDDs were more than 2 km from the nearest device. The bycatch rate in nets of 4 km or less in length was reduced by about 95% when DDDs were deployed.

Overall, DDDs appear to offer a viable and effective means of reducing porpoise bycatch in static net fisheries. We expect they will also result in reduced dolphin bycatch; however this has not yet been proven as current sample sizes are too small to provide statistically robust evidence. Feedback from the skippers and crews of the vessels involved has generally been positive, and we are in the process of ensuring that all of the >12m UK vessels fishing in the relevant areas have access to DDDs and so can continue to use them after the end of the trial.

A similar device, the DDD-03H, made by the same manufacturer has been tested in the winter bass mid-water pair trawl fishery in the Western Channel since 2006. Despite very low fishing effort in some years, results of these trials remain very promising. Bycatch rates in the three year period 2004-2006 exceeded 1 dolphin per tow on average (dolphins are usually caught in groups, unlike porpoises), but since the introduction of DDDs the rate has fallen to about 0.15 per tow, and all of the 38 animals that have been bycaught in the past 3 years, have been in tows either when DDDs were absent from the trawl, or when they were demonstrably or probably malfunctioning. It therefore seems very likely that these devices are a highly effective means of reducing dolphin bycatch in pelagic trawls.

All the vessels involved in the bass trawl fishery in recent years (three pair teams) have voluntarily requested pingers and observers every season to ensure that detailed records are maintained of any dolphin bycatches and the deployment patterns and functioning of the devices. Important lessons have been learned about the optimal positioning of DDDs inside the trawl and about battery management to ensure that they continue to function correctly. Any issues have been addressed collaboratively with considerable input from skippers and crews, who are now familiar with the procedures required to minimise or possibly, with further fine-tuning, eliminate dolphin bycatch in this fishery.

The use of these louder pingers has proven successful in reducing cetacean bycatch in two important fisheries where it has been a concern. However, there remains some unease about the widespread deployment of such loud devices (~165 dB re 1µPa@1m), in case cetaceans are displaced from large areas which could potentially reduce their foraging success. To investigate this possibility we conducted experiments using DDDs and a quieter device (Aquamark 100) to determine how significant any exclusion might be. Results from the experiments in two separate years using DDDs were equivocal, but there was some evidence of decreased cetacean activity when a single DDD was in the water out to at least 1.2 km from the device and possibly as far as 3 km or more. The Aquamark appeared to have an effect up to about 400 m, though this particular result is preliminary pending further analysis.

To calculate potential exclusion rates we have also produced estimates of the amounts of netting likely to be deployed in the waters around Cornwall in the Southwest of England using two different approaches. Firstly we combined official landings and effort data with our own observer records of the amounts of netting used by boats targeting different species, to obtain an initial estimate of net usage. This approach suggested that on a typical June day (when netting effort is at its highest) roughly 1500 km of net may be deployed at any one time. A higher estimate was later derived by including in the analysis interview data collected from 79 <12m boats, and by combining this with information about the fishing patterns of the 20 or so >12m boats working in Subarea VII. This more detailed analysis suggested that there could be up to a maximum of 3200 km of static netting deployed at any one time. Both of these figures are based on relatively crude calculations and provide what is essentially an estimate of the amount of netting that is potentially available for use, which may not necessarily be a particularly accurate reflection of the amount of netting that is actually in use at any time. Nevertheless these estimates provide a useful guide to the possible magnitude of netting effort in the Southwest UK.

On the basis of these figures we examined how various scenarios (pinger model chosen, spacing chosen and fleet sector affected) might affect the distribution of porpoises and dolphins by assuming that such devices might exclude cetaceans from areas ranging from a radius of 100 m up to at most 4 km away from each sound source. We found that depending on which model, spacing and fleet sectors were chosen, an area ranging from 0.04% to 11% of the total area of the Celtic Sea and Western Channel could potentially be denied to cetaceans during neap tides when most netting activity occurs.

We also calculated the likely financial costs to the relevant vessels, firstly if only the >12m vessels were to use pingers, and also if each of three other size categories of vessel (10-12m, 8-10m and <8m) were also required to use pingers at some point in the future. The total costs ranged from roughly £113,000 to over £2.5 million, depending on the pinger model used and the spacing chosen.

We caution that there are some extreme assumptions implicit in these calculations and that the exercise is most useful simply to highlight the fact that a ‘mix and match’ approach to pinger deployment – by using different models and different spacings in different fleet segments can radically alter both the financial costs to the industry and the potential impacts in terms of habitat exclusion.

Although much of the practical work we achieved focused on the above tasks, we have also developed and enhanced our understanding of bycatch through several other approaches. We have used the existing observer bycatch data to develop statistical models of the relationships between bycatch and various operational factors. Several of these factors were found to be associated with higher bycatch rates, but many of these were attributable to specific fisheries where higher bycatch rates had been observed and do not necessarily imply any causal relationship. For example in the North Sea we found that higher porpoise bycatch rates were associated with shorter fleet lengths, a counter-intuitive finding that is driven by high bycatch rates in one specific type of fishery where short fleets are set over wrecks. A more plausible explanation for this finding may be that these fishing areas simply coincide with areas of particularly high porpoise activity thus leading to higher bycatch rates.

However, two factors, net height and twine diameter, emerged from the analyses as being potentially more interesting in terms of developing bycatch mitigation measures. We suggest that an experimental approach will be required to fully explore how significant these factors might be and to determine whether they might provide a feasible alternative approach to bycatch mitigation.

We also developed an experimental approach to determine if porpoises are actively attracted to nets. Previous work had given rise to this hypothesis. In a carefully controlled experiment we used passive acoustic monitoring equipment in test and control areas and found that porpoise click frequency was similar at sites with a net present and at sites without a net. However, we did find a higher proportion of faster echolocation click-trains at sites with nets present, suggesting that either the nets provided an improved foraging area, or that the animals were actively examining the nets with their sonar.

Planned work to examine the movements of animals in relation to fishing gear was limited to a feasibility study of using satellite or GPS tags to track dolphin movements, but this objective was taken no further than a desk based study of the options for undertaking this type of work.

Another aspect of this project involved our team keeping up to date with related research in other European countries and globally. We have included in this report a summary of recent research efforts that address bycatch mitigation, including other pinger trials, the development of at-sea sonar equipment to check pinger functioning, trials of alternative gill net materials, use of pingers in trawl fisheries, trials of escape routes in trawls, methods and trials to minimise marine mammal depredation on fishing gear, and behavioural experiments looking at the reactions of cetaceans to pingers.

We have also summarised recent work in which we tried to use physical marks or cues on the bodies of stranded animals to determine the specific gear type that might have caused death. This work was not fully developed under the present project due to a lack of opportunity to examine beach cast animals, but some suggestions have been made which should allow us to develop this approach further in future.

Finally we conclude with a discussion of the significance of bycatch studies in relation to fisheries management and product marketing, and how despite the previous focus on cetaceans, other groups of species could also be considered under existing bycatch programmes. We highlight the fact that although DDDs appear to be effective there are still challenges to address including determining the optimal or agreed maximum spacing for these devices on static nets and the most effective configuration for mid-water trawls. We suggest that there is a continuing need for alternative mitigation measures to be explored and more fundamentally that it is important to understand how and why animals behave in the ways that they do around fishing gear and why this sometimes leads to their capture. We conclude by re-iterating the importance of engaging the fishing community with this task, and stress that their proactive involvement will be critical if these issues are to be satisfactorily resolved in the longer term.

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1. Introduction.

Policy Background.

Concern over the bycatch of protected species in commercial fishing operations has grown considerably over the past couple of decades. These concerns are reflected in policy initiatives, in international agreements, in vocal campaigns by animal welfare and environment advocates, and in popular books, newspaper articles and television programmes. Cetaceans (whales, dolphins and porpoises) have the highest profile among all wildlife groups that are impacted by fishing operations and have an iconic status as indicators of the health and diversity of the seas.

The UK is committed to the maintenance of healthy, diverse and productive seas and has signed up to several national and international policy drivers to minimise bycatch of cetaceans and other taxonomic groups or species. These drivers include the UN-Food and Agriculture Organisation's (FAO's) Code of Conduct for Responsible Fishing, the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS) and the Agreement on the Conservation of Albatrosses and Petrels (ACAP) – both of which are regional agreements under the (Bonn) Convention on Migratory Species (CMS), the Convention on Biological Diversity (CBD), and the Oslo and Paris Conventions, or the Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR). Additionally the UK is required to monitor incidental capture rates of species protected under the EU Habitats Directive, while Council Regulation 812/2004 also requires member states to monitor the bycatch of small cetaceans specifically, and to implement mitigation measures to reduce bycatch. The Marine Strategy Framework Directive (MSFD) will also require member states to ensure that the marine ecosystem is maintained in 'good environmental status'. Bycatch and abundance levels of sensitive species will likely be an important facet of such assessments. Other measures of relevance include the proposed EU Action Plan for reducing incidental catches of seabirds in fishing gears, a similar proposed EU action plan for elasmobranchs, the UK's Small Cetacean Bycatch Reduction Plan, and the UK's Biodiversity Action Plans for various marine species groups.

Within the specific framework of fisheries management, the EU has adopted a progressive implementation of an Ecosystem Approach to Fisheries Management (EAFM) as an operational objective of its Common Fisheries Policy (CFP), whereby fisheries management will strive to ensure that benefits from living marine resources are high, while the direct and indirect impacts of fishing operations on marine ecosystems are low and not detrimental to the future functioning, diversity and integrity of these ecosystems. This is in line with previously adopted objectives regarding ecosystem management under the CBD and the declaration of the World Summit on Sustainable Development (WSSD) in 2002, and with the Reykjavik Declaration adopted by the FAO in 2002. Although specific measures adopted so far have been limited to reductions in overall fishing effort, the promulgation of action plans and the adoption of Regulation 812/2004, the revision of the CFP will likely include a variety of new measures to address the bycatch of sensitive species.

All of the drivers and initiatives listed above underpin the continued need for developing means to quantify the effects of fisheries on sensitive parts of the ecosystem and to devise management tools to address these pressures while maintaining high levels of benefit from commercial fishing activities.

Current Understanding.

Addressing the concerns of fishery impacts requires a dual approach that includes both monitoring and mitigation. Monitoring is required to assess the nature and scale of pressures exerted on the ecosystem, and to identify specific pressures that may reduce 'good environmental status' (howsoever that may be defined). Tools for mitigation need to be developed where bycatch rates are considered too high. These could include temporal and/or spatial management approaches or the development and implementation of appropriate technical measures. Monitoring of cetacean bycatch in the UK began in earnest in 1995, though efforts were made to collect data directly from fishermen starting in 1984, after recommendations from the International Whaling Commission (IWC). A request was sent to all fishermen through port officials, but by 1990 only two records had been collected by this means. In 1987 an interview survey was conducted around the UK and many more instances of cetacean bycatch were collated (Northridge 1988). In 1992 an EC-funded project initiated the first direct bycatch monitoring scheme in the UK and Ireland on board hake gill net vessels working in the Celtic Sea. This programme ran for 18 months and resulted in the first estimates of cetacean bycatch for an individual fishery in the UK (Tregenza *et al.* 1997a). In late 1995, following recommendations from ASCOBANS, from the IWC and to address obligations laid down in the Habitats Directive, the UK Bycatch Monitoring Scheme was initiated to cover a variety of fisheries, initially in the North Sea, but then on the West Coast of Scotland and finally in the Southwest. Cetacean bycatch estimates have been produced more or less annually ever since, though monitoring has been patchy with some regions receiving little on-going monitoring as the focus of attention has shifted from region to region.

The conservation status of cetaceans with respect to bycatch around the UK remains poorly understood. One way of addressing this is to compare estimates of total bycatch with total abundance estimates. Abundance estimates are available for several species from three international surveys conducted in 1994, 2005 and 2007. The 1994 and 2005 surveys (SCANS I and SCANS II respectively) focused primarily on harbour porpoises (HP) in the shelf waters of the European North Atlantic, whereas the CODA survey in 2007 focused more on common dolphins (CD) in deeper water between the shelf edge and the outer limits of the EU Exclusive Economic Zone (EEZ). These surveys all represent snapshots of abundance at specific times, and particularly in the case of the common dolphin may not have covered the entire range of the population. Nevertheless the surveys provide information on the relative densities and likely abundance levels for these two common species, as well as for other less abundant species.

Figures for harbour porpoises and common dolphins are given in Tables 1-3 by area from the SCANS (HP) and SCANS II (HP&CD) surveys. In addition, Table 4 gives totals for all species for which abundance estimates were made from the SCANS II and CODA surveys, with certain corrections for estimates in the SCANS II report (P. Hammond pers. comm.).

Abundance estimates can be used to determine levels of bycatch that might be considered unsustainable. Several metrics have been used to determine whether or not a given level of cetacean mortality in specific fisheries may be unsustainable. The most widely used metric in Europe is the 1.7% of best estimate of abundance that was calculated as a yardstick against which to compare bycatch levels of porpoises at a joint IWC and ASCOBANS workshop in 2000 (Anonymous 2000). The 1.7% level is based on the premise that we can be reasonably sure that any removals through fishery bycatch would not result in less than 80% of the carrying capacity of the population concerned over a 100 year time horizon. This mortality rate has been adopted by ASCOBANS and Ministers of North Sea states under the North Sea Conference and is also now applied to other small cetacean species.

Reference limits of 1.7% of the best estimates of abundance are given in Tables 1 through to 4.

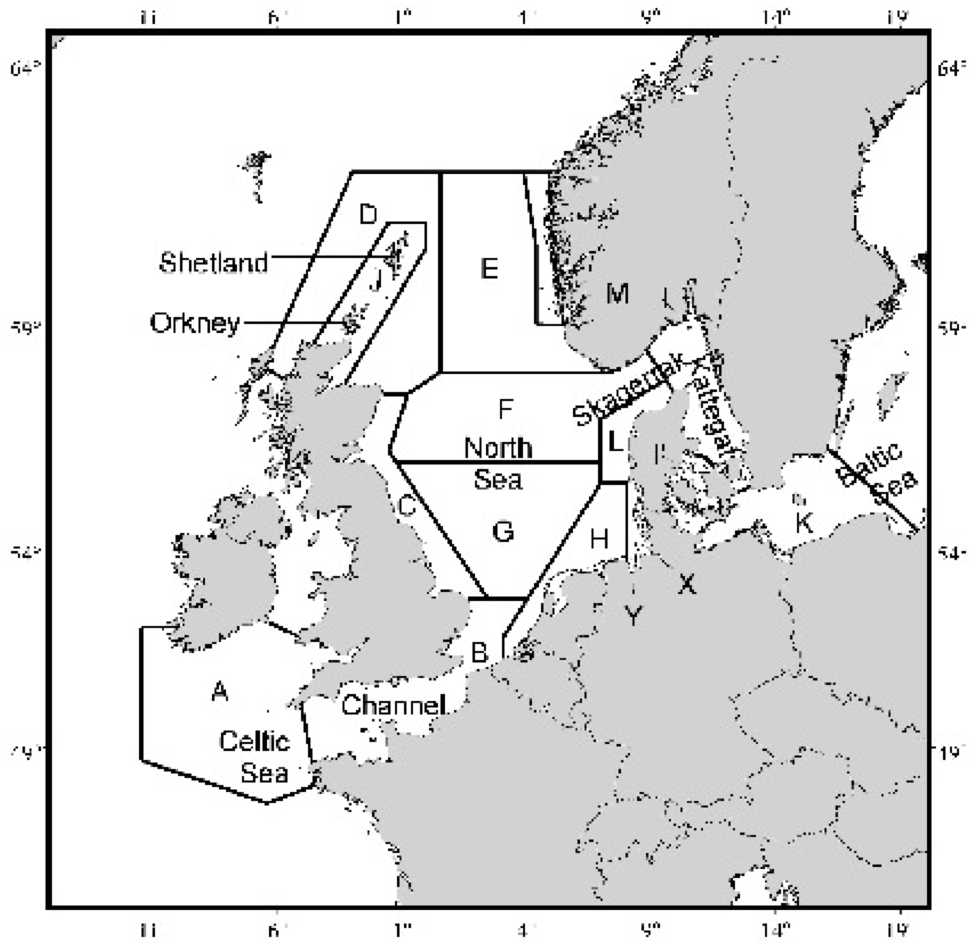

Figure 1: Scans Survey Blocks from Hammond et al (2002)

Table 1: Abundance estimates for harbour porpoises June 1994 from the SCANS survey (Hammond et al 2002)

Block and Description	Animal Abundance	CV	Animal density (nos/km^2)	Notional bycatch limit 1.7%
A Celtic Sea	36,280	(0·57)	0·180	617
C East Britain	16,939	(0·18)	0·387	288
D Minch to W Shetland	37,144	(0·25)	0·363	631
E Central Northern North Sea	31,419	(0·49)	0·288	534
F Central North Sea	92,340	(0·25)	0·776	1570
G central Southern North Sea	38,616	(0·34)	0·340	656
H Frisian Islands	4,211	(0·29)	0·095	72
J Northern Isles	24,335	(0·34)	0·784	414
L West Jutland	11,870	(0·47)	0·635	202
M Norwegian coast	5,666	(0·27)	0·449	96
Y German Islands	5,912	(0·27)	0·812	101
Total 'North Sea' Blocks	**268,452**			4564
X Danish Inner water Islands (S)	588	(0·48)	0·101	10
I Kattegat	36,046	(0·34)	0·725	613
I' Danish Inner waters	5,262	(0·25)	0·644	89
Total Kattegat / Danish Inner waters	**41,896**			712
Overall total	**341,366** [260,000–449,000]	(0·14)		5803

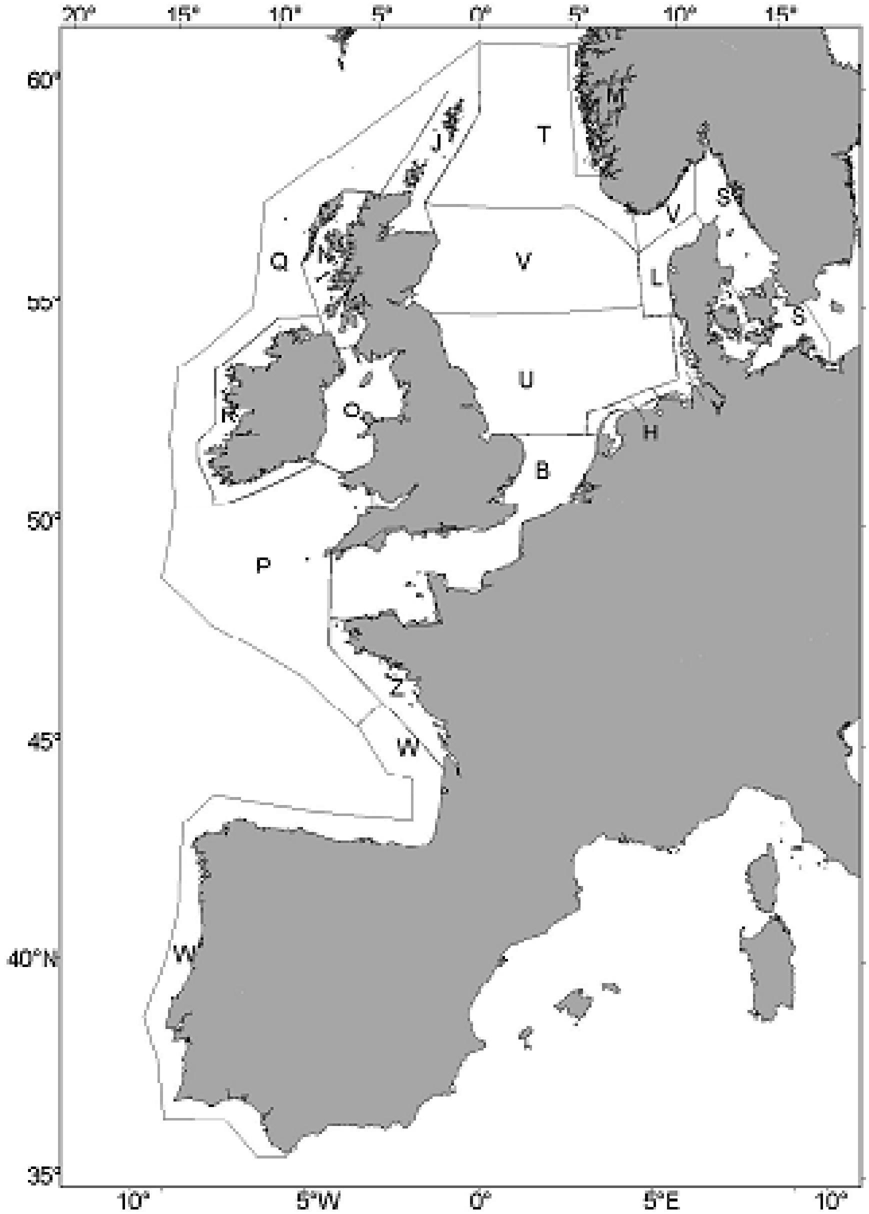

Figure 2: Scans II Survey Blocks from SCANS-II Final Report

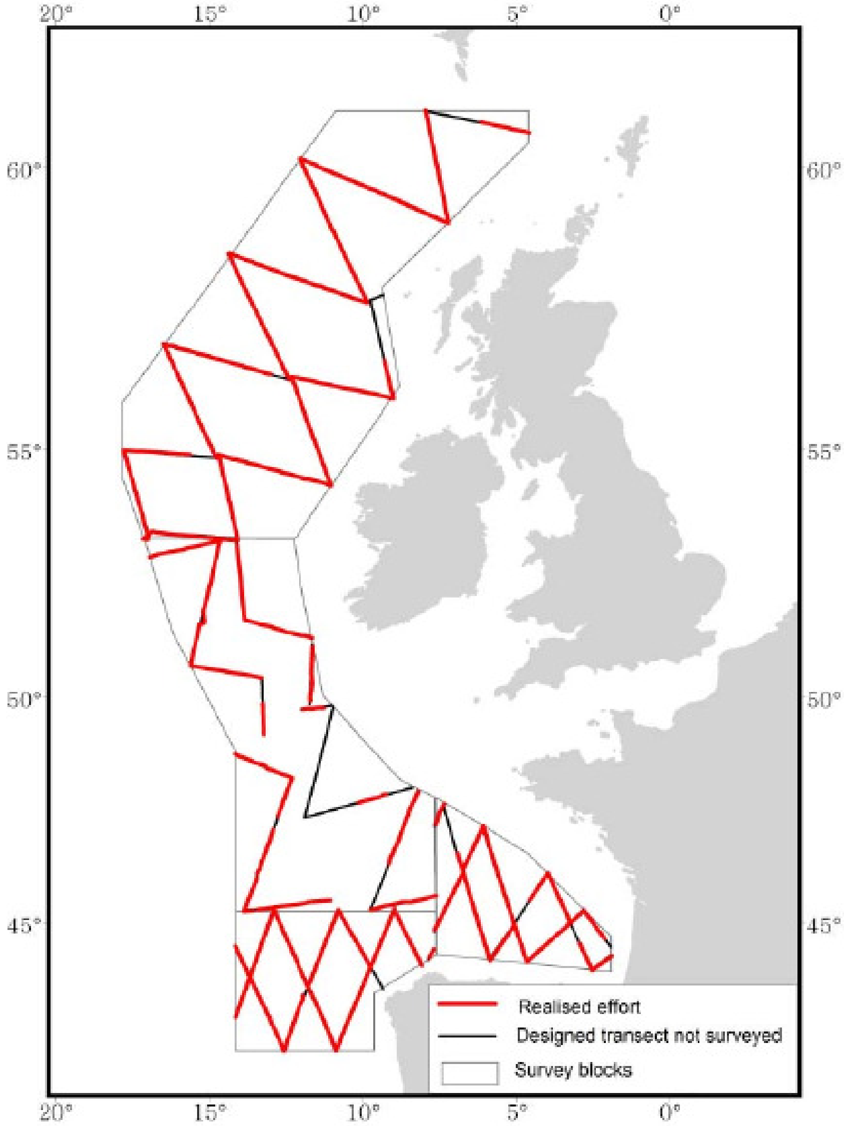

Figure 3: CODA Survey Blocks, designed cruise tracks (red/black) and actual survey effort (red)

Table 2: Abundance estimates for harbour porpoises June 2005 from the SCANS II survey (Anonymous 2006)

Block	Area	Abundance estimate	CV	Density (CV)	Notional Bycatch Limit
J	Northern Isles	10,254	0.36	0.274 (0.36)	174
T	Northern North Sea	23,766	0.33	0.177 (0.33)	404
M	Norwegian Coastal	3,948	0.38	0.305 (0.38)	67
V	Central North Sea	47,131	0.37	0.294 (0.37)	801
U	Southern North Sea	88,143	0.23	0.562 (0.23)	1,498
H	Frisian Islands	3,891	0.45	0.355 (0.45)	66
L	West Jutland	11,575	0.43	0.555 (0.43)	197
Y	German Islands	1,473	0.47	0.125 (0.47)	25
S	Skagerrak	23,227	0.36	0.340 (0.36)	395
	Total 'North Sea' blocks	***213,408***			***3,628***
B	Channel	40,927	0.38	0.331 (0.38)	696
P	Celtic Sea	80,613	0.5	0.408 (0.50)	1,370
O	Irish Sea	15,230	0.35	0.335 (0.35)	259
	Total SW Blocks	***136,770***			***2,325***
Q	Northwestern Shelf	10,002	1.24	0.067 (1.24)	170
N	Hebrides	12,076	0.43	0.394 (0.43)	205
R	Western Ireland	10,716	0.37	0.278 (0.37)	182
	Total NW Blocks	***32,794***			***557***
W	Iberian shelf	2,646	0.8	0.019 (0.80)	45
	NW EUROPE TOTAL	***385,618***			***6,556***

Table 3: Abundance estimates for common dolphins June 2005 from the SCANS II survey (Anonymous 2006). Abundance estimates given for common dolphins and for animals that were either common dolphins or striped dolphins or for mixed schools thereof.

Species / group	Block	Area	Abundance	CV	Density (CV)	Notional take limits
CD	B	Channel	14,349	1.66	0.1159 (1.66)	244
CD	N	Hebrides	2,322	0.61	0.0758 (0.61)	39
CD	O	Irish Sea	366	0.73	0.0081 (0.73)	6
CD	P	Celtic Sea	11,141	0.61	0.056 (0.61)	189
CD	Q	North-western Shelf	1,454	0.81	0.010 (0.81)	25
CD	R	Western Ireland	15,327	0.78	0.3972 (0.78)	261
CD	W	Iberian shelf	17,916	0.22	0.129 (0.22)	305
CD	Z	Biscay Coastal	491	0.87	0.0154 (0.87)	8
TOTAL			***63,366***			***1,077***

CD/SD	B	Channel	14,349	1.66	0.1146 (1.65)	244
CD/SD	J	Northern Isles	88	0.99	0.0022 (0.99)	1
CD/SD	N	Hebrides	2,322	0.61	0.0758 (0.61)	39
CD/SD	O	Irish Sea	749	0.68	0.0165 (0.68)	13
CD/SD	P	Celtic Sea	21,410	0.41	0.109 (0.41)	364
CD/SD	Q	Northwestern Shelf	1,578	0.79	0.011 (0.79)	27
CD/SD	R	Western Ireland	15,327	0.78	0.3972 (0.78)	261
CD/SD	W	Iberian shelf	32,921	0.27	0.238 (0.27)	560
CD/SD	Z	Biscay Coastal	660	0.77	0.0207 (0.77)	11
TOTAL			***89,404***			***1,520***

Table 4: Combined estimates from SCANS II and CODA for all species for which estimates were derived for the combined survey area (Hammond *pers comm*)

Species	**N**	**CV**	**L 95% CL**	**U 95% CL**	**Notional Limit**
Harbour porpoise	385,617	0.2	261,600	568,500	6,555
White-beaked dolphin	16,787	0.26	10,169	27,700	285
Minke whale	25,364	0.36	12,700	50,600	431
Bottlenose dolphin	31,940	0.19	22,300	45,800	543
Common dolphin	167,216	0.25	103,000	271,300	2,843
Striped dolphin	67,414	0.38	32,800	138,500	1,146
Long-finned pilot whale	25,101	0.33	13,400	47,100	427
Fin whale	9,019	0.11	7,300	11,200	153
Sperm whale	2,077	0.2	1,400	3,100	35
Beaked whales	6,992	0.25	4,300	11,300	119

These numbers provide some context with which to address bycatch concerns about European cetacean populations. Bycatch estimates for UK fisheries have only been made so far for the two most numerous species, harbour porpoise and common dolphins. Limited numbers of minke whales (1), pilot whales (5) and bottlenose dolphins (5) have also been observed bycaught in some fisheries under the UK bycatch monitoring scheme, and some other species have also been diagnosed as having died as a result of bycatch after post mortem examination of stranded individuals under the UK Cetacean Strandings Investigation Programme. It is not yet possible to use these sporadic records to estimate total bycatch for these less common species.

Project Objectives.

The project objectives are listed below. Most effort has been addressed towards objectives 1 through to 4 and objective 6. Objective 5 was not pursued because mitigation trials under objective 4 appear to be successful and adequate. Work on objective 7 was limited to a desktop study of possible methodologies, as the Steering Group considered this sufficient to meet the requirements of this objective. Work on objective 8 was hindered by a lack of access to stranded bycaught animals.

The project objectives were:

1. Test the effectiveness and practicality of using pingers (DDD-02, STM Products) as a potential cetacean bycatch mitigation tool for gill and tangle net fisheries in the Southwest.
2. Determine the amounts of netting in use for each of the major static net categories in Cornwall and Devon to assess the economic and environmental implications of widespread pinger use.
3. Determining how tangle net design features influence porpoise and seal bycatch rates, and how such features might be adapted to minimise bycatch rates.
4. Continue monitoring of pinger use in bass pair trawl fisheries to determine more precisely the extent of dolphin bycatch reduction by this method.
5. If necessary, to continue trials with exclusion devices to refine the design and improve the chances of dolphin and shark escape.
6. Analysis of existing bycatch monitoring data to examine relationships between bycatch rate and aspects of fishery practice for all major recorded bycatch species (including marine mammals, sharks and birds).
7. Develop methods to explore the effectiveness or otherwise of spatial management as a tool for minimising bycatch of certain species.
8. Continue to develop a diagnostic approach to the post mortem examination of net marks on beach cast animals with the aim of refining diagnoses of bycatch to enable specific gear types to be identified, or to be excluded, as possible causes of death.

Links with other Projects.

This project follows on from MF0736 (Northridge *et al.* 2008) where several of the hypotheses being tested here were developed. This project has also been managed in conjunction with the UK's protected species bycatch monitoring programme (Project CR0377). Whereas the present project aims to test mitigation measures and explore factors that may influence the probability of animals getting caught, the monitoring project was established to meet UK obligations under the Habitats Directive (92/43/EEC), ASCOBANS and Council Regulation 812/2004 to monitor and assess the scale of bycatch by species. Nevertheless these two projects provide support for one another. Where bycatch observations suggest that there may be a problem to be addressed, the present project provides a way by which the industry can address such problems. Conversely, the observations collected under CR0377 provide data that has helped inform the development of the present project. Additionally, the current project has been augmented with a collaborative project under the Fisheries Challenge Fund in collaboration with the Cornish Fish Producers Organisation (CFPO) to extend field trials of one particular mitigation device to the entire >12m netting fleet in Cornwall. The monitoring project also provides bycatch information for other protected species (e.g.shads), as well as seals, seabirds and elasmobranchs, and these data have been used in some of the analyses conducted for this project.

2. What We Know about Vulnerable Species Bycatch in UK Fisheries.

In this section we review information on the bycatch of various vulnerable species in UK fisheries that we have observed since 1996. We begin by summarizing our observer effort.

Overview of data collection under the bycatch monitoring scheme.

Since 1996 we have observed 1,552 trips on vessels using static gears, accounting for 10,666 observed hauls. The majority of observer effort has been in ICES Subareas IV and VII. Table 5 provides a summary of the number of hauls observed by Subarea.

Table 5: Number of static net hauls observed by ICES Subarea.

ICES Subarea	IV	VI	VII	VIII
No. of hauls	5,808	485	4,353	20

Observed static gears includes gill nets, tangle nets, trammel nets, drift nets and beach set stake nets. The majority of observed hauls were in gill, tangle and trammel nets (Table 6).

Table 6: Number of observed static net hauls by gear type.

Gear type	No of hauls
Drift net	117
Drift Trammel	254
Gill net	5,134
Gill net (unspecified)	98
Stake net	168
Tangle net	3,286
Trammel net	1,609

Since 1999, 484 trips have been observed on vessels fishing with trawl gears, resulting in 1,738 observed tows. The majority of tows have been observed in ICES Subarea VII. Table 7 provides a summary of the number of observed tows by Subarea.

Table 7: Number of observed trawl hauls by ICES Subarea.

ICES Subarea	II	IV	VI	VII	VIII
No. of tows	10	207	190	1,312	19

Observed trawl gears include demersal pair trawls, high-lift demersal trawls, light otter trawls, mid-water trawls and mid-water pair trawls. The majority of observer effort has been in mid-water trawl fisheries. Table 8 provides a summary of the number of tows observed for each trawl gear and the species targeted.

Table 8: Number of observed trawl tows by gear type and summary of targeted species.

Gear type	No of tows	Target species
Demersal pair trawl	11	Mixed
High lift demersal trawl	64	Cuttlefish, haddock, lemon sole, monkfish, squid
Light otter trawl	67	Cuttlefish, cod, lemon sole, monkfish, squid
Mid-water pair trawl	1,234	Anchovy, bass, herring, horse mackerel, mackerel, smelt, sprat, whitefish whiting.
Mid-water trawl	372	Anchovy, blue whiting, herring mackerel, pilchard, sandeels, sprat.

Bycatch of non-target species.

A number of non-target vulnerable species have been reported during observed fishing operations in both static net and trawl fisheries. These include cetaceans (harbour porpoises, bottlenose dolphins, common dolphins, pilot whales and minke whales), pinnipeds (grey and harbour seals), seabirds (guillemots, cormorants and gannets), large sharks (basking shark, blue shark, thresher shark, porbeagle shark and tope) and protected fish species (allis and twaite shad). Summaries of observed bycatch rates for each of these species or groups in static and trawl net fisheries are provided in the following sections.

Cetacean bycatch.

Bycatch estimates for common dolphins and harbour porpoises have been produced annually since 2006. Estimates for harbour porpoise bycatch in the North Sea (Table 9) are based on observed bycatch rates in certain static net métiers from 1996 to 2000 and by applying these rates to recent annual fishing effort estimates for the same métiers.

We have been working to update these observed bycatch rates under project CR0377 by deploying increasing observer coverage in the North Sea.

Table 9: UK porpoise bycatch estimates in the North Sea

Year:	*Estimate*	*LCL 95%*	*UCL 95%*
2003	**391**	**315**	**602**
2004	**438**	**363**	**648**
2005	**386**	**293**	**619**
2006	**361**	**295**	**533**
2007	**276**	**218**	**418**
2008	**306**	**162**	**547**
2009	**242**	**125**	**440**

Estimates of porpoise and dolphin bycatch in the Southwest have been made annually since 2005 for set net fisheries and since 2001 for the winter bass pair trawl fishery. These are summarised below.

Table 10: Porpoise bycatch estimates in UK set net fisheries in the Southwest

Year:	*Estimate*	*LCL*	*UCL*
2005	**453**	**247**	**686**
2006	**728**	**375**	**1,117**
2007	**592**	**206**	**1,699**
2008	**823**	**307**	**1,882**
2009	**791**	**na**	**na**

Table 11: Common dolphin bycatch estimates in UK set net fisheries in the Southwest[1]

Year:	*Estimate*	*LCL*	*UCL*
2005	**221**	**84**	**398**
2006	**544**	**211**	**947**
2007	**114**	**29**	**440**
2008	**594**	**22**	**797**
2009	**237**	**na**	**na**

Table 12: Common dolphin bycatch in the UK bass pair trawl fishery

Winter Season		Point Estimate or Census	LCL	UCL
2000 to	**2001**	**190**	**172**	**265**
2001 to	**2002**	**38**	**23**	**84**
2002 to	**2003**	**115**	**88**	**202**
2003 to	**2004**	**439**	**379**	**512**
2004 to	**2005**	**139**	**139**	**146**
2005 to	**2006**	**84**	**84**	**85**
2006 to	**2007**	**70**	**55**	**117**
2007 to	**2008**	**0**	**0**	**0**
2008 to	**2009**	**2**	**2**	**2**
2009 to	**2010**	**28**	**28**	**28**

[1] Figures from UK reports to the European Commission on the Implementation of Council regulation 812/2004; no confidence limits provided for 2009.

Bycatch estimates of porpoises in the North Sea, though reliant on rather old observations, may be in the low hundreds for UK fisheries at present. These can be compared with notional bycatch limits of around 3,500-4,500 from Tables 1 and 2. Other major gill net fisheries exist in Denmark and Norway, while Sweden, Belgium, the Netherlands and France also prosecute gill net fisheries in the North Sea. Bycatch rates in these other nations' fisheries are not known at present, but a recent analysis by ICES suggested that total effort in commercial fisheries is not currently high enough to take as many as 3,500 porpoises per year in the North Sea, though concerns have been raised about large scale recreational gill net fisheries that exist along the continental shore of the North Sea. Increasing fuel prices and a potential cod stock recovery could lead to increased gill net effort in the future.

In the South and Southwest, porpoise bycatch in UK set net fisheries are likely to be in the mid to high hundreds of animals per year, and although bycatch limits are likely to be over 2,000 animals per year in this area, there are limited data available regarding porpoise bycatch levels by other nations vessels, so it is not possible to make an overall assessment of the conservation status of harbour porpoise in Subarea VII.

Common dolphin bycatch currently amounts to some few hundreds of animals per year taken by the UK fleet, including now just a few or a few tens of animals at most in UK pelagic pair trawl fisheries. The UK total is therefore much lower than the estimated sustainable take limit of around 2,800 animals, but bycatch levels by other European member states are likely to run into the thousands of animals annually, so it remains a moot point whether or not current international bycatch levels for common dolphins are sustainable.

Seal bycatch in static nets.

A total of 107 seals have been observed bycaught in static nets. All bycatches have been recorded in ICES Subareas IV and VII, with the highest bycatch rates in ICES Subarea IV. Table 13 provides a summary of seal bycatch rates observed by Subarea.

Table 13: Summary of seal bycatch rates in static net fisheries by ICES Sub-area.

ICES Subarea	No of hauls	No of seals	Bycatch rate
IV	5808	84	0.014
VI	485	0	0.000
VII	4353	23	0.005
VIII	20	0	0.000

Seals have been observed bycaught in a drift net targeting bass (DN2), in gill nets targeting bass (GN1), gadoids (GN2), sole / monkfish (GN6), tangle nets targeting monkfish and ray (TN2), crustaceans (TN3) and in trammel nets targeting sole/monkfish (TR1). Highest bycatch rates were observed in tangle nets in ICES Subarea IV. Of the 80 seals observed bycaught in tangle nets in this area, 75 were bycaught during experimental trials in ICES Division IVb. Table 14 provides a summary of seal bycatch rates by metier and Subarea.

Table 14: Seal bycatch rates by metier and ICES Subarea.

Gear type	Target species	Metier	ICES Sub-area	No of hauls	No of seals	Bycatch rate (per haul)
Drift net	Pilchard, herring, cod	DN1	IV	16	0	0
Drift net	Bass	DN2	IV	55	1	0.018
Drift net	Salmon	DN3	IV	8	0	0
Drift trammel	Bass, cod, sole, ray	DRT	IV	227	0	0
Gill net	Bass, haddock	GN1	IV	221	1	0.005
Gill net	Cod, ling, pollack, whitefish	GN2	IV	2,213	1	0
Gill net	Hake	GN4	IV	21	0	0
Gill net	Dogfish, spurdog	GN6	IV	98	0	0
Gill net (unspecified)	Mackerel, herring	GNU	IV	23	0	0
Stake net	Sole, crab, plaice, ray, turbot, monkfish, skate	STK	IV	168	0	0
Tangle net	Ray, monkfish, skate, turbot, dogfish	TN2	IV	1,406	80	0.057
Trammel net	Sole, ray, flounder, lobster, turbot, brill, crayfish, monkfish	TR1	IV	393	1	0.003
Trammel net	Cod, bass	TR2	IV	959	0	0
Drift net	Pilchard, herring, cod	DN1	VI	1	0	0
Gill net	Cod, ling, pollack, whitefish	GN2	VI	2	0	0
Gill net	Hake	GN4	VI	324	0	0
Gill net	Dogfish, spurdog	GN6	VI	4	0	0
Tangle net	Ray, monkfish, skate, turbot, dogfish	TN2	VI	57	0	0
Tangle net	Lobster, crayfish	TN3	VI	97	0	0
Drift net	Pilchard, herring, cod	DN1	VII	15	0	0
Drift net	Bass	DN2	VII	22	0	0
Drift net	Salmon	DRT	VII	27	0	0
Drift trammel	Bass, cod, sole, ray	GN1	VII	222	0	0
Gill net	Bass, haddock	GN2	VII	1,000	1	0.001
Gill net	Cod, ling, pollack, whitefish	GN3	VII	348	0	0
Gill net	Mackerel, herring	GN5	VII	2	0	0
Gill net	Sole, crab, plaice, ray, turbot, monkfish, skate	GN6	VII	555	1	0.002
Gill net	Mullet	GN7	VII	124	0	0
Gill net (unspecified)	Mackerel, herring	GNU	VII	75	0	0
Tangle net	Brill	TN1	VII	8	0	0
Tangle net	Ray, monkfish, skate, turbot, dogfish	TN2	VII	1,609	16	0.01
Tangle net	Lobster, crayfish	TN3	VII	89	1	0.011

Trammel net	Sole, ray, flounder, lobster, turbot, brill, crayfish, monkfish	TR1	VII	252	4	0.016
Trammel net	Cod, bass	TR2	VII	5	0	0
Tangle net	Ray, monkfish, skate, turbot, dogfish	TN2	VIII	20	0	0

Mackay (2011), as a NERC-CASE[2] studentship linked to the present project, used generalized linear models (GLM) with a Poisson error distribution and log-link function to investigate which factors were related to highest seal bycatch rates. Although seals were observed bycaught in driftnets, the number of hauls observed in this particular gear type was too few to be modeled. In addition, the majority of observed trammel net hauls did not have information recorded on the mesh size of the outer panel of netting used so these were also excluded from the statistical analysis. Data from gill net and tangle nets fisheries were then modeled separately for each ICES Subarea to account for temporal differences in observer effort in each area. Sufficient data for the model were only available for ICES Subareas IV and VII. Seal bycatch was modeled as a rate, as the number of seals caught per km net hour for each haul. The km net hour is calculated by multiplying the length of net in the water by the soak duration. The results are summarized below. Further details are available at http://hdl.handle.net/10023/1888 (Mackay 2011).

Seal bycatch in ICES Sub-area IV.

The results of an initial model of seal bycatch rates, where data were combined for gill nets and tangle nets, had confidence intervals on retained covariates that were very large and predicted bycatch rates that were higher than those observed. Because 98% of all observed seal bycatch in ICES Sub-area IV occurred in tangle nets, a second model was constructed using data collected in tangle nets alone. These data consisted of 1,356 hauls, after hauls with missing values had been removed and a total of 80 bycaught seals that had been caught in 69 separate hauls. The best fitting model retained the covariates fleet length, depth, season (summer: April-September, winter: October – March), depth, mesh size, year and an interaction between depth and season. Table 15 provides parameter estimates, 95% confidence intervals and p-values for each retained covariate.

Table 15: Parameter estimates, 95% confidence intervals and p-values for each retained covariate.

Covariate	Estimate	95% C.I.	p-value
(Intercept)	-429.268	-736.3 to 460.5	p<0.01
Fleet length (m)	-0.56326	-0.83 to 0.4	p<0.001
Depth (m)	-0.03101	-0.06 to0.04	p<0.05
Season (summer/winter)	4.44273	-1.53 to 8.96	p>0.05
Year	0.21768	0.06 to 0.23	P<0.01
Mesh size (mm)	-0.03026	-0.06 to 0.04	P<0.05
Depth: Season	-0.45914	-0.98058 to 0.78216	p>0.05

[2] Natural Environment Research Council - Collaborative Award in Science and Engineering

There is a significant negative relationship between seal bycatch rates and fleet length, mesh size and depth, and a positive significant relationship between seal bycatch rates and year. This model was then used to predict seal bycatch rates in tangle nets for the most represented value of each retained covariate (Figure 4 -. Fleet length = 184m, effort = 24, Season = summer, mesh = 267, depth = 20, year= 2000).

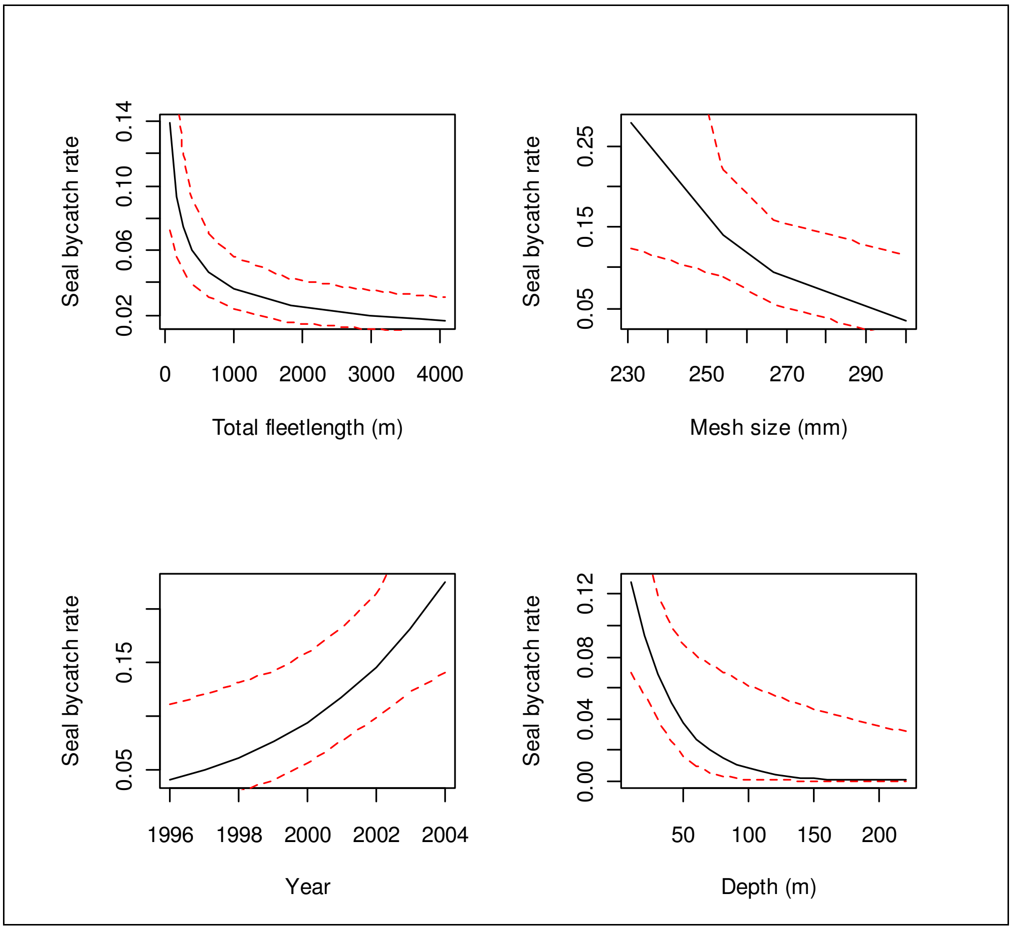

Figure 4: Plots showing the relationship between predictor variables and seal bycatch rates (per km net hour). The red dashed lines indicate the 95% confidence intervals. N.B. y-axis scales are different.

The relationships between seal bycatch rates and fleet length, mesh size, year and depth are driven by the high proportion of seals (94%) observed bycaught during experimental trials conducted in ICES Subarea IV. These trials were conducted between 2000 and 2004, and with highest bycatch rates (per km net hour) occurring in 2003 when fleets of deployed nets were 91 m in length. Average depth during experimental trials ranged from 13 to 25 m, while non-experimental tangle net hauls were observed in waters up to 220 m in depth. Table 16 summarizes the bycatch rate per km net hour of seals observed caught during experimental trials in ICES Subarea IV.

Table 16: Summary of seal bycatch rates observed during experimental trials in ICES Subarea IV.

Year	Average fleet length (m)	Average depth (m)	Effort (km net hours)	No of seals	Bycatch rate per km net hour
2000	114	18	1,057	6	0.006
2001	1,000	16	3,840	6	0.002
2002	1,000	25	5,760	12	0.002
2003	91	20	1,305	24	0.018
2004	640	13	7,168	27	0.004

Seal bycatch in ICES Subarea VII.

In Subarea VII there were 19 seal bycatch observations, all single animals, two in gill nets and 17 in tangle nets. As 89% of all observed seal bycatch occurred in tangle net hauls, a model was constructed using just these data. Due to the relatively low number of seals observed bycaught in tangle nets, to avoid over-parameterisation of the model, a maximum of three explanatory variables were allowed in the final model. The best model retained the covariates year, season (summer: April-September, winter: October – March) and latitude (Table 17).

Table 17: Parameter estimates, 95% confidence intervals and p-values for each retained covariate

Covariate	Estimate	95% C.I.	p-value
(Intercept)	661.9	-311.41 to 1985.69	P<0.05
Year	-0.37	-0.16 to -1.11	P<0.05
Season (winter)	1.97	-0.64 to 5.92	P<0.01
Latitude	1.37	-0.43 to 4.13	P<0.01

Seal bycatch rates had a significant negative relationship with year and a significant positive relationship with latitude. Predicted bycatch rates were also highest during the winter. This model was then used to predict seal bycatch rates in tangle nets for most represented value of each retained covariate (Figure 5 -. Year = 2005, effort = 48, Season = winter).

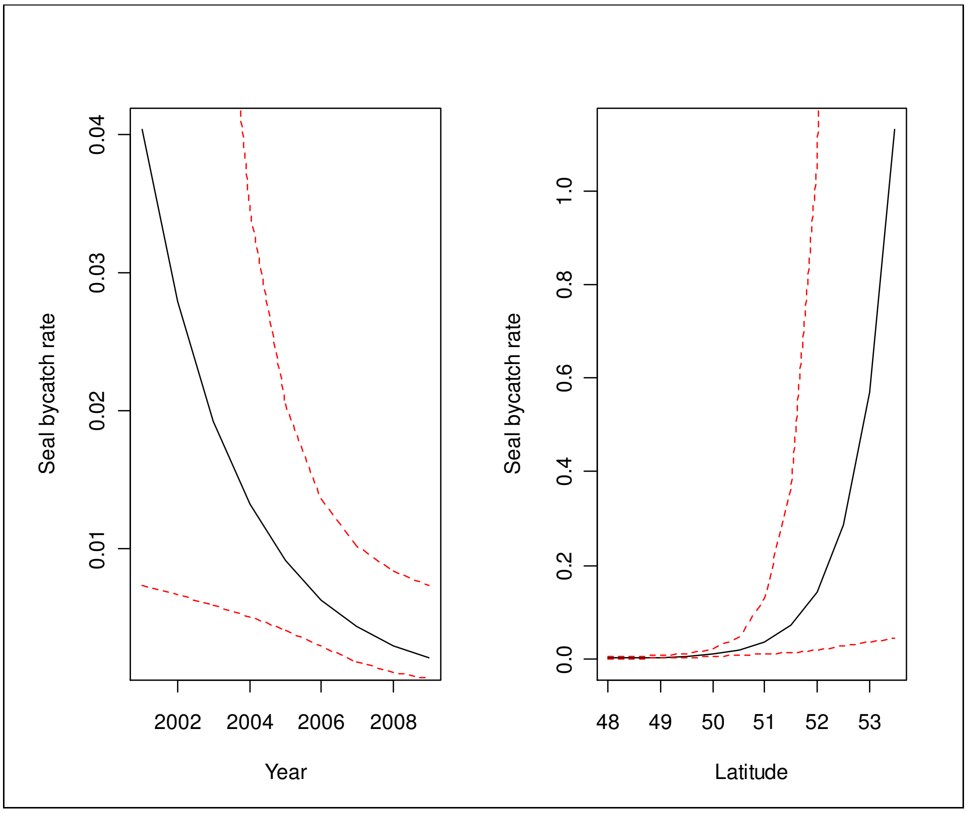

Figure 5: Plots showing the relationship between predictor variables and seal bycatch rates (per km net hour). The red dashed lines indicate the 95% confidence intervals. N.B. y-axis scales are different.

The positive significant relationship between seal bycatch rates and latitude is driven by 9 seal bycatches observed in 95 hauls in ICES Division VIIf (Table 18).

Table 18: Summary observer effort and seal bycatch rates in ICES Subarea VII by depth.

ICES Division	Effort (1000 km net hours)	No. of seals	Bycatch rate per 1000 km net hours
VIIa	0.4	0	0.00
VIId	0.1	0	0.00
VIIe	173	7	0.04
VIIf	95	9	0.09
VIIg	29	1	0.03
VIIh	10	0	0.00

Bycatch rates were highest during winter months (October-March) as a result of the relatively low amount of observed effort during these moths (Figure 6). Likewise the negative significant relationship between seal bycatch rates (per km net hour) is driven by low total observed effort in tangle nets in earlier years (Figure 7).

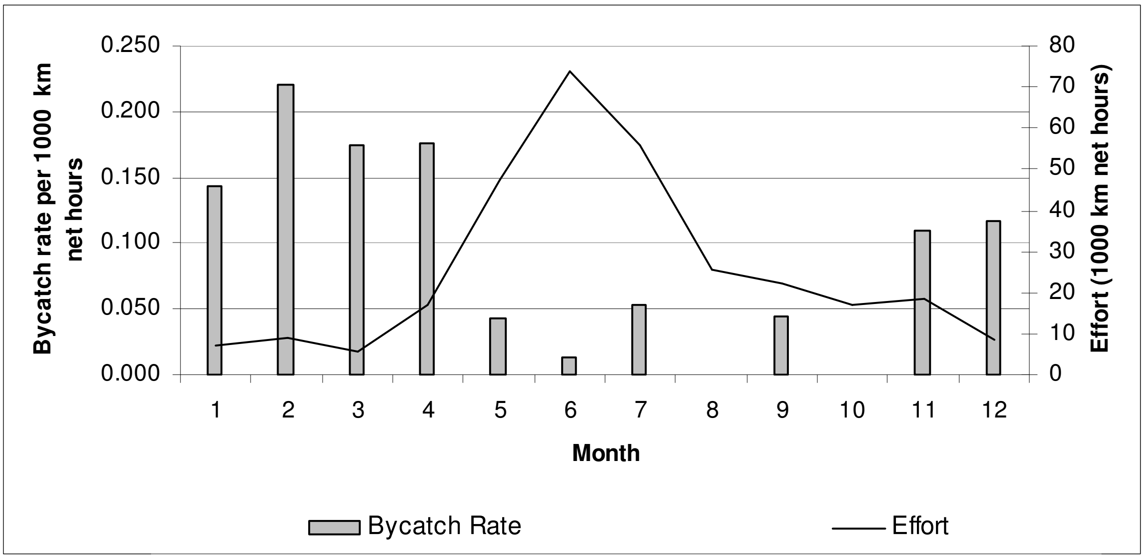

Figure 4: Observed effort and seal bycatch rates per month in ICES Subarea VII

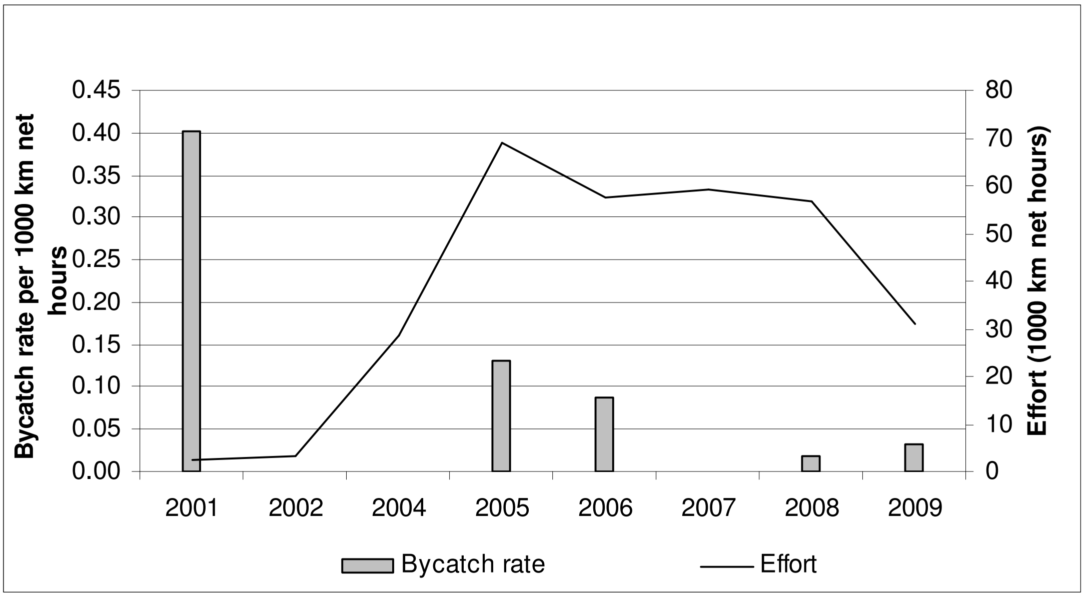

Figure 5: Observed effort and seal bycatch rates per year in ICES Subarea VII

In contrast to ICES Subarea IV, depth was not retained as a significant explanatory variable. Although highest bycatch rates were observed in tangle nets fished between 20-39 m, highest observer effort was in tangle nets fished between 60 m and 80 m (Table 19)

Table 19: Summary observer effort and seal bycatch rates in ICES Subarea VII by depth

Depth (m)	Effort (1000 km net hours)	No. of seals	Bycatch rate per 1000 km net hours
<20	3	0	0.000
<40	16	2	0.126
<60	32	2	0.063
<80	129	8	0.062
<100	121	5	0.041
<150	4	0	0.000
>150	4	0	0.000

Seal bycatch in trawls.

A total of 54 seals were observed bycaught in 1,742 trawl tows. Highest bycatch rates were in ICES Subarea IV with no seals observed bycaught in trawl nets in ICES Subareas II, VII or VIII. Table 20 provides a summary of the number of trawl tows observed and seal bycatch rates by ICES Subarea.

Table 20: Summary of observer effort and seal bycatch rates by ICES Subarea.

ICES Subarea	No. of tows	No. of seals	Bycatch rate per tow
II	10	0	0.00
IV	206	50	0.24
VI	190	4	0.02
VII	1,294	0	0.00
VIII	19	0	0.00

Bycatch was recorded in a total of 14 trawl tows, and the number of seals caught per tow ranged from 1 to 14, with an average of 4 seals per tow (S.E. =1). 53 of the bycatches occurred in mid-water, or mid-water pair trawls targeting herring and 1 bycatch occurred in a mid-water trawl targeting mackerel. Of these, 32 seals (grey seals) were caught in 3 successive tows in a mid-water pair trawl targeting herring in ICES Subarea IV. Table 21 summarises observer effort and seal bycatch rates in mid-water trawl fisheries targeting herring and mackerel in ICES Subareas IV and VI.

Table 21: Summary of observer effort and seal bycatch rates in mid-water trawls targeting herring and mackerel by ICES Subarea.

ICES Subarea	Target species	Trawl gear	No of observed tows	No of seals	Bycatch rate per tow
IV	Herring	Mid-water pair trawl	94	48	0.51
IV	Herring	Mid-water trawl	145	2	0.01
IV	Mackerel	Mid-water pair trawl	19	0	0.00
IV	Mackerel	Mid-water trawl	52	0	0.00
VI	Herring	Mid-water trawl	74	3	0.04
VI	Mackerel	Mid-water pair trawl	64	0	0.00
VI	Mackerel	Mid-water trawl	167	1	0.01

Currently, data are not sufficient to construct statistical models to investigate which factors may be related to seal bycatch rates in trawl fisheries.

Shark bycatch in static net fisheries.

Four large shark species have been observed bycaught in UK static net gears. These are blue sharks, basking sharks, porbeagle sharks and tope. Sharks were observed bycaught in 259 static net hauls. However, the individual number of sharks caught was only recorded for 133 hauls, with the total weight of sharks caught recorded for the remaining hauls. Table 22 provides a summary of the number of hauls in which each species were caught, by net type and ICES Subarea. The number of hauls with shark bycatch includes those hauls where only the total weight of sharks caught was recorded.

Table 22: Summary of the number of individual sharks caught by species, gear type and ICES Subarea.

				Number of hauls with bycatch			
Net Type	**ICES Subarea**	**Total number of hauls**	**Number of hauls with bycatch**	**Basking shark**	**Blue Shark**	**Porbeagle shark**	**Tope**
Drift net	IV	79	1	0	0	0	1
Drift Trammel	IV	227	2	0	0	0	2
Gill net	IV	2553	26	0	0	2	23
Stake net	IV	168	3	0	0	0	3
Tangle net	IV	1406	83	0	0	1	82
Trammel net	IV	1352	13	0	0	0	13
Gill net	VI	330	8	0	0	0	8
Gill net	VII	2251	69	0	3	9	57
Tangle net	VII	1706	43	0	2	4	37
Trammel net	VII	257	11	1	3	0	8
Total		**10329**	**259**	**1**	**8**	**16**	**234**

Tope were the shark species most frequently bycaught in static nets (n=127), and were caught in gill nets and drift nets with mesh sizes ranging from 90-175 mm and in tangle nets with mesh sizes ranging from 241-279 mm. Data were not available on the mesh sizes of the outer walls of trammel nets in which tope were caught. Table 23 summarises tope bycatch rates in static net fisheries by gear type and ICES Subarea. This table does not include an additional 106 hauls in which tope were bycaught, as the number of individual tope caught during these hauls was not available. Highest bycatch rates were observed in tangle nets in ICES Subarea IV.

Table 23: Summary of tope bycatch rates by gear type and ICES Subarea.

ICES Subarea	Gear type	No of hauls	No of tope	Bycatch rate per haul
IV	Drift net	79	1	0.013
IV	Drift Trammel	227	2	0.009
IV	Gill net	2,553	24	0.009
IV	Gill net (unspecified)	23	0	0.000
IV	Stake net	168	3	0.018
IV	Tangle net	1,406	119	0.085
IV	Trammel net	1,352	14	0.010
VI	Drift net	1	0	0.000
VI	Gill net	324	2	0.006
VI	Tangle net	154	0	0.000
VII	Drift net	37	0	0.000
VII	Drift Trammel	27	0	0.000
VII	Gill net	2,197	3	0.001
VII	Gill net (unspecified)	75	0	0.000
VII	Tangle net	1,670	0	0.000
VII	Trammel net	249	0	0.000
VIII	Tangle net	20	0	0.000

Shark bycatch in trawl fisheries.

A total of 7 large sharks of 4 species (and 1 unidentified species) have been reported bycaught in 1,742 trawl tows (Table 24). All bycatches were recorded in mid-water pair trawls. Two thresher sharks were caught in subsequent tows in the bass pair trawl fishery in November 2004. In addition 2 basking sharks were observed exiting through the escape hatch in two tows in the bass pair trawl fishery in which an excluder grid was deployed. A single shark was bycaught in each tow, both escaped alive.

Table 24: Summary of shark bycatch by species and ICES Subarea.

		No of hauls with bycatch	
Trawl gear	Shark species	ICES Subarea IV	ICES Subarea VII
Midwater pair trawl	Basking shark	1	0
Midwater pair trawl	Blue Shark	0	2
Midwater pair trawl	Porbeagle shark	1	0
Midwater pair trawl	Shark - not identified	0	1
Midwater pair trawl	Thresher shark	0	2

Bird bycatch.

Three seabird species (guillemots, cormorants and gannets) have been observed bycaught in 74 hauls observed in UK static nets. All bird bycatches were reported in ICES Subareas IV and VII. Table 25 provides a summary of the number of hauls with bycatch, by species, for those gear types in which bycatch has occurred.

Table 25: Summary of the number of hauls with bird bycatch by species and ICES Subarea.

			Number of hauls with bycatch		
Gear type	ICES Subarea	Total no. of hauls	Cormorant	Gannet	Guillemot
Gill net	IV	2,553	3	1	16
Stake net	IV	168	0	0	3
Tangle net	IV	1,406	0	0	9
Gill net	VII	2,251	8	0	28
Tangle net	VII	1,706	0	0	6

Guillemots were the most frequently bycaught bird species, with a minimum of 99 individuals caught in static net gear. Highest bycatch rates occurred in gill nets, with 14 birds bycaught in one gill net haul. A total of 10 cormorants and 1 gannet were also recorded.

Guillemots have also been observed bycaught in seven tows by mid-water pair trawls in ICES Subarea VII. The number of individuals caught was recorded for six of these tows, resulting in a total of 24 guillemots. Three cormorants have also been observed bycaught in a single haul by a mid-water pair trawler in ICES Subarea IV.

Bird bycatch appears to be very clumped and further analysis and possibly further data will be needed before we will be able to produce reliable estimates of bycatch totals.

Protected fish species.

A number of fish and elasmobranch species in UK waters are protected under national or international legislation. These species are listed by common name in Table 26.

Table 26: List of protected fish species in UK waters

Common Name	Berne Convention	EU Habitats Directive (Annex II)	CITES	Wildlife and Countryside Act
Allis shad		X*		x
Atlantic salmon		x		x
Basking shark	x			
Seahorses	x		x	
Sturgeon	x	X*	x	x
Twaite shad		X*		x

*These species are also listed under Annex V of the EU Habitats Directive.

A total of three basking sharks have been recorded bycaught in observed static hauls and trawl tows in UK fisheries. In addition shad have been recorded in 73 observed static hauls in UK fisheries. Table 27 shows the number of observed hauls with allis and twaite shad bycatch and for unidentified shad species.

Table 27: Summary of shad bycatch by species, static gear and ICES Subarea.

		Number of hauls with bycatch		
Gear	ICES Subarea	Allis shad	Twaite shad	Unidentified shad species
Drift net	IV	4	0	6
Drift Trammel	IV	5	6	2
Gill net	IV	0	0	33
Stake net	IV	0	0	7
Tangle net	IV	0	0	2
Trammel net	IV	0	0	3
Drift net	VII	0	1	0
Gill net	VII	0	1	3

In total 190 shad have been observed bycaught in static net fisheries. The total number of individual shad caught was not recorded for four hauls, instead the total weight of catch was reported. Table 28 provides the total number of individual shad caught by species, gear type and ICES Subarea.

Table 28: Number of individual shad caught by species, static gear and ICES Subarea.

		No of individuals caught		
Gear	**ICES Subarea**	**Allis shad**	**Twaite shad**	**Unidentified shad species**
Drift net	IV	10	0	22
Drift Trammel	IV	10	18	7
Gill net	IV	0	0	106
Stake net	IV	0	0	9
Tangle net	IV	0	0	3
Trammel net	IV	0	0	4
Gill net	VII	0	1	0

Table 29 shows the number of hauls with shad bycatch observed for each year by gear type and ICES Subarea.

Table 29: Number of hauls with shad bycatch by year, ICES Subarea and gear type

Year	Gear type	ICES Subarea	Total number of hauls	Number of hauls with bycatch	Species
1999	Drift net	IV	37	2	shad
1999	Stake net	IV	79	2	shad
2000	Stake net	IV	39	4	shad
2000	Trammel net	IV	111	1	shad
2001	Gill net	IV	74	12	shad
2001	Stake net	IV	15	1	shad
2002	Gill net	IV	103	21	shad
2002	Tangle net	IV	152	2	shad
2007	Drift net	IV	6	4	shad
2007	Drift Trammel	IV	101	8	shad (6 Twaite shad)
2008	Trammel net	IV	30	1	shad
2009	Drift net	IV	36	4	Allis shad
2009	Drift Trammel	IV	73	5	Allis shad
2009	Trammel net	IV	28	1	shad
1998	Gill net	VII	41	1	Twaite shad
2007	Drift net	VII	10	1	Twaite shad
2007	Gill net	VII	297	1	shad
2009	Gill net	VII	466	2	shad

Shad have also been recorded as bycatch in 18 tows by mid-water pair trawls (ICES Subarea VII = 17, Subarea IV = 1). The number of individuals' bycaught was recorded for seven of these tows and were identified as twaite shad or shad. The total number of individual shads caught was 71, 67 of which were identified as twaite shad.

Discussion.

Our monitoring programme has been focused so far mainly on cetaceans. It has not been optimised with respect to other species or taxonomic groups, several of which exhibit clumped bycatches in specific times, areas and fisheries. Consequently we have not extrapolated our observations to fleet levels, because without more detailed analysis of the existing data, and possibly some more targeted or focused data collection, we cannot produce statistically robust estimates.

3. Testing DDDs in set net fisheries in Western Waters.

Background.

EU Council Regulation 812/2004 requires certain vessels >12m in length to use acoustic deterrent devices (pingers) to minimise the risk of accidental capture of dolphins and porpoises in static nets. There are several such devices on the market, and the regulation specifies the characteristics of those that must be used. Although these devices are known to be effective at minimising porpoise bycatch they are not always practical to use (SMRU *et al.* 2001a). Trials by Seafish (Anonymous 2003; Anonymous 2005) in the UK and similar trials conducted by the relevant authorities in Ireland and France (Cosgrove, Browne & Robson 2005; Le Berre 2005) have shown that none of the devices described by the regulation are suitable for fisheries that use long fleets of gill or tangle nets. High levels of damage to and loss of pingers was reported, as were potential dangers to crew members when devices broke during deployment or retrieval.

Part of the problem with the devices specified in the regulation is that pingers are required every 100 m or 200 m of netting. Where fleet lengths of many kilometres are used, pingers cannot be attached and removed from each net panel as and when required – that would take too long and expose crew members to too much risk. Instead pingers need to be attached and left on the nets for the duration of their battery life. This tactic of constant attachment means they often get broken or come away from the gear as the nets are shot or pass through the deck machinery, and often become entangled among the meshes of the nets when stored in pounds on board. The industry therefore suggested using louder pingers with a greater range so that fewer would be needed per fleet of nets. It may then be practical to attach one or two pingers to each fleet of nets (each fleet being generally 2-4 km in length) during shooting and remove them as the gear is hauled, thereby minimising the likelihood of damage to pingers or harm to crew. A suitable pinger (DDD made by STM in Italy) was identified by the SMRU as being loud enough theoretically to enable inter-pinger spacing to be increased up to 2 km, but this device does not conform with the specifications listed in Council Regulation 812/2004.

Under the present project we have therefore tested the applicability of DDDs in the >12m fleet of set gill net and entangling net vessels operating in ICES Subarea VII, as permitted under Article 2 Paragraph 3 of Council Regulation 812/2004, which allows member states to develop new technical measures to reduce the incidental capture or killing of cetaceans.

It should be noted that when Council Regulation 812/2004 was drafted it was not clear that common dolphins were bycaught in gill nets to the extent to which we now know they are and it is not known whether the pingers described in the regulation are effective in minimising dolphin bycatch. One study in California has shown a reduction in common dolphin bycatch in a drift net fishery while pingers were used (Barlow & Cameron 2003b), but this has not to our knowledge been repeated elsewhere for common dolphins in set nets and neither is it clear that the bycatch reduction was more than temporary.

Under the present project we have therefore attempted to deploy DDDs under somewhat controlled conditions among the fleet of boats using set nets in the Southwest of England to determine how well these louder devices work, and to determine any operational problems associated with their use. We had two main objectives with respect to porpoise bycatch – firstly to confirm that these devices were effective in reducing porpoise bycatch by 80-90% as other devices have been shown to be and secondly to try to determine the likely optimal spacing of DDDs on nets. Putting DDDs too close together would be wasteful both economically and in terms of acoustic 'pollution' whereas having them spaced too far apart will likely reduce any mitigation effect.

Boats required to use deterrent devices under Council Regulation 812/2004.

The UK fleet that is required to use acoustic deterrent devices is specified in Annex I of Council Regulation 812/2004, which refers to all vessels ≥12m using any bottom set gill nets or entangling nets in ICES Divisions VIId, e, f, g, h and j. Reference to the UK IFISH database, the official repository of EU fisheries logbook information, suggests that there are around 20 such vessels though the number fluctuates from year to year as vessels are sold on, sink, scrapped or switch gears. In 2010 there were 21 >12m boats that were UK flagged and reported having fished using set nets in the relevant area. Four of these were boats that are owned by Spanish companies and that operate mainly out of Spanish ports and of these two were only present in the relevant area for 6 days in total. Of the remaining 17 vessels, three reported less than 20 days fishing with gill nets in 2010 (1, 14, 18 days respectively) and do not appear to be regular netters. Of the remaining 14, two are day boats that fished for 139 and 31 days respectively in 2010, while the remaining core of 12 vessels made an average of 44 trips with 177 days at sea during 2010. Net fishing in this area is constrained by tides and generally speaking only neap tides are fished, with average individual trip lengths of roughly 4 days.

There are therefore three groups of UK vessels required to use acoustic deterrent devices – day boats (2), boats operating from Spain (2 or 4) and regular netters (12) primarily targeting hake, pollack, and monkfish/turbot seasonally in three distinct fisheries. Of the latter group 8 are based in Newlyn, with 2 based in Grimsby and 2 in Padstow. We have aimed to work with all three of these groups of boats.

Industry concerns.

Industry concerns about the use of pingers have been focused on the fact that when pingers are required on more or less every net, they are liable to malfunction or frequently break. This means that they are ineffective in reducing bycatch and it increases the cost of maintenance dramatically, while also posing a safety risk to crew members. When pingers are permanently attached to the head-rope of a gill net or a tangle net they can become enmeshed in the netting as the net is stowed into pounds or net bins. When the net is shot away again, the pingers may pull bunches of netting out with them, which reduces the net's effectiveness and can be a safety issue for the crew member overseeing net deployment. Attaching pingers to the net as it is being shot is also potentially dangerous and practically speaking very difficult when long fleets of nets are being shot away at speeds of sometimes 7 or 8 knots.

Industry is therefore looking for a solution that would involve deploying far fewer pingers, and preferably only on the end or anchor ropes of each fleet of nets. A simplistic consideration of the spherical spreading loss of the sound propagated by a variety of commercial pingers can be used to explore how increased acoustic output levels might influence the effective operational range of a louder device. In such a scenario we assume that it is the source level (amplitude) alone which influences the response of a cetacean, rather than any other aspect of the signal's characteristics.

In Figure 8 we have plotted the predicted received level of three signals with source levels of 130, 140 and 165dB respectively, crudely mimicking the expected source levels of three different acoustic deterrent devices. Under the assumption of spherical spreading the three devices have an equal received level of about 98dB at distances of very roughly 100 m, 200 m and 2 km respectively. This simple analysis suggests that a DDD may be as effective at 2 km as other pingers may be at 100 or 200 m.

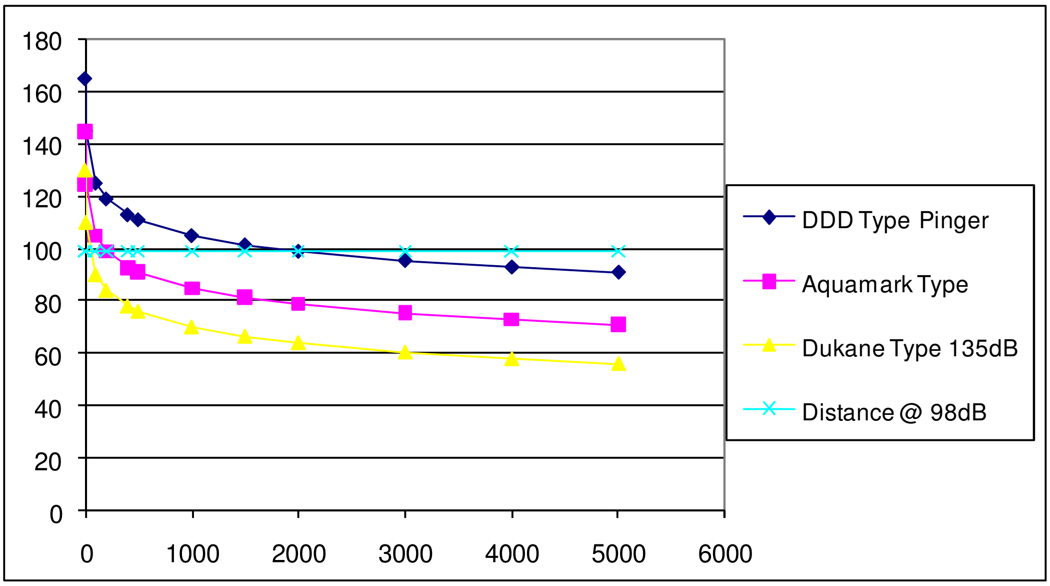

Figure 6: Spherical spreading loss of acoustic signal with distance from source for three pinger types

This consideration led us to propose to industry that DDDs should be trialled on netters to determine their efficacy and handling characteristics.

Methods.

DDDs were ordered from the manufacturer in Italy, and we began making contact with vessels in the gill net fleet shortly after the start of the project and over the summer of 2008. We began the trial by placing DDDs in the middle of each section of 20 net panels, so that for a 40 net fleet DDDs would be placed on net numbers 10 and 30. We also began with a mix of fully observed trips and trips where skippers were asked to keep a log of pinger deployment and bycatches. On some trips all fleets were equipped with DDDs and on other trips with the same boats in the same area no fleets were equipped with DDDs to provide a control.

As the trial progressed it became apparent that this method of working was somewhat impractical. Logistically the collection of skippers' logs became too difficult and skippers and crews were generally unhappy with the placement of DDDs midway along nets. We therefore moved to a scheme whereby DDDs were only deployed on trips with observers who could then keep more detailed records of where and how DDDs were deployed. We also altered the placement of the DDDs to just the end ropes of each fleet, one at each end and approximately 10 m above the anchor. This change in system took place over the summer of 2009. A perceived advantage of the second mode of operation was that we would also now be able to determine the effective spacing of DDDs. Although we had conducted experiments to determine the likely effective exclusion distance of DDDs, this would not necessarily translate into an effective spacing distance in terms of bycatch reduction, so by placing DDDs only at the ends of fleets some of which can be up to 8 km in length we would expect to see some bycatch occurring in the middle of these longer fleets which would provide some insight into the devices effective range. Clearly DDDs need to be spaced close enough to ensure that bycatch rates are significantly reduced, but far enough apart to minimise the cost implications and operational difficulties of attaching devices part-way along the net. Minimising the number of DDDs per fleet, while maintaining their bycatch mitigation effectiveness, will also minimise any collateral effect of habitat exclusion.

Additional funding became available in 2010. This was used to increase our sampling coverage of vessels using DDDs and to roll out DDD deployment to the rest of the fleet. During the three years of the trial additional batches of DDDs were bought and deployed on an increasing number of >12m UK vessels working in the Celtic Sea and Western Channel.

During the trials observers recorded the end positions of each fleet as they were hauled. They also recorded the positions of any bycatch that occurred so that we could calculate the distance to the nearest DDD. Midway through the project we also took delivery of a new testing device from STM to check the battery charge levels within a DDD (standard multi-meters do not work with these devices). Once these were available observers began recording the charge of every DDD at the start and end of each deployment. Details were also recorded for any nets deployed without DDDs, including bycatches and fleet locations (start and end position). Observers also reported on skipper and crew feedback concerning DDD use.

Results.

Observations were made on 15 vessels each of which made between 1 and 18 observed trips using DDDs between August 2008 and April 2011. In addition a number of trips were also observed among these same 15 vessels when DDDs were not used at all. In total 1,906 fishing observations were reported on between August 2008 and April 2011, 1,709 of which were observed by SMRU observers and a further 197 that were recorded by skippers. Overall 23 porpoises, 5 common dolphins and 37 seals (species not determined but presumed to be mainly grey seals) were bycaught. The numbers of hauls observed with and without DDDs and the numbers of marine mammals recorded are given in Table 30.

Table 30: Observations of numbers of mammals in fleets of nets with and without DDDs: all fleet lengths and all DDD deployment types.

No of Hauls	**DDDs Used**	**Porpoises**	**Dolphins**	**Seals**
Observations by SMRU observers alone				
780	No	16	3	8
929	Yes	7	2	29
1,709		23	5	37
All Observations – SMRU and Skippers				
907	No	19	3	8
999	Yes	7	2	29
1,906		26	5	37

Nets with DDDs caught significantly fewer porpoises for the whole dataset whether including skippers' observations (p=0.01: χ^2 Test), or using only SMRU observations (p=0.02). The overall bycatch rate with DDDs is 63% or 66% lower when DDDs are used. None of the bycaught animals was associated with any abnormally low voltage readings for the DDDs on retrieval.

There is no significant difference in the observed bycatch rate of dolphins when DDDs are used, though sample numbers are too small to be confident that this reflects no real difference.

There is an apparently significantly higher bycatch rate of seals in nets equipped with DDDs, but this is misleading. Significance tests assume that bycatch events are independent and usually dolphin and porpoise bycatch events exhibit a binomial distribution with respect to fleet hauls. The data on seals are highly affected by a single extraordinary trip in which 19 seals were entangled. Among the fleets of nets used during this trip, 26 of 28 were equipped with DDDs with one or more seals taken in 7 of these, all of which happened to have been equipped with DDDs. If this trip is excluded there is no difference in seal bycatch rates between hauls with and without DDDs.

The reduction in porpoise bycatch rate by 63-66% is substantially less than has been reported in previous studies with pingers and porpoises, where bycatch rate reductions are typically in the 80%-95% range. This is explained by the fact that many of the nets we observed had widely spaced DDDs that were greater than 4 km apart.

The data described include fleets of nets that were up to 8 km in length, most of which only had DDDs at each end, so that some acoustic deterrent 'dead space' would be expected in the middle of such fleets. None of the dolphins or porpoises caught in nets with DDDs was closer than 1.2 km from the nearest DDD. Table 31 shows the distances to the closest DDD on the same fleet for nets for each of the two dolphins and 7 porpoises listed in Table 30.

Table 31: Distances to closest DDDs on the same fleet of nets.

Species	Distance to closest DDD (km)
Common dolphin	1.3
Common dolphin	2.5
Harbour porpoise	1.2
Harbour porpoise	1.3
Harbour porpoise	1.6
Harbour porpoise	1.9
Harbour porpoise	2.1
Harbour porpoise	2.2
Harbour porpoise	3.1

These data are difficult to interpret. Overall the observed fleets of nets fell into three board categories – short, medium and long with modal values of about 100 m, 4 km and >6 km respectively (Figure 9). The numbers of porpoise taken in each length category of net is then plotted in Figure 10. There is a tendency for porpoise bycatch when DDDs are present (3 instances) to occur in the longer nets – with bycatches in one fleet of 4 km, one of 7 km and one of 7.8 km. This supports the notion that weakly ensonified longer fleets are more likely to take porpoises than shorter fleets that are more fully ensonified.

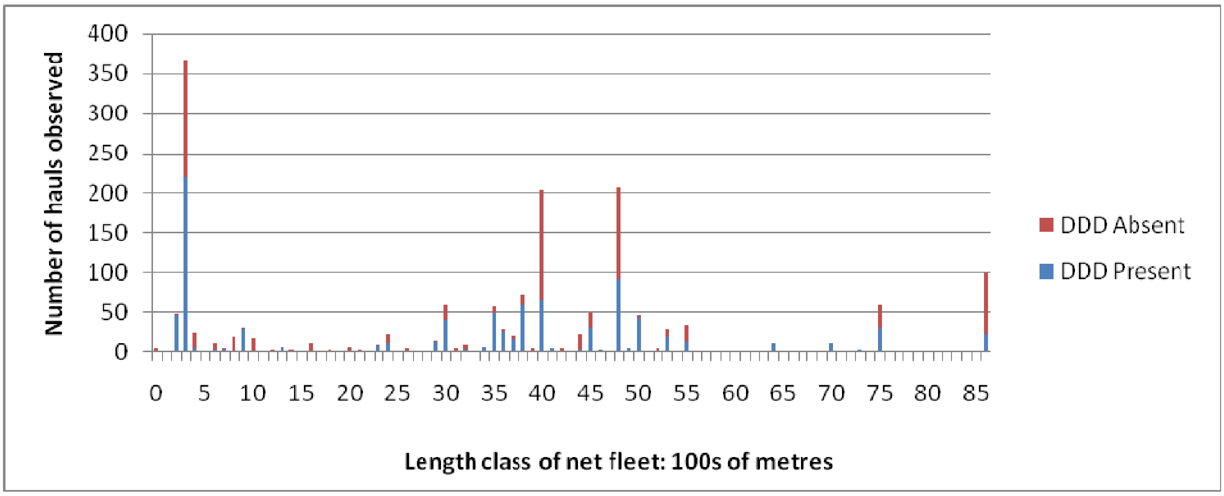

Figure 7: Length frequency distribution of observed fleets of nets with and without DDDs

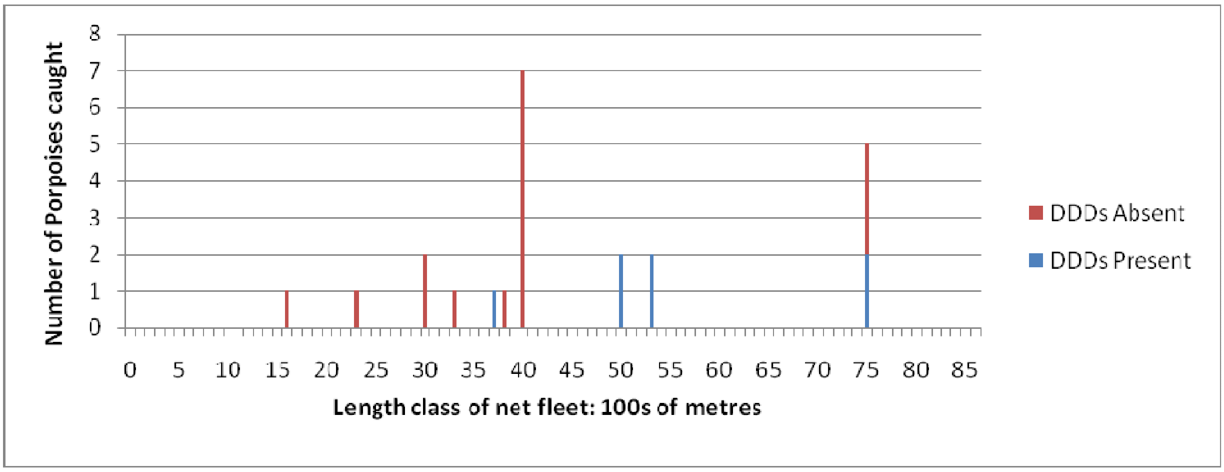

Figure 8 Net lengths in which porpoises were reported caught in 100 m bin lengths.
Note that porpoises caught in nets with DDDs (blue) are predominantly (6/7) in longer nets (>4 km)

A priori evidence (Figure 8) suggests that porpoises should be less affected by DDDs beyond 2 km. An analysis of the observed net lengths has shown us that some 22% of all observed net is beyond 2 km from the nearest DDD, yet 3 of 7 porpoises were taken in such areas. The probability of this having happened by chance was determined by bootstrap simulation to be less than 0.04, indicating that significantly fewer than expected animals are indeed taken within 2 km of a deployed DDD.

Another way to examine this difference in bycatch rates between short and long nets is to consider nets that are up to 4 km in length and those that are longer than 4 km, and to compare porpoise bycatch rates between these two categories. In this case we find that 3 porpoises were caught in 305 'long' fleets without DDDs, while 6 were taken in 973 'long' fleets with DDDs. The rate with DDDs is 37% lower than without DDDs but the difference is not significant. Among fleets of 4 km and less, 13 porpoises were reported caught in 475 fleets without DDDs, while just 1 was taken in 665 fleets with DDDs. When DDDs were used on nets of 4 km or less the bycatch rate of porpoises is therefore much lower ($p=0.0001$: χ^2 Test), with 94.5% fewer porpoises per haul, which is in line with previous studies on the effectiveness of other pingers.

Discussion.

The results presented here show that DDDs are effective in reducing porpoise bycatch. Bycatch was reduced by about 95% in nets less than 4 km in length but by only about 66% among nets of all lengths as DDDs were mostly only applied to the ends of the fleets of nets that we observed. A greater overall rate of reduction could be achieved by shortening the maximum length of net or by placing more DDDs on longer nets. This would require some changes to fishing practices. However, there is clearly a trade-off to be made between optimising uptake within the industry and minimising bycatch rates, while also minimising unnecessary use of acoustic deterrents, which are expensive and will also affect animals beyond the area required to prevent them becoming entangled.

The effects of DDDs on dolphin bycatch rates cannot yet be fully determined because we only observed 5 dolphin bycatches during the course of the trials. Continued monitoring will eventually clarify this point. The closest dolphin bycatch event was 1.3 km from a DDD.

Feedback from industry about using DDDs has generally been positive. Our communications with skippers suggest that they will be prepared to use mitigation devices routinely, provided the system is safe, practical, financially viable and effective at reducing cetacean bycatch. The following paragraphs highlight some of the main concerns expressed by skippers during the trials.

1. Initial concerns were mainly associated with the attachment of pingers in the middle of long fleets of nets which could potentially pose a significant hazard to crew members during shooting operations. As mentioned previously, because of these concerns, we decided during the trial to alter the attachment method and simply deploy pingers above the anchors on the end ropes of fleets. This means that pingers are now deployed at more or less the same time as the anchors, which reduces potential risks and minimises interference with the crews' normal duties. Consequently this approach is favoured by most, if not all, skippers, and will probably continue to be so unless a suitable automatic deployment method for attaching and deploying pingers in the middle of fleets can be devised.

2. Regulation 812/2004 currently requires all >12m netters working in ICES Divisions VIIdefghj to use pingers regardless of the specific net type in use. However a number of skippers have questioned the need to use pingers when they are working short fleets of wreck nets which they claim have very low incidences of bycatch in the Celtic Sea and Channel. This claim is supported by observed bycatch rates from wreck netters albeit from fairly limited sampling levels.

3. In the early stages of the trials a couple of skippers suggested a possible link between DDD use and reduced fish catches and/or possible increased seal depredation from nets. Our data to date do not show any clear difference in the proportion of fleets that experienced seal damage when DDDs were used or not. Nevertheless this remains an issue that should be monitored closely.

4. Voltage data indicate that a single full charge should allow DDDs to be used over the duration of a typical neap tide (roughly 7 days), so in theory pingers could be charged ashore between tides. However there are certain times of year when vessels may work through smaller spring tides and in these instances ideally vessels would have a suitable charging system on board which is currently not available.

The DDD pinger, despite not meeting the current specifications required by Regulation 812/2004, would appear to provide the most suitable existing solution to pinger implementation in the UK based >12m netting fleet operating in ICES Subarea VII. Since 2009, when some skippers were taking DDDs to sea and recording observations for us, all pinger deployments have been under the supervision of our observers so that we could be clear about what pingers were being used where. One vessel has recently been supplied with a full complement of DDDs and as far as we are aware is now using them routinely. We intend to provide the rest of this fleet with DDDs in the coming months after further discussions with industry, Defra and the MMO on aspects of implementation, enforcement and best practice.

The approach of attaching pingers only to the end ropes of fleets may not, depending on the fleet length, provide the optimum acoustic deterrent. However, if all vessels in the fleet adopted this approach with continued observation, it would be possible, over time, to determine with a greater degree of confidence the expected bycatch reduction rates for both porpoises and dolphins at different pinger spacing's.

We have carried out one 45 day trip on an Anglo/Spanish netter which trialled the DDDs, albeit mainly in ICES Subarea VI. Feedback from the owner and skipper was relatively positive. However this vessel, like others in this fleet, tends to work mainly in deep water on the continental slope, outside the normal foraging depth range of most small cetaceans. The skipper thinks that when bycatch does occur the animals are caught as the gear is being shot, rather than when the net is lying on the seabed, and suggested that a more sensible approach for this fleet might involve having a powerful pinger attached to the boat to deter animals from the vicinity during shooting operations. This vessel is open to further collaboration to test such a device.

4. Mitigating dolphin bycatch in the bass pair trawl fishery.

Introduction.

The pair trawl fishery for bass has been studied and monitored with the aim of developing measures to minimise bycatch of common dolphins since 2001, when the SMRU was approached by industry to assist them in this task. The fishery is operated typically by just two pair teams, and runs sporadically from November to April primarily in the Western Channel. Boats may switch between gears for various other species, even within trips, depending on bass catch rates. Annual fishing effort is typically measured in tens to a few hundred fishing operations (Range 0-493).

Observations from previous years have shown that the bycatch rate in unmodified pelagic pair trawls in this fishery is very high, with mean bycatch rates of around 1 common dolphin per tow. Trials with exclusion devices showed some promise between 2003 and 2006, but were curtailed in 2006 after destructive intervention by an animal welfare organisation. Instead, DDD acoustic deterrents were used and these seemed to show an immediate and positive effect in reducing bycatch. The fishery did not operate in 2007-2008. We have therefore not pursued Objective 5, which would have involved pursuing trials with the exclusion devices, which are logistically and financially much more challenging than work with pingers.

The current project has covered three winter seasons of the bass fishery, 2008/9, 2009/10 and 2010/11. Reporting deadlines preclude any analysis of the 2010/2011 winter season as no fishing occurred in this season until February 2011. Our report therefore summarises work done in the preceding seasons, and places this in the context of work that was initiated in 2011.

Methods.

During the present project we have continued to monitor bass pair trawl teams to the maximum extent possible during the winter seasons of 2008/9 and 2009/10. We have mainly been working with one pair team of <15m boats since 2006. A second pair team operated in the 2008/2009 season and they approached us for DDDs and for observers. We monitored all their trips in that season, but they did not fish in 2009/2010. During the 2009/2010 season a third pair team became involved and they also approached us and asked to use DDDs and to take an observer. We also monitored all hauls by this pair during 2010 as well as all those by the smaller pair team during both seasons.

Most tows were equipped with two DDDs, but different models have been used. In 2009-2010 the smaller pair team was using DDD-02Fs first bought in late 2006 and by now over three years old. The larger team was equipped with new DDD-03Hs. According to the manufacturer the signal characteristics of the DDD-02 and those the DDD-03 are the same, but battery management hardware has been improved. We have not yet verified this by independent comparison of the acoustic signals. Observers record the use of DDDs, where they are placed, and check that they are working before and after deployment. More recently with the introduction of testing devices, the charge level is also recorded before and after deployment.

Results.

Overall, bycatch levels have been greatly reduced in this fishery since the winter of 2006/2007 when we began to use DDD-02Fs. Table 32 shows the overall pattern since 2001. Figure 11 shows the bycatch rate by season.

Table 32: Observations and Observed Bycatch by Season

Winter Season Ending	Days	Trips	Hauls	Dolphins	Rate per tow
2001	57	10	92	52	0.565
2002	50	14	91	9	0.099
2003	76	16	113	27	0.239
2004	98	26	136	169	1.243
2005	133	39	176	176	1.000
2006	61	21	53	77	1.453
2007	15	5	34	8	0.235
2008	0	0	0	0	0.000
2009	23	10	28	2	0.071
2010	133	41	188	28	0.149
TOTALS	**646**	**182**	**911**	**548**	**0.602**

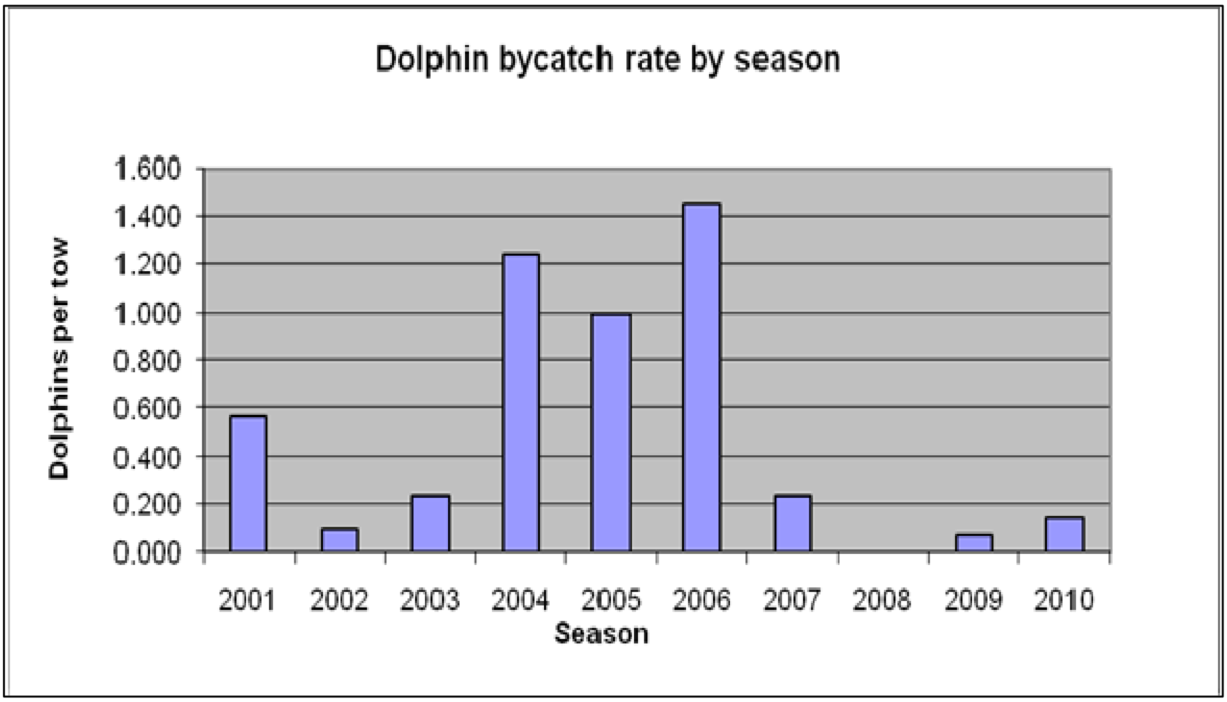

Figure 9: Bycatch rates by fishing season

After the introduction of DDDs to this fishery in the 2007 season (in Dec 2006) most observed tows have been conducted using DDDs, though not necessarily always in a consistent manner. We are not aware of any pair trawling for bass in 2008 due to the relative scarcity of fish and high fuel costs. During the 2007 and 2009 seasons 62 tows were monitored, and DDDs were used on 56 of these. Three of the 56 tows with DDDs in place resulted in dolphin bycatch of 10 (7+1+2) common dolphins. In two of these tows one or both pingers were not working. In the third of these tows our observer reported that the pingers had been placed in a suboptimal position on the gear close to the surface. The manufacturer recommends that the devices should always be deployed in at least 10 m of water for the acoustic signal to propagate properly. It is not clear how many other tows may have involved the use of DDDs close to the headrope, but this issue is now being recorded more carefully and skippers have been made aware of the issue.

Overall the bycatch rate in tows with DDDs during 2007-2009 was 0.178 dolphins per tow, compared with 0.772 dolphins per tow overall for the previous seasons (2001-2006), a 77% reduction in bycatch rate. The lower rate may be attributed to the use of pingers, but the absence of any significant number of control tows (tows without DDDs) with associated bycatch prevents us from being sure on this point, because it is conceivable that after 2006 the bycatch rate had simply declined independently of the use of pingers. On the other hand, if DDDs are effective, it could be argued that the three instances of bycatch during 2007 and 2009 can be attributed to specific problems with DDD deployment.

During the most recent season for which we have collated data (2009-10), two pair teams were observed for the duration of the fishery and we believe that all bass pair tows were observed. Overall we observed 188 tows, with 9 dolphin bycatch events involving 28 animals.

DDD-03s were only available for one of the vessels in the new pair team, which resulted in observations of 23 'control' tows by this pair team without DDDs, during which 4 bycatch incidents were recorded involving 10 dolphins, a rate of 0.435 animals per tow. A further 34 tows with DDDs resulted in no bycatch. Whichever way this result is analysed there is a very significant difference between the bycatch rate with and without DDDs ($p<0.002$ using a bootstrapped binomial test).

On their own these results would have been straightforward and clear cut. However, the pair team using the older DDD-02s yielded more equivocal results in the 2010 season. 131 tows were observed – 123 using DDDs and 8 not using DDDs. The 131 'DDD tows' resulted in 5 bycatch events involving 17 dolphins. The remaining 8 tows during which active DDDs were not deployed for one reason or another, resulted in 1 bycatch event and 1 animal (see Table 33). Although the number of animals per tow are not significantly different between these two sets of data, a consideration of bycatch events (ignoring the number of animals present in each event – as individuals are unlikely to get caught in a statistically independent manner) again suggests that the DDDs may have an effect in reducing dolphin bycatch. The probability of encountering 5 or fewer bycatch incidents among a sample of 123 tows where the underlying probability of bycatch is 1/8 was estimated at 0.014 based on a bootstrap simulation. However, this does not alter the fact that the total number of animals caught per tow was still no lower when the DDD-02s were used by one pair team.

Table 33: Results of DDD trials in the bass pair trawl fishery 09/10.

Trawler Pair Team	1	2	1	2
DDDs in Use?	Yes (DDD-02F)	Yes (DDD-03H)	None	None
No of Tows Observed	123	34	8	23
Dolphins	17	0	1	10
Bycatch Events	5	0	1	4
Dolphins per Tow	0.138	0.000	0.125	0.435

This result was surprising because previous observations have led us to believe that the DDDs, if used correctly, may be close to 100% effective. Discussion with the observers involved in these operations led us to question whether or not the DDD02s were functioning correctly. In order to check pinger functioning we took delivery of several of STM's Voltester devices in March 2010 and then asked observers to monitor the DDD voltages (an indication of how well they are holding their charge) before and after deployment. Two subsequent bycatch events were associated with lower than expected voltage readings when the devices were recovered. Discussion with STM suggests a finite life of the internal (sealed) batteries, and we may therefore have reached the end of the life of those DDD-02s that were first deployed in 2006.

We have subsequently tested 5 of the DDD-02s that have been used in the bass fishery since 2006, as well as some new DDD-03s. After 24 hours on a charger the latter devices all registered a voltage of between 6.9 and 7.1 volts, as expected. Of the five older DDD-02 devices, two would not hold any charge at all over the 24 hours, while the voltage readings of the remaining three were 6.2v, 5.9v and 5.0v. The manufacturer's handbook suggests that a reading of at least 6.0v is required for effective acoustic deterrence. We have not yet tested the relationship between voltage and signal strength or other signal characteristics but these observations confirm that the devices being used by one of the two pair teams had passed their useful life expectancy.

This is an important finding because it suggests that DDDs should not be used for longer than three seasons in this fishery.

Discussion.

Overall, bycatch rates in the bass pair trawl fishery remain very low compared with previous years, yet bycatch events occurred more frequently in the 2009-2010 season than we would have expected given the extent of DDD use. We conclude that this is because the internal rechargeable batteries are no longer working in the older DDD-02Fs. The simultaneous trial of newer DDD-03H devices shows that DDDs can be effective and that bycatch rates are significantly lower when they are used correctly. Table 34 demonstrates that despite the malfunctioning devices used in the 2009-10 season, some 39 fewer dolphins died in bass pair trawls (28) than would have done if no devices had been used (67). If all tows had used new DDDs, we would have expected a zero bycatch this season based on the observations that were made.

Table 34: Observed and expected dolphin bycatch based on 2009-10 observations.

Mitigation Measure Used or Supposed	Tows this season	Dolphins	Bycatch Tows
Tows using DDDs	157	17	5
Tows not using DDDs	31	11	5
Season's totals	**188**	**28**	**10**
Expected if no DDDs had been used	188	67	30
Expected if all tows used new DDDs	188	0	0

Looking Forward.

The use of acoustic deterrent devices to reduce cetacean bycatch in fisheries is notoriously hard to implement in an effective way. The results of the 2009-10 season demonstrate that DDDs are effective in reducing bycatch. This re-enforces conclusions drawn from more limited data collected in 2008-2009 and in 2006-2007. At this stage we cannot be sure of the extent of the expected reduction, in part because observations have been confounded by operational and technical problems with the use of DDDs. The results of three seasons' monitoring (2006-7; 2008-9 and 2009-10) have shown three potential problems with implementing these devices as a mitigation measure:

1) Devices may not always be properly charged or working when deployed
2) Devices may be placed too close to the surface
3) Devices may be degrade after three years and are unable to hold adequate charge

A code of best practice in this fishery should therefore address these points and ensure that DDDs are fully charged, functioning and deployed on the lower wing ends or bridles of the trawl. However, we cannot yet be sure that we have identified all of the potential deployment problems inherent in using these devices and a full season of clean tows would be required to ensure that this is the case. The 2010-11 seasons' observations may yield further insights once the data have been collated.

It is also the case that few if any mitigation measures can be relied upon to be 100% effective anyway. As yet we do not know exactly how effective DDDs are in reducing common dolphin bycatch in the bass pair trawl fishery, but we can speculate: we have observed 56 tows during the 2007 and 2009 seasons where DDDs were deployed. Of these 56, there were 12 tows in January 2009 during 5 trips that yielded one bycatch event involving two animals, but the DDDs were placed close to the surface in some if not all of these tows and we are therefore uncertain where all the DDDs were placed during these trips. If these 12 DDD-02 tows in 2009 are ignored, and we add just the observations of the DDD-03H devices from the 2009-2010 season then we have a further 34 tows without bycatch. Ignoring the 12 tows in January 2009, and all the DDD-02 tows in the 2010 season, we would have observed 78 tows without bycatch in tows where we are sure we had functioning and correctly placed DDDs.

Based on these observations of zero bycatch a statistical analysis suggests that a bycatch rate of less than 0.037 bycatch events per tow is likely (95% level of certainty). This compares with a current observed rate of 0.161 bycatch events per tow (5 events among 31 tows) without DDDs in 2010 (both pair teams). A simplistic assumption would therefore be that the bycatch rate in tows with DDDs is at least 77% lower than in tows without DDDs, noting that this implied rate of reduction can only improve if further observations of tows with DDDs result in no dolphin bycatch.

However, the comparison between DDD and control tows proposed here may be considered invidious because we have selectively excluded tows where we believed there were technical or operational problems with the DDDs.

Further tows will be needed under stable deployment conditions to provide a more robust estimate of the level of bycatch reduction and the rate of bycatch that we might expect with fully functioning DDDs. Ideally and with no ethical or welfare considerations, background bycatch levels should also be determined during the same time period by monitoring tows without DDDs. This is difficult to justify from an ethical perspective, and was only achieved in 2009-10 accidentally. Continued monitoring will help define the upper limit of the bycatch rate when properly functioning DDDs are deployed in this fishery.

5. Wider implications of pinger use.

Concerns – expense, enforcement and collateral impact.

Concerns about the use of pingers abound (Dawson, Read & Slooten 1998). From an industry perspective, pingers are expensive for gill netters who may require tens or hundreds of devices according to the current EU Council Regulation 814/2004. Expense is less of an issue for trawlers who will only require three or four at a time. DDDs may help address this concern for gill netters as their use would drastically reduce the numbers required by an individual gill net vessel.

There are also well founded concerns about reliability and durability of several models which have not necessarily been tested in the rigorous environment in which they are expected to be used. Again, using DDDs attached to end ropes, attaching and detaching at each operation may help address this.

Battery management is also a concern. The logistical complexity of trying to ensure that tens or hundreds of devices are all kept with charged batteries is hard to imagine. Devices that do not require battery replacement (such as the Aquamark devices) may therefore have an advantage. Although rechargeable devices such as the DDD may prove easier to manage than those that require battery replacement, once there are more than two or three such devices that need recharging, another logistical challenge needs to be confronted. DDDs are supplied either with a single charger or with a 4-way multicharger. The former devices quickly become unmanageable when more than a few devices need to be charged. The latter, while a good idea in principle, did not prove very robust when used at sea. A more reliable prototype was sourced from an electronic company in Scotland to be able to charge 8 devices at a time, but the cost of producing these worked out to be prohibitively expensive. DDDs like all devices with rechargeable internal batteries have a limited lifetime. We estimate this is about three years. This is similar to the sealed Aquamark devices.

Enforcement is another concern that is being addressed in several other countries, notably Germany, Denmark and the USA. The current EU Council Regulation 814/2004 requiring pinger use will be hard to enforce legally, as it will always be difficult to determine whether a non-functional pinger found on a net has only recently stopped working. If Regulation 814/2004 is to be enforced effectively, then enforcement agencies will need to develop strategies for addressing compliance.

A final concern about pinger use relates to the possible 'collateral damage' caused by introducing yet more acoustic energy – in this case specifically intended to deter cetaceans from an area, into an already very noisy environment. If pinger use becomes widespread, and particularly if pingers were ever to be required or proposed for the large number of <12m vessels in Europe, then it is conceivable that the combined effect of tens of thousands of pingers might effectively deny some part of certain cetacean populations access to foraging sites. In the remainder of this section we address these concerns first by estimating the amounts of netting being used in one of the more significant areas of interest- the Southwest of England and specifically in Cornwall, and secondly by examining how the expected deterrent effect of pingers might impact the overall foraging habitat area for porpoises and dolphins under different pinger usage scenarios.

Estimates of the amounts of netting in use in the Southwest of England.

In order to estimate the amount of netting in use in the Southwest of Britain, we adopted two approaches. In the first we used official landings and logbook data to estimate the number of trips per month (for 2008) by UK boats targeting 6 different species or species groups. These were tangle nets (estimated from the number of trips where typical tangle net species such as monkfish, turbot, spider crabs were the most important species landed by netters), sole, hake, cod, driftnet species (as reported in logbook and landings records) and a 6th category of 'other' target species. Effort was estimated for the entire fleet fishing in ICES Divisions VIIefghj and the proportion of effort (days at sea) attributed to each of the six categories was used to gain a picture of monthly changes in net types. This is shown in Figure 12.

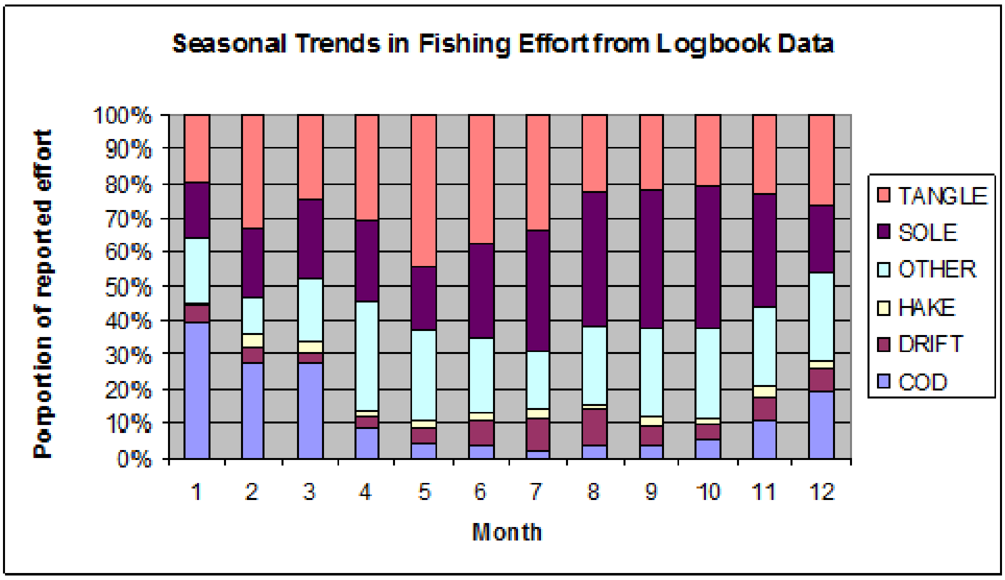

Figure 10: Changes in the proportion of effort by métier in Southwest static net fisheries

Tangle net effort peaks in May, while sole netting peaks in late summer and early autumn. Cod netting is highest in winter. Each of these sub-fisheries employs different fleet lengths. Drift nets and cod nets are typically fairly short, while tangle nets are normally relatively long.

We then used our observer data to estimate the mean lengths of net deployed per day from the number of fleets of nets hauled per day, and the average soak time and fleet length by target category. The logbook and landings records give the number of days the entire fleet was at sea. Using these data we therefore estimated the length of net likely to be in the water per day during each month.

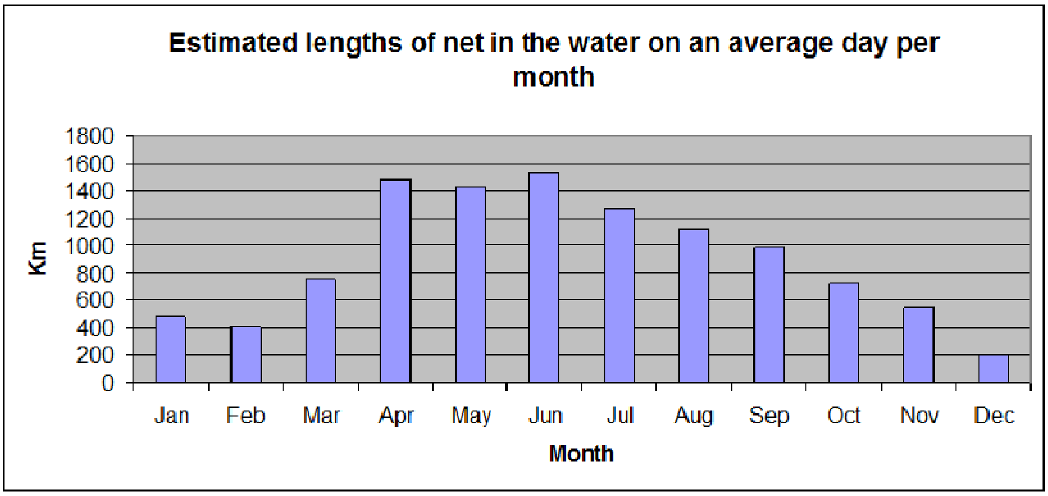

Figure 11: Changes in the proportion of effort by métier in Southwest static net fisheries

From this we estimate that on a typical June day around 1500 km of net may be in the water in the Western Channel and Celtic Sea (Figure 13).

This method of estimation is crude as it does not take account of differences in net usage by different length categories of vessel. Larger boats tend to use more nets, and we have simply taken the mean length by category from our observer database, and may therefore have an unquantified bias – probably towards larger boats which are disproportionately represented in our database.

A second approach involves using questionnaire data. As part of a PhD project, one of our team (AK) has interviewed the skippers from a sample of Cornish inshore boats, which represents the main gill netting fleet in terms of vessel numbers. Information on net lengths, types and seasonality was collected from 81 boats, or 26% of the 310 vessels that used static nets in Cornwall in 2009. Vessels were grouped into length classes: <8m, 8-10m and 10-12m. A further category was for boats that mainly use nets (n=36), and those that use more than one gear type but work some nets (n=45). A distinction was also made between those boats fishing off the north coast of Cornwall and those on the south coast, as the nature of the fisheries in these two areas are different. Because netting is seasonal, vessel skippers were asked about the amounts of netting used by quarter. Landings and logbook effort from the IFISH database were then used to obtain numbers of boats using nets mainly and sometimes, by length category, season and region. Mean sample values were then used to estimate the total number of nets used for the entire fleet. A summary of these estimates, broken down by region (north or south), by size class and quarter is shown in Table 35.

Table 35: Estimates of the amounts of netting in use.

Area	Size Class	Quarter	No of boats	No of fleets	Km net used
N	<8m	1	15	55	33
N	<8m	2	34	83	68
N	<8m	3	47	119	89
N	<8m	4	31	102	58
N	8-10m	1	17	100	70
N	8-10m	2	24	215	215
N	8-10m	3	29	263	256
N	8-10m	4	27	195	160
N	10-12m	1	8	38	36
N	10-12m	2	6	17	22
N	10-12m	3	4	13	18
N	10-12m	4	5	14	19
S	<8m	1	104	479	337
S	<8m	2	168	708	546
S	<8m	3	189	803	537
S	<8m	4	162	811	535
S	8-10m	1	100	926	586
S	8-10m	2	97	866	724
S	8-10m	3	95	785	654
S	8-10m	4	79	767	521
S	10-12m	1	16	135	160
S	10-12m	2	19	103	185
S	10-12m	3	20	99	170
S	10-12m	4	13	93	102

Table 35 shows that there is much more static net effort on the south coast compared to the north, that there are more nets being used in quarters 3 (N coast) and 2 (S coast) and that there are relatively few boats in the 10-12m category (maximum of 28).

Examining just the peak quarters, the maximum amount of netting deployed by these sectors is likely to be around 1,800 km distributed among about 2,000 fleets of nets (Table 36). This figure is slightly higher than that obtained under the preceding estimation (1,500), even though it does not include estimates for the 20 or so >12m vessels.

Table 36: Maximum amounts of netting likely to be deployed by <12m boats in Cornwall.

Coast of Cornwall	Quarter	No of boat-métiers[3]	Max no of fleets of nets	Max length of netting
N	3	80	362	394
S	2	284	1,456	1,677
Total		364	1,818	2,071

Extrapolated costs.

The cost to the fleet will depend on a number of factors that include: which type of pinger will be used, what spacing is required, which parts of the fleet will be required to use pingers, and whether or not pingers can be attached to the net at each deployment or need to be left on the headline permanently. If we assume that pingers can be removed from nets on a quarterly basis and that the amounts of netting used in the peak quarters represent all that need to have pingers attached then we can make some estimates of costs under a variety of scenarios.

We will assume here that the fleet might use Fumunda pingers, Aquamark pingers or DDDs. The prices for these devices depends to some extent on what quantities are being purchased, but we assume here that the costs are those listed in a recent ICES workshop report (Anonymous 2010) at 67, 80 and 200 Euros respectively for the three devices or about £60, £70 and £175.

We can assume that Fumunda devices might be used at either 100 m or 200 m spacing, that Aquamarks might be used at 200 m or 400 m spacing, and that DDDs might best be used at 2 km spacing, or one per fleet of nets if the fleet is less than 3 km in length. No fleets of more than 3 km were recorded in the <12m survey. We might then consider the consequences of other parts of the gill net fleet in Cornwall adopting pingers. The results of these permutations are given in Table 37.

In order to estimate the total cost to the Cornish fleet we have also included information from the >12m vessels, based on our understanding of their operational characteristics, to estimate the maximum potential amount of netting that each might deploy, and therefore the maximum number of pingers each might require. This produces some figures that are much higher than the preceding estimate based on logbook and observer records alone.

Totals for the entire fleet using the information on maximum potential net usage based on interviews and personal knowledge of the fleets concerned, and the possible maximum number of pingers that could be used by each fleet segment are shown in Table 38.

[3] Some vessels counted twice if they are using more than one sort of nets in this quarter, as it is possible they may be working two sets of nets simultaneously and require two sets of pingers; 310 boats in population

Table 37: Number of vessels by length category, maximum potential net usage at any one time, and potential pinger requirements for different spacings.

				Spacing intervals[4]				
Length category	No of boats	Max Km netting	Max No of Fleets	100 m	200 m	400 m	2 km	4 km
>12m	21	1,400	251	14,000	7,000	3,263	502	705
10-12m	11	207	119	2,070	1,035	358	119	119
8-10m	89	939	1,081	9,390	4,695	2,161	1,081	1,081
<8m	210	626	921	6,260	3,130	921	921	921
All	331	3,173	2,373	31,720	15,860	6,703	2,624	2,827

Table 38: Costs for three different pinger types at spacings appropriate for each pinger type.

		Fumunda		Aquatec		DDD	
Length class	No of boats	100 m	200 m	200 m	400 m	2 km	4 km
>12m	21	£1,106,000	£553,000	£637,000	£296,933	£160,035	£113,954
10-12m	11	£163,530	£81,765	£94,185	£32,578	£27,099	£27,099
8-10m	89	£741,810	£370,905	£427,245	£196,651	£245,365	£245,365
<8m	210	£494,540	£247,270	£284,830	£83,811	£209,159	£209,159
All	331	£2,505,880	£1,252,940	£1,443,260	£609,973	£641,658	£595,577

These costs and pinger totals are likely maximums, as we have probably over-estimated the total amounts of netting that might be used. Nevertheless they provide some guidance as to the possible scale of the cost to the industry if pingers were mandatory on different segments of the fleet. These figures relate to Cornish boats only.

Potential impacts on cetaceans.

The use of pingers presumes that the devices will deter animals from the surrounding area so that they do not come close to the sound source or the net to which it is attached. Experimental studies using passive acoustic monitoring have shown the exclusion effect of DDDs during two studies in 2007 and 2008 respectively. Both studies were conducted in April, one under MF077 and the second under the present project. Both studies involved deploying 6 T-Pod acoustic monitoring devices arrayed at various distances around a short string of nets to which a DDD was attached. The DDD was then removed after two weeks, then replaced and

[4] 100 m and 200 m spacings assuming one pinger per net or one every other net. 400 m spacings and above – most parsimonious layout for average fleet length

removed again[5]. There were two exposure periods and two control periods. The number of 'click-positive minutes' – that is minutes when either dolphin or porpoise clicks were detected with a 24 hour period were then compared at each locations and the results compared between DDD deployment and control periods. The ratios of click positive minutes during deployment to click positive minutes during control periods for the two studies are shown in Figure 14 and 15 for 2007 and 2008 respectively. The results suggest that porpoises and dolphins were excluded to at least 1.2 km, and by extrapolation possible to 2km during 2007, but in 2008, the deterrent effect seemed even stronger, with a click ratio of less than 1 even at 3 km from the source. We cannot explain this difference.

A third trial to quantify the exclusion effect of DDDs was planned in conjunction with a similar trial to test the deterrent effect of Aquamark pingers in St Andrews Bay in the autumn of 2010. The Aquamark trial, done in collaboration with the Danish National Institute of Aquatic resources was completed successfully, but we relied on local fishing vessels to deploy and retrieve the gear. This proved logistically difficult with very sporadic fishing and by the time we had finally recovered all the Aquamark devices, the present project was due to end. The results of the Aquamark trails are still being analysed in Denmark, but preliminary results suggest that the Aquamark devices have an effect on porpoises out to about 400 m. A preliminary report is provided by Lotte Kindt Larsen of DTU-Aqua in an Annex to this report.

Taken together these experiments suggest that Aquamarks may exclude porpoises to 400 m, though it should be noted that exclusion is not complete but rather decreases with increasing distance from the sound source. The fact that some effect in terms of reduced echolocation was detected at 400 m does not mean that animals are excluded to 400 m. Similarly with the DDD experiments, partial exclusion may extend to as much as 3 km, but even within this radius of a DDD, some animals remain.

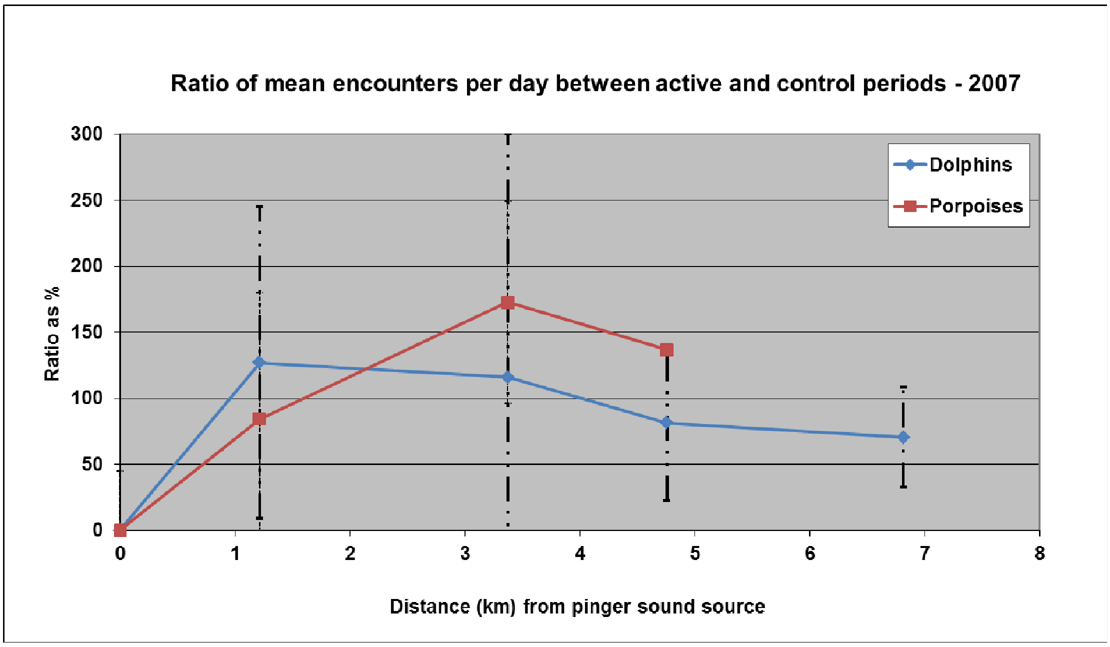

Figure 12: 2007 experimental exclusion trials off the Lizard, Cornwall.

[5] Appropriate permissions were obtained from Natural England to 'disturb' cetaceans

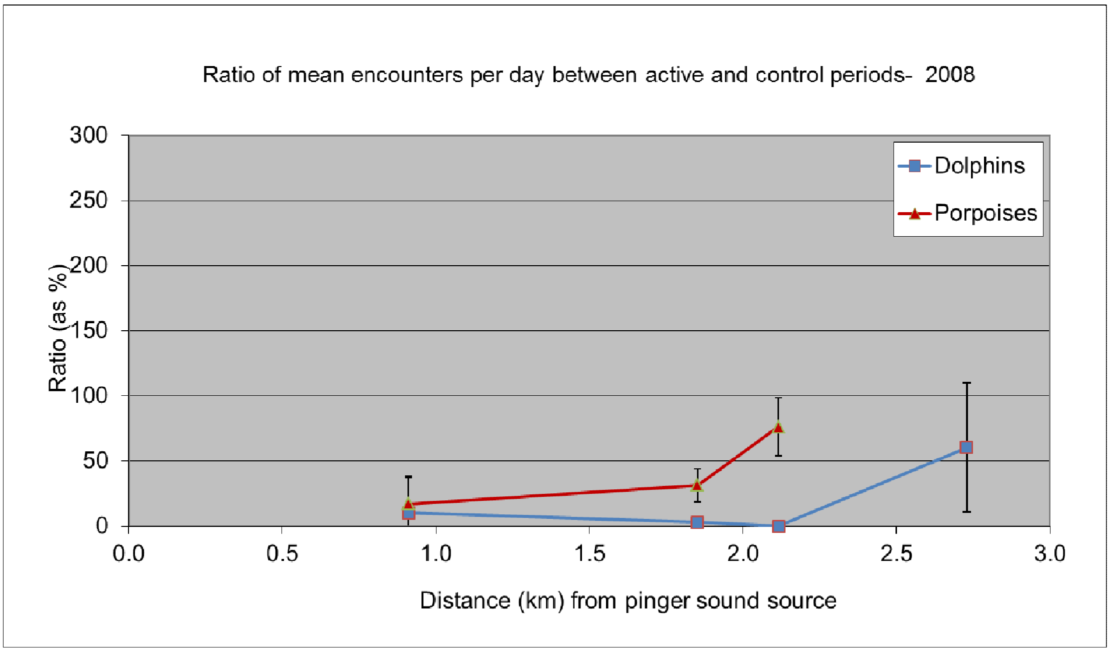

Figure 13: 2008 experimental exclusion trials off the Lizard, Cornwall.

These experiments show that the use of acoustic deterrent devices can be expected to reduce habitat occupancy by cetaceans in the surrounding areas. An important question is therefore whether the cumulative effect of these exclusion zones might have a significant impact on the available foraging habitat for cetaceans in the area. To address this question we have used the scenarios on potential pinger deployment, by model type, spacing and by fleet segment presented above, to estimate possible exclusion areas as a percentage of total available habitat in the Celtic Sea and Western Channel, which we take to be around 300,000 km^2.

Table 39: Potential 'habitat loss' if pingers exclude animals completely and without overlapping effect

Diameter of exclusions shown in column headings; two scenarios for each pinger type are shown

		Exclusion zone: putative diameter of complete exclusion.					
Length class	No of boats	Fumunda 100 m	Fumunda 200 m	Aquamark 200 m	Aquamark 400 m	DDD 2 km	DDD 4 km
>12m	21	0.04%	0.07%	0.07%	0.14%	0.74%	2.10%
10-12m	11	0.01%	0.01%	0.01%	0.01%	0.13%	0.50%
8-10m	89	0.02%	0.05%	0.05%	0.09%	1.13%	4.53%
<8m	210	0.02%	0.03%	0.03%	0.04%	0.96%	3.86%
All	331	0.08%	0.17%	0.17%	0.28%	2.96%	10.99%

The relative 'impacts' of the various pinger deployment strategies can now be seen in terms of possible habitat loss (Table 39). It should be stressed that these figures are very conservative as animals will likely overcome the deterrent effect of pingers if they need or want to feed in an area. Nevertheless they provide a worst case scenario means of comparing pinger deployment strategies. One obvious inference is that the use of DDDs in short nets used by coastal vessels is probably unnecessary, because the average fleet length is around or less than 1 km, so deploying a DDD would ensonify a far greater area than is needed, and a single Aquamark could be as effective if placed in the centre of an 800 m fleet of nets.

Discussion.

As with many environmental problems, the issue of cetacean bycatch is one that requires some sense or perspective and balance regarding the costs and benefits of the impact of bycatch itself and of the proposed mitigation measures. Roughly 600-800 porpoises per year die in UK fishing nets in the Southwest and surrounding seas. The population size is thought to be in excess of 80,000 animals in the Celtic Sea alone and there is no evidence of a decline. This is not a reason for complacency, as an ongoing decline could easily go unnoticed for several decades, while we also have only very limited information on total kills by other EU member states' fisheries. Furthermore, consumers are demanding that bycatch of vulnerable species should be minimized wherever possible. The issue here is one of balance. The total cost of putting deterrents on all Cornish vessels is estimated at between roughly £600,000 and £2.5 million, and there is a risk that a proportion of available habitat might also be lost as a result. There are also likely costs associated with enforcement that will need to be addressed. Ideally some economic analysis would be made to balance the cost to industry and regulators with the increased chances of survival for an individual porpoise, and the resulting loss of habitat under each of the possible scenarios described above (and mixtures thereof).

As an example of the sort of trade off that might be made: if pingers were judged to be desirable for any of the <12m sectors, then it seems likely that the use of Aquamarks at 400 m spacing would be only marginally more expensive than the use of DDDs, but the collateral effect on foraging habitat could be reduced by 13 to 50 times. The appropriate conservation strategy will depend upon the positions adopted by the various stakeholders in this debate, which include the fishing community, animal welfare and environmental organisations, fish buyers and the buying public, and government agencies. It is likely that the outcome will depend as much on politics and human psychology as on quantifying costs, impacts and benefits.

The human element in bycatch mitigation.

Bycatch needs to be considered from both an environmental and a societal perspective, but its solution requires human actions. The various groups with an interest in or influence over bycatch and bycatch mitigation, include the government, industry, fishery scientists and managers and more recently environmental NGOs, conservationists and the public. Often members of these groups appear to have conflicting interests or agendas but these seemingly disparate views can be reconciled in the future provided the development of sustainable, profitable and environmentally responsible fisheries remains the stated and actual goal of all parties involved. To achieve this goal will require a sensible, pragmatic and informed approach to addressing bycatch issues where they are considered significant.

A strained industry / science relationship has historically been viewed as one of the major barriers to the development of sustainable fisheries. In recent years that relationship has slowly improved through greater industry / science collaboration. The fishing industry has the most significant role in and potentially the most to gain by addressing bycatch issues. Ongoing assessments of bycatch levels and the development of appropriate mitigation measures where necessary will be achieved most effectively by close collaboration between the industry and scientific institutions with support from Government.

Nevertheless, the industry / science relationship is only one facet of many that drive the development of fisheries management systems in general and bycatch mitigation in particular. The media, for example, can play a critical role in shaping public opinion and in turn influencing Government actions. Environmental and animal welfare groups often seek to influence the media, which can lead to misrepresentation of the complexities of issues like bycatch or other fisheries management issues. Consequently the fishing industry and fishing communities are often the main focus of poorly informed criticism regarding fisheries effects such as bycatch. Greater understanding, clarity and a willingness to engage with some of the more difficult questions about bycatch from all relevant parties will help to overcome the present monochrome portrayal of these important and often complex issues.

Fisheries if managed effectively have the potential to provide a naturally renewable source of protein, provide employment and generate economic activity in many peripheral and/or poor regions. As with farming there will always be 'collateral damage' to the environment that is being exploited for food production, and a sensible management strategy will recognize this and seek to balance the potentially conflicting needs of fisheries with those of maintaining biodiversity. Of course the objectives of fisheries management and nature conservation are not by any means mutually exclusive, indeed the whole focus of fisheries management is shifting from one of single species management for economic gain to a more ecosystem based approach within which target species are viewed as just one of a number of components requiring consideration. Managing bycatch is just one aspect of this ecosystem approach, but one that we hope this project will have helped address.

During this project and in previous years, we have been struck by the willingness of many in the fishing industry to try to do what they can to minimize bycatch. This attitude can be contrasted with the image of the industry portrayed by many as wilful 'pillagers' of the marine environment. From a perspective of simple human psychology it seems obvious that continued berating of the industry is unlikely to produce an atmosphere of willing participation and engagement. Perhaps it is time that fishermen were recognized and rewarded for the efforts that they do make to manage the marine environment in a manner that will benefit us all.

To this end it is encouraging to see that some of the certification schemes now take the issue of bycatch quite seriously and in some instances specific bycatch monitoring activities and mitigation measures are now required for fisheries to obtain or maintain certification. By no means guaranteed but hopefully this will translate into improved market value for fish landed under such schemes as consumers become increasingly discerning and look for assurances regarding the provenance of different products.

6. Other approaches to bycatch reduction in static nets.

Introduction.

In this section we summarise a detailed statistical analysis of the observer data collected since 1996 in order to isolate potential gear or fishing characteristics that might be useful in reducing cetacean bycatch. A total of 1,542 trips in static net fisheries were monitored between April 1996 and December 2009 accounting for 2,416 days at sea. In total, 10,666 hauls were observed, during which 144 harbour porpoises and 27 dolphins (2 bottlenose dolphins and 25 common dolphins) were observed bycaught. Static net fisheries fall into to one of six categories: drift nets, drift trammel nets, trammel nets, gill nets, wreck nets and tangle nets. Statistical models were developed in order to see which factors were related to bycatch rates of marine mammals in these fisheries. The main aim of this analysis was to investigate which factors influence the bycatch rates of cetaceans in UK commercial set net fisheries and in particular, to see whether any specific gear characteristics may be associated with high or low bycatch rates, and whether there is any potential to modify these characteristics to reduce cetacean bycatch in static net fisheries.

Data treatment.

A number of hauls recorded in the observer database contained missing values. Where possible, data recorded from hauls within a same trip or from previous trips by the same vessel were used to fill in these missing values. For example, if soak time was not recorded for a haul, the mean soak time of the other hauls recorded in that trip was used. Where there was high variability in soak time between all hauls in the trip, this value was left blank. If fleet length for a haul had not been reported, but the previous trip on that vessel had been observed, then the missing value could be obtained from reviewing the hauls in the previous trip. The same was possible for missing values of mesh size and net height. If either longitude or latitude had missing values, these were approximated from the recorded values of the closest haul.

A reduced subset of the entire database was created prior to statistical modelling. In the first instance a number of métiers were removed. Stake nets were excluded from the analysis, because although a harbour porpoise bycatch had been observed in this gear, the animal was released alive. Sample sizes for drift nets and drift trammel nets were low and no bycatch was reported in either of these gear types so they were also excluded from the analysis. While harbour porpoise bycatch was recorded in trammel nets, the sample size was relatively low and was compromised by missing data on the mesh size of the outer panels used for the majority of trammel net hauls. Therefore this gear type was also excluded. Due to differences in the temporal scale of observer coverage in different geographical areas the data were split by ICES Subarea prior to modelling. Finally, all hauls where values were missing for candidate explanatory variables were also excluded. The final dataset contained only gill nets and tangle nets.

Model description.

It has been suggested that the best measure of fishing effort for gill nets is the total length of net in the water multiplied by the total duration of time the nets were soaked. This measure is commonly termed km net hours. The bycatch of harbour porpoises and common dolphins in gill nets and tangle nets were modelled as the number of animals entangled per km net hour. Generalized linear models (GLMs) with a Poisson distribution and logarithmic link function were constructed. Bycatch rates were then modelled using logged fishing effort as an offset in the model.

Several candidate explanatory variables were selected from the observer database. These related to the spatial and temporal deployment of fishing gear, target catch species and gear characteristics. Explanatory variables available for modelling are listed in Table 40.

Table 40: Explanatory variables available for statistical analysis

Variable name
Year
Month
Métier – Defined by the target catch and gear characteristics of each observed haul
Mesh size (mm) – stretched measured mesh size
ICES Division
ICES Subdivision
ICES Rectangle
Latitude – decimal degrees
Longitude – decimal degrees
Soak time - hours
Total fleet length - metres –length of all nets in the fleet
Vessel length - length overall (LOA), the maximum length of a vessels hull measured at the water line.
Observer ID – categorical by assigned letter code
Depth (m)
Rigged net height – calculated by multiplying stretched mesh size by the number of meshes in height of the net
Presence of floats on float line – yes/no
Experimental haul – yes/no

The relationship between each explanatory variable and bycatch rates of each species was assessed by investigating plots produced by generalized additive models (GAMs). Covariates that did not show a linear relationship were tested to see if the inclusion of a polynomial term or adding them as a categorical variable improved model fit of the GLM. Co-linearity between variables can lead to unstable parameter estimates and therefore influence the perceived importance of the predictor(s) and lead to poor model selection. Therefore, prior to modelling, possible co-linearity between all explanatory variables was investigated.

The rarity of bycatch events limits the amount of data available to fit complex models, and care therefore needs to be taken not to over-parameterise the model. Therefore a cut-off point of a minimum of 5 bycaught animals for each covariate retained in the final model was set. If the best model had more parameters than this rule allowed, the term with the smallest effect on the AIC (Aikake's Information Criterion – used to determine the best fitting model) was removed and the step process reran, until the final model did not retain more than the specified allowable number of parameters.

Results.

Using the main target catch *per haul* as the main identifier, 17 métiers were classified for the six net types recorded by observers. Table 41 summarises the target catch species and gear characteristics of each of these métiers.

Table 41: Summary of target catch and gear characteristics of assigned metiers.

Metier	Target species	Average mesh size (mm)	S.E.	Average soak time (hrs)	S.E.	Average fleet length (m)	S.E
DN1	Pilchard, herring	64.6	1.6	2.4	0.2	564.8	27.6
DN2	Bass	96.8	0.8	2.6	0.3	542.7	40.3
DN3	Salmon	120.0	0.0	0.9	0.4	550.0	0.0
DRT	Bass, cod, sole, ray	102.9	0.7	1.8	0.4	484.0	12.0
GN1	Bass, haddock	99.5	0.5	19.3	0.5	589.8	20.3
GN2	Cod, ling, Pollack, gadoids	138.8	0.4	17.6	0.3	473.9	10.6
GN3	Hake	122.4	0.3	24.9	0.4	4774.6	80.8
GN4	Dogfish, spurdog	113.9	0.7	20.1	0.5	645.7	11.6
GN5	Mackerel, herring	89.0	19.0	3.0	0.0	900.0	321.5
GN6	Sole, crab, plaice, ray, turbot, monkfish, skate	121.0	0.7	27.3	0.9	763.0	13.2
GN7	Mullet	67.9	0.4	6.3	0.4	334.4	23.5
STK	Salmon, Sea trout	101.8	0.7	5.8	0.4	383.0	7.2
TN1	Brill	212.8	2.1	66.0	14.2	1990.0	268.9
TN2	Ray, monkfish, skate, turbot, dogfish	272.9	0.3	71.2	0.8	1589.0	27.3
TN3	Lobster, crayfish	284.3	2.1	189.6	8.8	741.0	35.9
TR1	Sole, ray, flounder, lobster, turbot, brill, crayfish, monkfish	168.0	3.0	49.1	2.1	1767.0	75.2
TR2	Cod, bass	125.2	0.6	18.7	0.3	402.8	5.5

Table 42 summarises bycatch rates of harbour porpoise and dolphin species, per km net hour, in all gill net and tangle net metiers in ICES Subareas IV, VI and VII.

Table 42: Summary bycatch rates per km net hour per metier by ICES Subarea.

ICES Division	Metier	No of hauls	Km net hours	No of porpoises	No of dolphins	Bycatch rate per haul		Bycatch rate per 10 km net hours	
						Porpoises	Dolphins	Porpoises	Dolphins
IV	GN1	195	3,955	1	0	0.005	0	0.003	0
IV	GN2	1,721	10,725	19	0	0.01	0	0.02	0
IV	GN4	21	394	0	0	0	0	0	0
IV	GN6	51	784	0	0	0	0	0	0
IV	TN2	1,366	53,174	53	0	0.04	0	0.01	0
VI	GN2	2	20	0	0	0	0	0	0
VI	GN4	237	2,913	5	0	0.02	0	0.02	0
VI	GN6	4	29	0	0	0	0	0	0
VI	TN2	52	2,877	2	0	0.04	0	0.007	0
VI	TN3	92	14,487	3	0	0.03	0	0.002	0
VII	GN1	215	1,572	0	0	0	0	0	0
VII	GN2	926	13,187	9	3	0.01	0.003	0.007	0.002
VII	GN3	345	40,560	15	6	0.043	0.02	0.004	0.001
VII	GN5	2	3	0	0	0	0	0	0
VII	GN6	508	10,473	0	0	0	0	0	0
VII	GN7	114	258	0	0	0	0	0	0
VII	TN1	8	1,064	0	0	0	0	0	0
VII	TN2	1,438	280,372	19	8	0.01	0.006	0.001	0
VII	TN3	89	10,260	0	9	0	0.1	0	0.009
Total		**7,386**	**44,7107**	**126**	**26**				

When km net hours is used as a measure of fishing effort, highest harbour porpoise bycatch rates were observed in gill nets targeting cod and other whitefish in ICES Subarea IV, gill nets targeting dogfish in ICES Subarea VII and tangle nets targeting ray and monkfish in ICES Subarea VII. Dolphin bycatch was only observed in ICES Subarea VII, where highest bycatch rates per fishing effort were recorded in tangle nets targeting crustaceans (TN3), gill nets targeting cod and whitefish, followed by gill nets targeting hake.

Harbour porpoise bycatch in gill nets and tangle nets in ICES Subareas IV and VII.

Initial models were constructed using data collected in gill nets and tangle nets in ICES Subarea IV and ICES Subarea VII. The best model for harbour porpoise bycatch rates in ICES Subarea IV retained the variables fleet length, depth, mesh as a categorical variable, soak time and an interaction between depth and soak time. The only significant variable retained by the model was fleet length, which had a negative relationship with harbour porpoise bycatch. This relationship was driven by high bycatch rates in short wreck nets. The best model for harbour porpoise bycatch rates in ICES Subarea VII retained the explanatory variables net height, soak time, depth and year. Harbour porpoise bycatch rates had a significant positive relationship with net height and a non-significant positive relationship with year. The relationship with soak time and depth was negative and non-significant for both these explanatory variables. The significant positive relationship with net height was driven by high bycatch rates in wreck nets and nets targeting hake and other whitefish, both of which fish taller nets than those used in other fisheries observed in this area.

As the results of these models (all nets ICES Subarea IV and all nets ICES Subarea VII) did not provide any more insight into which gear characteristics may influence harbour porpoise bycatch in this region, further to the information already provided by estimating bycatch by metier. Therefore the data collected for observed hauls were modelled separately for gill nets and tangle nets hauls for each ICES Subarea.

Once all missing values had been omitted, the subset of the data for gill nets in ICES Subarea IV comprised 1,998 hauls and 20 bycaught harbour porpoises. Therefore a maximum of four explanatory variables were allowed in the final model. Table 43 summarizes the effort (as number of hauls and km net hours) for the four metiers observed in this data set.

Table 43: Summary of harbour porpoise bycatch rates by gill net metier in ICES Subarea IV.

Metier	No. of hauls	km.net hour Effort	No. of porpoises	Porpoise per haul	Porpoise per 10 km.net hour
GN1	195	3,955	1	0.005	0.003
GN2	1,721	10,725	19	0.011	0.018
GN4	21	394	0	0	0
GN6	51	784	0	0	0

The best model retained the variables fleet length, latitude, mesh size and depth. Fleet length had a significant negative relationship with harbour porpoise bycatch rates and there was a positive significant relationship with latitude. The relationship between harbour porpoise bycatch rates and mesh size was positive but non-significant, while depth had a negative non-significant relationship. The negative significant relationship between harbour porpoise bycatch rates and fleet length as predicted by the model is driven by the high bycatch rate (per unit effort) in fleets of length 550 m or less. These particular fleets are termed wreck nets, and as the name suggests, are typically shot over wrecks or patches of rough ground. Observed wreck nets had a larger mean mesh size than longer nets targeting cod, and harbour porpoise were caught in depths greater than 65 m.

All harbour porpoise bycatch occurred in ICES Division IVb where 87% of the observed effort (number of hauls) was recorded. Therefore to allow investigation of any spatial effect on bycatch rates only those hauls that were observed in ICES Division IVb were considered further. The final model showed a negative significant relationship between harbour porpoise bycatch rates and tangle net fleet length and latitude. Of the 1,202 hauls observed in ICES Division IVb, 83% had been observed as part of experimental trials conducted to test the effects of different gear characteristics on bycatch rates. These experimental trials account for 46 of the 53 harbour porpoise caught in tangle nets in ICES Division IVb. The significant relationship with latitude is driven by these experimental trials which were all conducted off the coast of Bridlington and the relationship with shorter fleet lengths is driven by the experimental trial conducted in 2003 where bycatch rates in standard skate nets and acoustically reflective ($BaSO_4$) tangle nets were investigated.

Once missing values had been removed, the final data modelled for gill nets in ICES Subarea VII consisted of 2,110 hauls and 24 bycaught harbour porpoise. To avoid over-parameterisation, a maximum of four parameters were allowed in the best model. All harbour porpoise bycatches were recorded in gill nets targeting cod and other whitefish (GN2) and gill nets targeting hake (GN3). The best model of harbour porpoise bycatch indicated a positive significant relationship with net height, a positive significant relationship with mesh size and a negative but non-significant relationship with depth.

Once missing values had been removed, the final data modelled for tangle nets in ICES Subarea VII consisted of 1,645 hauls and 19 bycaught harbour porpoise. Therefore a maximum of 3 parameters were allowed in the best model. However, the best model for this dataset proved unstable when re-sampled, indicating there was insufficient data to allow statistical investigation of which factors influence bycatch rates of harbour porpoises in tangle nets in this region.

Dolphin bycatch in all nets in ICES Subarea VII.

Twenty-seven dolphins were recorded bycaught in 3,709 hauls observed between 2004 and 2009. Of these, two individuals were bottlenose dolphins and the remaining animals were common dolphins. The bottlenose dolphins were observed in two separate trips, the first was caught in a tangle net targeting monkfish, the second was caught in a short gill net (180 m) targeting pollack. Given differences in the distribution and behavioural ecology of bottlenose dolphins and common dolphins, the two hauls with bottlenose dolphin bycatches were removed from the data prior to modelling. Therefore the model is explicitly capturing the relationship between covariates and common dolphin bycatch rates. Table 44 summarises bycatch rates of this species by metier in ICES Subarea VII. Highest bycatch rates per km net hour were recorded in tangle nets targeting crustaceans (TN3) followed by gill nets targeting cod and other whitefish (GN2).

Table 44: Summary of common dolphin bycatch rates by metier in ICES Subarea VII.

Metier	No. of hauls	Effort	No. of Dolphins	Dolphins per haul	Dolphins per km.net hour
GN1	202	1,473	0	0.000	0
GN2	860	12,624	2	0.002	0.00016
GN3	345	40,560	6	0.017	0.00015
GN5	2	3	0	0.000	0
GN6	479	9,244	0	0.000	0
GN7	116	258	0	0.000	0
TN1	8	1,064	0	0.000	0
TN2	1,411	276,168	8	0.006	0.00003
TN3	81	8,172	9	0.111	0.00110

No dolphin bycatch was observed in ICES Divisions VIIa or VIId so these hauls were removed prior to analysis (n= 205). The final data set modelled comprised 3,504 hauls and 25 common dolphins. The best model of common dolphin bycatch showed a significant positive relationship between common dolphin bycatch rates and mesh size and month, and a non-significant positive relationship with soak time.

Discussion of main factors influencing bycatch rates.

When independent on-board observer data collected in gill net and tangle net hauls were combined for each ICES Subarea the significant explanatory variables retained for the best models to predict harbour porpoise bycatch rates were fleet length (ICES Subarea IV) and rigged net height (ICES Subarea VII). The significant negative relationship between harbour porpoise bycatch and fleet length in ICES Subarea IV was driven by highest observed bycatch rates occurring in short gill nets targeting cod (<500 m) and short tangle nets (<150 m). The significant positive relationship between harbour porpoise bycatch and net height in ICES Subarea VII was driven by highest observed bycatch rates occurring in short wreck nets (GN2) and in long gill nets targeting hake (GN3) both of which had an average rigged net height of 5.2 m. While the results of these models identified specific fisheries with high bycatch rates, they did not provide information on which characteristics within these, and other fisheries, might be appropriate to investigate for their potential to mitigate bycatch. For this reason separate models were constructed to investigate bycatch rates of harbour porpoises in gill nets and tangle nets for ICES Subareas IV and VII.

Fleet length.

Fleet length was found to have a significant negative relationship with harbour porpoise bycatch rates in the best models retained for both gill nets and tangle nets in ICES Subarea IV. In this area, 95% of harbour porpoise bycatches were recorded in gill nets targeting cod and other whitefish, prior to 1999. This metier (GN2) accounted for 87% of all hauls observed in ICES Subarea IV, and 16 of the 19 porpoises observed in this metier were caught in nets less than 500 m in length, the remaining 3 in nets less than 1000 m in length. While no porpoises were observed bycaught in nets longer than 1000 m, these nets only accounted for 2.6% of all observed hauls. These short fleets of net, mostly targeting cod, are known as wreck nets. Wreck nets are similar to standard cod nets, although with slightly larger mesh sizes, and are shot over wrecks or rough ground to target aggregations of fish. Vinther (1999) also reported that the bycatch rates of harbour porpoise were higher in Danish North Sea wreck nets than in longer cod nets. The negative relationship between fleet length and harbour porpoise bycatch rates in the North Sea described in both this study and by Vinther (1999) indicate that some other characteristic of wreck net fisheries results in increased bycatch rates. This may be due to higher densities of harbour porpoise prey species around wrecks or the close proximity that wreck nets are set together in an area. While harbour porpoise bycatch rates per haul was the same for wreck nets in ICES Subareas IV and VII (0.01 animals per haul), bycatch rates per km net hour were much higher in wreck nets in ICES Subarea IV (0.02 v. 0.007). This higher bycatch rate per km net hour is a result of shorter average fleet length and shorter average soak durations of wreck nets in ICES Subarea IV compared to ICES Subarea VII.

The best model for predicting harbour porpoise bycatch rates in tangle nets in ICES Subarea IV was for a subset of the data which contained those hauls observed in ICES Division IVb. 83% of the observed hauls in this subdivision were part of experimental trials testing bycatch rates in nets with different gear characteristics, which were conducted in the waters off Bridlington, North Yorkshire. The explanatory variables retained by this model were fleet length, as a categorical variable, and latitude. Bycatch rates, per km net hour, were significantly higher in fleets with length less than 150 m, and this relationship was driven by two experiments in years 2000-2001 and in 2003. While soak time was not retained as an explanatory variable in the best model, average soak times were highest in the two aforementioned trials compared to the two experimental trials using longer fleet lengths.

Net height.

The positive significant relationship between rigged net height and harbour porpoise bycatch rates in ICES Subarea VII is driven by high bycatch rates in gill nets targeting cod and other whitefish (GN2) and gill nets targeting hake (GN3). The mean rigged height of gill nets targeting cod and gill nets targeting hake in ICES Subarea VII was 5.5 m and 5.2 m respectively. These metiers accounted for 60% of all observed hauls in gill net fisheries in this area. The next most frequently sampled gill net metier in ICES Subarea VII was sole nets (GN6) which accounted for 24% of observed hauls during which no harbour porpoises were observed bycaught. While the mesh size of sole nets is similar to those used in gill net targeting cod and hake the rigged height of these nets is much lower, averaging 1.6 m. Sole nets are also constructed of thinner nylon twine than either gill nets for cod or hake. Although UK observers record twine diameter when possible this variable had too many missing values to be included as a covariate in the model. However, available data show that the average twine diameter of sole nets is 0.35 mm compared to 0.64 mm for nets targeting hake. It is unclear whether the lower profile or the thinner netting material of sole nets (or some other factor) resulted in the lack of harbour porpoise bycatch observed in this metier. In contrast rigged net height was not retained as a significant predictor of harbour porpoise bycatch in gill nets in ICES Subarea IV. However, 87% of observed gill net hauls in this area were in wreck nets and longer cod nets, both of which had an average rigged height of 3.6 m.

Although the effect of rigged net height on cetacean bycatch rates has not been directly investigated, the use of tie downs in large mesh US Atlantic sink net fisheries were associated with lower bycatch rates of harbour porpoises (Palka 2000) and their use is now mandatory in some fisheries. Tie downs are lines that are shorter than the height of the fishing net and connect the float line to the lead line of the net at equal distances along the net. By using tie downs, not only is the height of the net reduced, but also the meshes of the net form a bag that aid in entangling demersal fish. Preliminary results of a recent experimental trial to investigate the effect of tie downs on bycatch rates of Atlantic sturgeon, found catch rates of sturgeon were lower in experimental nets where no tie downs were used. However, common dolphins were bycaught in these nets, while none were recorded in control nets with tie downs, suggesting lower profile nets may also reduce the bycatch rates of this species.

Mesh size.

Mesh size was found to have a positive but non-significant relationship with harbour porpoise bycatch in gill nets in ICES Subarea IV and a significant positive relationship in ICES Subarea VII. In contrast mesh size was not retained as an explanatory variable of harbour porpoise bycatch in tangle nets in either ICES Subareas IV or VII. For tangle nets in ICES Subarea IV, model results were driven by experimental trials in ICES Division IVb where the majority of hauls were of nets with a mesh size of 267 mm. Although mesh size was not retained in the best model for tangle nets in ICES Subarea VII this model was unstable and it is not clear whether the retained variable floats present is actually a proxy for mesh size.

Mesh size has previously been shown to have a positive relationship with bycatch rates of harbour porpoise (Palka 2000, (Orphanides 2009), bottlenose dolphins (Palka & Rossman 2001) and loggerhead turtles (Murray 2009) in static net fisheries. Palka & Rossman (2001) estimated highest bycatch rates of bottlenose dolphins in the US Mid-Atlantic States static net fishery, in mesh sizes greater than 155 mm, and intermediate bycatch rates for mesh sizes of 127-155 (Palka & Rossman 2001). Murray (2009) reported a positive relationship between loggerhead turtle bycatch and mesh size in the same fishery, with 20% of the variation in loggerhead turtle bycatch rates being explained by mesh size.

While no harbour porpoise bycatch was recorded in 508 observed hauls in sole nets in ICES Subarea VII, this metier had a similar average mesh size to nets targeting hake (124 mm and 123 mm) respectively. Likewise, no harbour porpoise bycatch was recorded in the UK sole gill nets in ICES Subarea IV, although only 51 hauls were observed, so the sample size is too low to conclude anything. Although observer coverage in the Danish sole fishery was also low, Vinther (1999) concluded that the lack of harbour porpoise bycatch in that fishery could be as a result of small mesh size, or equally a result of the lower profile of the net or the less robust netting material used. As previously stated, while mesh sizes of hake and sole nets are similar, the latter metier has a much lower profile and thinner netting material. In addition, five harbour porpoise have been reported bycaught in sole nets rigged as trammel nets. While the height of these sole nets is similar to those consisting of a single wall of webbing, the outer mesh sizes are much larger. Therefore, the probability of harbour porpoise entanglement in trammel nets fishing for sole is likely increased by this large mesh size. The lack of observed harbour porpoise bycatch in gill nets targeting sole in both UK and Danish fisheries suggests that some characteristic of these nets may result in a reduction in the probability of bycatch. Whether this is due to the low profile of these nets or the thin twine diameter of the meshes (and therefore lower breaking strain) remains unclear.

Common dolphin bycatch in static nets.

The best model predicting common dolphin bycatch in static nets in ICES Subarea VII retained the variables soak time, mesh size ($\geq$ 203 mm), month category (October-December) and an interaction between mesh size and soak time. Examination of the data from this model showed significant autocorrelation between hauls, with this autocorrelation driven by the extremely clumped nature of observed bycatches of common dolphins. Almost half of all common dolphin bycatches were recorded from four successive trips on the same vessel over a period of 8 days. Nine of the common dolphins were bycaught in tangle nets (eight in one trip) while two were caught in wreck nets. It is the nine animals caught in tangle nets by this boat that drive the apparent relationship between common dolphin bycatch and mesh sizes greater than 203 mm. However, it is clear that common dolphins were susceptible to being caught in both of the two gears this boat fished over a small spatial and temporal scale. The two types of nets deployed are very different in their gear characteristics. The wreck nets are 7.8 m tall, with a mesh size of 130 mm and one was 376 m in length while the other was 752 m in length. The tangle nets used by this boat had a mesh size of 300 mm, a fleet length of 1152 m and were 1.5 m tall. Over half of the bycatch events occurred between October and December. An increase in sightings rates of common dolphins during winter months in the Western approaches of the English Channel has been reported as well as concurrent increase in stranding's of this species. Tregenza *et al.* (1997a) found a peak in sightings rates between November and December when investigating the bycatch of this species in the UK and Irish hake gill net fishery. Four common dolphins were observed bycaught during this study, of which one was alive and fell out of the net as it was being hauled. Given that this animal was still alive during haul back, and common dolphins had been observed in the vicinity of nets as they were being shot in two of the three times bycatch had been recorded, the authors suggested three possible mechanisms' for common dolphin bycatch in these nets. That animals become entangled during hauling or shooting of nets, that the risk of entanglement is increased if dolphins are engaged in playing with nets, and the observed responsive reaction of attraction to boats may increase the probability of coming into contact with nets (Tregenza *et al.* 1997b). The observation of common dolphin bycatch in two very different gears deployed by the same boat in the same area does suggest that it is the animals being there and maybe interacting with gear during shooting or hauling that affects the bycatch and not the gear characteristics. The 20 common dolphin bycatch events observed in UK fisheries were caught in nets with soak durations ranging from 12 –240 hours, and over half the bycatch events in nets soaked for 24 hours or less. Therefore the probability of entanglement for this species does not seem to be related to the length of time that gill nets or tangle nets are deployed. Of the 25 common dolphins recorded in static nets, core temperature was recorded for 6 individuals and this ranged from 11-29 degrees Celsius. None of these animals had died within a few hours of hauling the net, but we do not know enough about cooling rates of animals to determine if bycatch might have occurred when the nets were shot. Given that four of these six animals were caught in nets set for 24 hours, with core temperatures of 11-26 degrees, it seems unlikely that all bycatch events occur during net shooting.

While there appeared to be a positive relationship between common dolphin bycatch and mesh sizes in static nets in ICES Subarea VII it was clear that this was driven by eight animals caught in four tangle net hauls in the same trip in 2005.

Conclusions.

Results of analysis of gear characteristics affecting the bycatch rates of harbour porpoises and common dolphins in UK gill net fisheries indicate two gear characteristics which could be investigated for bycatch mitigation. These are twine diameter and net height.

7. Experimental approaches.

Introduction.

Although it has been hypothesised that harbour porpoise may not be able to detect nets in time to avoid them, studies utilising passive acoustic monitoring have shown that harbour porpoise are in the vicinity of nets much more frequently than bycatch occurs (SMRU 2001, Cox & Read 2004). For example, SMRU et al. (2001) found that in a 24hour deployment of a TPOD on a bottom set gill net, approximately 40% of hours contained at least one harbour porpoise detection. However the occurrence and echolocation of harbour porpoises in the presence or absence of gill nets has not previously been examined.

It has been hypothesised that harbour porpoises may be attracted to struggling fish caught in static gill nets (Gaskin 1984). However, as yet there is no evidence to suggest that porpoises are feeding on fish caught in gill nets. Furthermore, one study looking at the stomach contents of hake and bycaught harbour porpoise showed no overlap in ingested prey (Kindt-Larsen 2007). SMRU et al. (2001) found no clear relationship between the amount of fish in the net and the amount of echolocation click activity recorded, though the amount of fish in the net may not indicate the amount of (smaller) fish associated with the net.

SMRU et al. (2001) found that harbour porpoise bycatch rates were significantly higher in nets with a buoyant float line made of rope with a polystyrene core than in nets with a standard polypropylene float line and additional plastic floats. The authors postulated that the buoyant float line rope may have changed the behaviour of the net while fishing, such as lowering or increasing the float line height, or may have been less conspicuous to echolocating harbour porpoise than the floats on the standard propylene headline.

A study was conducted in Bridlington Bay, North Yorkshire in 2009 that had three main objectives. The first was to investigate the echolocation behaviour of harbour porpoise in the presence and absence of bottom set gill nets, to determine whether porpoise are attracted to nets. The second was to investigate whether echolocation behaviour varied with float line type. The final objective was to investigate whether data collected by passive acoustic monitoring (PAM – this case C-Pods™) could be used to determine if harbour porpoise are foraging in the vicinity of nets.

Methods.

An experimental trial was conducted in Bridlington Bay, North Yorkshire between the 8th of July and 20th of August, 2009. A homogenous fishing ground consisting of a sandy benthos was chosen to minimise the influence of habitat type on harbour porpoise occurrence. Eight Chelonia CPOD V0 porpoise click detectors (PODs) (Chelonia Ltd., www.chelonia.co.uk) were used to record the occurrence of harbour porpoises in the study area. The CPODs were deployed in pairs separated by 500 m (west-east) and in a water depth of approximately 14m. Each pair was either attached to either end of a 200 m tier of nets, or was anchored at a 200 m separation.

The nets deployed in the study were standard and modified turbot gill nets. Two tiers of nets were rigged with different amounts and types of flotation. The single net was rigged with the standard amount of flotation consisting of a single 9.5 mm float line and 3.6 mm lead line. The double net was rigged with a single 12 mm float line and 9.4 mm lead line and the floats net was rigged with a nominal 10 mm braided polypropylene float line with 6 inch polystyrene cigar floats spaced at 5 m intervals. A short tier length of 200 m was chosen to minimise the amount of net in the water to reduce the likelihood of porpoise bycatch. All nets had a mesh size of 10 inches and a rigged height of 2 m. Each CPOD remained in the same position for the duration of the experiment, while tiers of nets were rotated every few days between positions. In addition data were recorded on fishing activity, including soak time, shot and haul time and fish catches.

All eight CPODs were deployed for a period of 51 days. However, there was variation in the number of days logged by individual CPODs. Figure 16 shows the number of days recording for each CPOD. CPOD 268 failed to start logging at all, while CPODs 270, 264, 237 and 281 appear to have stopped logging during hauling of the nets. Data could not be downloaded until the end of the trial and therefore it was not possible to know that one of the CPODs had failed to record, and four of the CPODs had stopped recording prematurely.

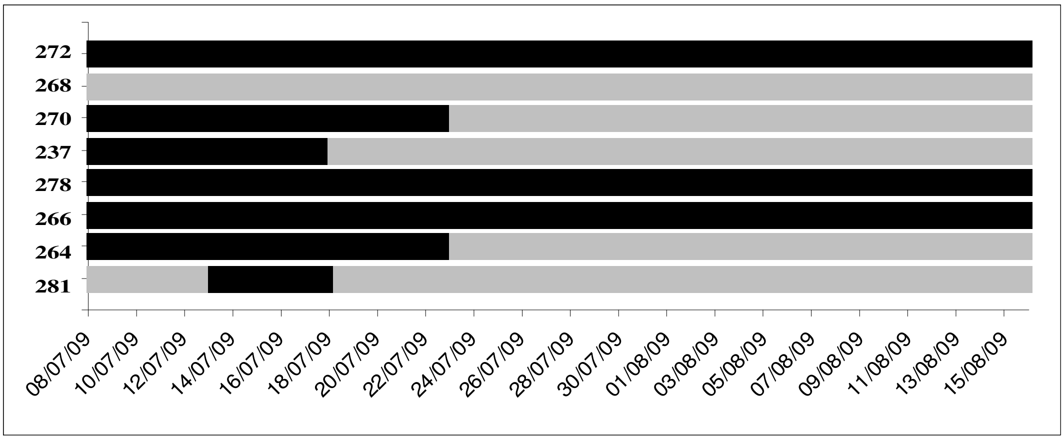

Figure 14: Number of data days: black bars indicate days when each POD was recording

All data recorded by CPODs was processed using version 1.053 of the CPOD.exe computer software.

Area of acoustic detection.

During design of this experiment it was assumed that CPODs would have the same detection range as TPODS (~200 m). However, it is possible for CPODs to detect echolocation clicks at a distance of 300 m from the source (*N. Tregenza pers com*). The likelihood of logging a detection at this range will depend on the orientation of a porpoise towards the POD and the source level of the echolocation click. Figure 17 is a schematic of the theoretical acoustic detection range of CPODs in the study. Although an overlap between PODs within a pair was expected during experimental design it was not expected that there would also be overlap between PODs separated by 500 m. This overlap has implications with regards to treating click trains logged by CPODs within a treatment as independent to those logged by CPODs in neighbouring treatments.

Echolocation metrics.

The time and duration of each click train is logged, and the number of detection positive minutes (DPM), hours or days can be exported from CPOD.exe, as well as number of detections per tidal cycle. DPM also be assigned to encounters by grouping bouts of detection positive minutes into events separated by intervening periods, of a specified length, when no clicks are detected. Figure 18 shows a schematic of how the process by which clicks become assigned to encounters.

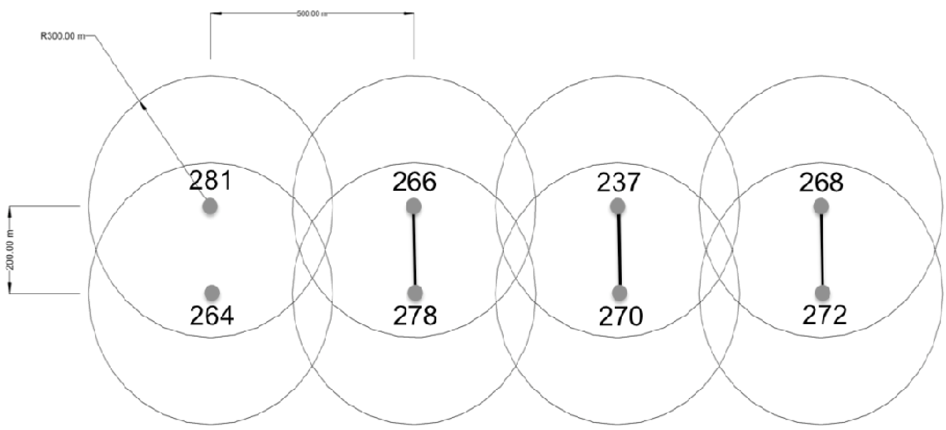

Figure 15: Schematic of the theoretical acoustic detection range of PODs in the array.

A detection positive minute (DPM) is a minute in which a POD detected at least one echolocation click train. DPM per minute were exported from CPOD.exe and used as the basis metric on which to assign encounters. A new encounter was assigned each time a period of ten minutes of more had passed without an echolocation click being detected. Encounter rates per hour were then used to estimate daily echolocation encounter rates (DEER) and the proportion of DPM within an encounter relative to the length of that encounter was used as a measure of encounter intensity.

Clicks → Trains → DPM → Encounters

Figure 16: Schematic of process of assigning encounters logged echolocation clicks.

The inter-click interval (ICI) is the time between two clicks in an echolocation train. CPOD.exe exports the details of all trains provided including the minimum inter-click interval (mICI) of that train. Todd et al (2009) identified potential feeding trains of harbour porpoises using a feeding buzz ratio, which was calculated by dividing the number of mICIs <10 ms (fast trains) by those with mICIs >10ms (slow trains) for each diel phase. Although it has not been experimentally proven that fast trains recorded by PODs do indicate feeding events there is evidence to show that porpoise do produce buzzes, which are short series or rapid echolocation clicks, during prey capture.

Results.

Harbour porpoise echolocation click trains were logged on all pods on all days during the deployment period, except on the 16th of August when no harbour porpoise click trains were recorded on one of the two CPODs which recorded for the entire duration of the study. There was no trend in daily echolocation encounter rates throughout the study period. Table 45 summaries the number of encounters and mean encounter rates per hour detected by each POD.

Table 45: Summary of encounters and encounter rate by POD.

POD	Total number of encounters	Mean enc rate per hour	S.E.
272	233	0.25	0.03
278	280	0.30	0.03

Encounter lengths recorded by both PODs over all deployments ranged from a minimum of 1 minute (the minimum encounter length possible when encounters are assigned to DPM) to a maximum of 44 minutes. Average encounter lengths for PODs 272 and 278 were 4.9 minutes (S.D. 5.7) and 5.1 minutes (S.D. 5.4), respectively. 33% of all encounters recorded by both PODs were one minute in length. There was no significant difference in echolocation encounter rate with different tidal states. However, there were significantly more encounters per hour during the day than the night. Minimum inter click intervals were significantly lower in the day than the evening, and lower in the night than the morning.

The experiment in Bridlington was designed to allow contemporaneous comparisons of harbour porpoise echolocation behaviour for each of the four treatments (no net, single float line net, double float line net, float net). As a number of CPODs failed to record such a comparison was not possible and analysis was restricted to comparing pairs of treatments where PODs recorded simultaneously. These treatment pairs were no net – double net, and single net – float net. As treatments were rotated between the four deployment locations in Bridlington Bay, each of the two PODs that recorded for the entire duration of the 51 day experiment was deployed with each treatment for a minimum of four deployments.

Results showed no significant difference in encounter rates of harbour porpoises between treatments in any of the four deployments. In addition there was no significant difference in encounter length or encounter intensity in the presence or absence of a net, or between the net with a single float line net compared to the net with additional ellipsoidal floats. However, there were significantly more 'fast' than 'slow' trains, per encounter, in the presence of a net than when there was no net present. There was no significant difference in the proportion of fast to slow trains recorded by PODs deployed with the net with a single float line or the net with additional floats.

Only data recorded during the second deployment could be used to investigate the movement of harbour porpoises around the array. A general trend was found between the length of an encounter and the number of PODs in the array that detected echolocation clicks. This suggests that the longer a harbour porpoise stays in the vicinity of the array, the more it moves around the array.

Discussion.

Harbour porpoise echolocation clicks were recorded on 100% of days that PODs were deployed at the Bridlington study site. Encounters lasted between 1 and 44 minutes, with an average encounter length of 4.9 minutes, and there were significantly more encounters per hour recorded during the day. Minimum inter click intervals were lower in the day than at night but this difference was not significant. Both Carlstrom (2005) and Todd et al. (2009)also reported highest minimum ICIs at night. Carlstrom (2005) hypothesized that an increase in echolocation rate during darkness may be a behavioural response by porpoise to compensate for the loss of visual information, while Todd et al. (2009) suggested an increase in the click trains with minimum ICIs <10 ms may be indicative of increased foraging due to a nocturnal increase in prey availability. A further factor, which may drive diel variations, will be the influence of tidal state on harbour porpoise distribution. Results showed no relationship between echolocation encounter rate and tidal phase.

Previous studies using PODs have shown that harbour porpoise are in the vicinity of commercial static gill nets much more often than they become entangled (SMRU *et al.* 2001a; Cox & Read

2004)). However, no studies have previously compared the echolocation behaviour of porpoises in the presence or absence of bottom set gill nets.

There was no significant difference in echolocation encounter rate, encounter length or encounter intensity recorded by PODs deployed with and without a net. However, the proportion of fast to slow trains was significantly higher when a net was deployed and there was a significant positive relationship between the proportion of fast trains in an encounter and encounter length. Fast click trains have been shown to be used when an animal locks its sonar onto an object during navigation or produces an echolocation buzz immediately prior to prey capture. The higher proportion of fast trains when a net is present could be interpreted as porpoises adjusting their bio-sonar to investigate or navigate around the net, or that there is more foraging opportunity when a net is there. Whether a higher proportion of fast trains in the presence of gill nets represents the closer inspection of nets acoustically by harbour porpoise or is an indicator of foraging remains unclear.

The target distance of each treatment to an echolocating harbour porpoise was calculated using the medians average ICIs and minimum ICIs for all encounters recorded by PODs with that treatment (Table 46). Target distance calculated from average ICIs ranged from 14.3 - 26.3 m when no net was present and from 15 – 19 m when a net was present. These estimates fall into the range of 13-26 m that Villadsgaard et al. (2007) recalculated for detection distances reported by Kastelien et al. (2000) using a higher source level of 191 dB re 1 µPa pp. Calculated target detection distances to the net with a single float line was 15 m for both deployment periods and ranged from 9.8 –18 m for the net with polypropylene floats.

Table 45: Estimated detection distances of different treatments using a lag time of 20 ms.

	Target distance (m) using median of average. ICI		**Target distance (m) using median of min. ICI**	
Deployment	**No net**	**Net**	**No net**	**Net**
5 & 6	14.3	15.0	15.0	16.5
9 & 10	26.3	19.5	24.8	21.8
Deployment	**Floats**	**Single**	**Floats**	**Single**
1 - 4	9.8	15.0	7.5	12.8
7 & 8	18.0	15.0	15.0	18.8

If the median ICI really does represent the average detection range of a porpoise to a net then these results raise a number of questions. We would expect that detection ranges would be greater when a net is present than when no net is present, but this is only the case for deployments 5 & 6 and is opposite for deployments 9 & 10. Likewise we would expect that a float line with polypropylene floats would be detected at greater distances than a net with a single polypropylene float line. However, this is only the case in deployments 7 & 8. Given there is no difference in detection ranges with or without a net it would suggest that animals are detecting the PODs possibly before the nets. This is not illogical given the target strength of a POD is –1.8dB and therefore provides a strong returning echo to an echolocating porpoise.

Only limited data were available to investigate the movement of harbour porpoise around gill nets. Results show that porpoises moved between treatments in the array but also circumnavigated the array. Over 50% of encounters were recorded by both PODs deployed within a treatment, suggesting that for a high proportion of time animals do indeed move along nets when they are present.

The most interesting result is the significant difference in the proportion of fast echolocation clicks produced by porpoise when they are in the vicinity of a net compared to when no net is present. But it is impossible to say whether these faster click trains are related to closer acoustic inspection of the net or are indicative of foraging behaviour.

Only a small proportion of encounters contained a feeding buzz ratio that was greater than 1 in Bridlington (3%), while the proportion in recorded in the Southwest was slightly higher (10%). However, calculating feeding buzz ratio using all trains in an encounter may produce an underestimate of the true ratio, as depending on encounter length, a higher number of navigational trains may be recorded. The effect of float line type on echolocation activity was more ambiguous.

These results support previous observations that harbour porpoise are in the vicinity of nets more often than they become entangled. They also suggest that porpoises may be foraging around nets. Kindt-Larsen (2007) analyzed the stomach contents of bycaught harbour porpoise and hake captured during the same haul in a commercial static gill net fishery in Denmark. Kindt-Larsen found no significant overlap in prey items in the stomachs of porpoise or hake, though her sample sizes were small. Clearly, further evidence will be needed to confirm that harbour porpoise are actively foraging around gill nets. This is important in that foraging may increase the risk of entanglement to a foraging individual under a number of scenarios. The target strength (TS) of the prey item it is approaching may mask echoes from the net mesh and therefore the porpoise may not detect the net, resulting in entanglement. Or, the porpoise may not concentrate on the closeness of a net in the final moments of prey pursuit. Harbour porpoise have been observed to forage by bottom grubbing. During this foraging behaviour an animal positions its rostrum close to the seabed, focusing its echolocation clicks downwards (Stenback 2006). It is clear that animals engaged in such behaviour would have a lower likelihood of detecting a bottom set gill net before entanglement would occur, or during foraging may get closer than intended to a net it has previously detected.

8. Spatial management.

The project included an objective to address the possibility of matching animal movements with the distribution of fishing effort, with the aim of being able to identify times and areas of highest risk of entanglement. A possible avenue for research may be to examine in detail how animals behave in the vicinity of fishing fleets, particularly common dolphins that appear to be attracted to fishing vessels such as pair trawlers. This lethal attraction is poorly understood. One potential way to address this may be to attach electronic tags to animals and then examine how they move in relation to fishing vessels. This objective was not pursued very far as there are considerable welfare implications of trying to catch free swimming animals and attach tags to them.

Trying to understand how fisheries and marine mammals overlap in their distribution and how animal behaviour and animal density may influence bycatch rates is an important research area and an important topic to address in trying to understand interactions between these two groups. Although theoretically tagging could help with this, it is unlikely that this will be acceptable in the UK in the foreseeable future, though porpoises and other cetaceans have been successfully tagged in Denmark. Other approaches my involved the use of passive acoustic monitoring, and indeed this was attempted under Objective 3 described above, but we found that the passive acoustic devices that we were using (CPods) were not suitable for this task. Other measures including towed and vertical hydrophone arrays are currently being developed at the SMRU with funding from Scottish Government, and these tools may yet prove useful in quantifying behaviour of vulnerable cetaceans around fishing gear.

9. Trials conducted elsewhere in the EU or internationally.

In this section we summarise information on cetacean bycatch mitigation trials that have been conducted elsewhere. These include trials and other research addressing acoustic deterrents (pingers), gill net modifications, trawl excluders and modifications to other gear types.

Pingers.

Pinger effectiveness in commercial gill net fisheries.

The first widespread experiment using pingers in a commercial fishery was conducted in the Gulf of Maine set gill net mixed fishery in the mid-1990s where a 92% reduction in harbour porpoise bycatch was recorded (Kraus *et al.* 1997). Pingers have become an integral part in two bycatch reduction strategies in the US for the Gulf of Maine set gill net fishery and the California drift gill net fishery.

Palka et al.(2008) found that the reduction in harbour porpoise bycatch rates in US Atlantic gill net fisheries that are required to use pingers was between 50-70%, depending on the time, area and specific gear characteristics (mesh size). Observed bycatch rates in hauls without pingers remained higher than those in hauls with pingers deployed. The reduction in pinger effectiveness from the 92% reduction reported by Kraus et al. (1997) in an experimental trial is partially due to a lack of compliance in some years. Observed compliance rates have ranged from 3%-8%. In addition, the proportion of pingers, which were actually functioning when tested, ranged from 36% to 87%. The study found no temporal trends in bycatch rates in nets with pingers suggesting that harbour porpoise had not habituated to pingers. Likewise the long term deployment of pingers in the Danish wreck net fishery has not resulted in an increase in harbour porpoise bycatch rates (Vinther & Larsen 2004).

Additional, short term, pinger trials in commercial fisheries have also observed a reduction in bycatch rates for a number of marine mammal species, including harbour porpoise (*Phocoena phocoena*) (Trippel *et al.* 1999; Gearin *et al.* 2000; SMRU *et al.* 2001b; Larsen, Vinther & Krog 2002), Franciscana (*Pontoporia blainvillei*) (Bordino *et al.* 2002), beaked whale species (Carretta, Barlow & Enriquez 2008) and short-beaked common dolphin (*Delphinus delphis*) and California sea lion (*Zalophus californianus*) (Barlow & Cameron 2003a).

More recent trials have focused on testing the efficacy of newer pinger models and to investigate the minimum spacing between pingers required to maintain a reduction in marine mammal bycatch rates.

The results of a pinger trial, conducted by DIFRES in 2006, in a Danish bottom-set gill net fishery found that harbour porpoise bycatch rates could still be minimised when pingers were deployed at a spacing of up to 455 m. This is now the minimum spacing required under Danish national administrative law (ICES 2009). The Irish Sea Fisheries Board (BIM) also conducted a study during 2006 and 2007 to determine the number of pingers required on fishing gear to reduce cetacean bycatch rates. Due to low bycatch rates, no statistical difference was observed between control nets or those with a pinger spacing of 200 m or 600 m.

In 2009, three types of pinger (Aquamark 100, Marexi V2.2, DDD-02) were tested in a trammel net fishery in the Iroise Sea, off the west coast of Brittany, France. The DDD pingers were attached at each end of a tier of nets, while the Aquamark and Marexi pingers were attached at a spacing of 400 m and 200 m intervals respectively. A total of 465 km of control and 150 km of nets with pingers were monitored. Observed bycatch rates in control and pingered nets were too low to allow statistical analysis. However, two harbour porpoise were caught in nets equipped with Aquamark pingers while no marine mammals were caught in nets deployed with Marexi or DDD pingers (ICES 2010)

A study in the Black Sea in 2009 showed that harbour porpoise bycatch rates in a turbot gill net fishery in the Black Sea were significantly reduced in nets with Dukane NetMark 1000 pingers. There was no significant reduction in target catch in control or pingered nets
A trial to test the effectiveness of SaveWave pingers at reducing cetacean bycatch is ongoing in the Netherlands. The project will use voluntary reporting of pinger effectiveness and bycatch rates by fishermen involved in the trial. The trial will end in 2012 (ICES 2010).

A pinger with a 10 kHz signal deployed at a spacing of 100 m was tested in a gill net fishery in Queensland, Australia. There was no difference in the bycatch rates of inshore bottlenose dolphins between control and pingered nets although sample sizes were small (McPherson *et al.* 2004).

Pinger tester device.

In the USA, the Northeast Fisheries Observer Program has contracted a company called EVO (Connecticut) to design and manufacture 30 devices to test the operational status of pingers used in the Northeast sink gill net fishery. These devices are presently being field tested but will not be used as an enforcement tool. Instead the aim is that independent onboard observers will be able to determine whether pingers deployed on gill net gear are functioning properly so these data can be used to evaluate the overall effectiveness of pingers at reducing harbour porpoise bycatch rates in this fishery (ICES 2011).

Developing and testing of pingers to mitigate marine mammal bycatch in trawl fisheries.

In 2004/2005 the Fisheries Research and Development Corporation (FRDC) in Western Australia funded a project to test the effectiveness of pingers and exclusion grids with the aim of reducing dolphin bycatch in a bottom trawl fishery at Pilbara. Video footage collected from 14 of these tows was deemed to be of sufficient quality to count the number of dolphins recorded on screen during tows with or without pingers deployed. There was no significant difference in the number of dolphins counted on screen between tows with or without pingers (Stephenson & Wells 2006).

Field trials were conducted to assess the effects of a prototype pelagic trawl acoustic deterrent and an interactive pinger on bottlenose dolphins in the Shannon Estuary, Ireland (Leeney *et al.* 2007). Dolphins were observed to display evasive behaviour to both pinger types when deployed directly in the water from the boat on all but two occasions. Significantly fewer echolocation clicks were recorded on TPODs when the continuous pinger was active, but no difference was found when the responsive pinger was active. The authors could not explain why no change in behaviour was observed on two occasions that an active pinger was deployed from the boat

IFREMER and a French company called Ixtrawl developed a prototype pinger, the Cetasaver, for use in trawl fisheries. This pinger was tested in the French pair trawl fishery for bass in 2007 and 2008. Results suggested a 50% - 70% reduction in the bycatch rate of common dolphins in this fishery when the Cetasaver is deployed (ICES 2009).

BIM conducted a trial in February 2009 to test the response of common dolphins to recordings of killer whale vocalizations, as a first step to see if such sounds could be used in an interactive pinger to mitigate cetacean bycatch in pelagic trawl fisheries. However, no effect on common dolphin behaviour was observed during this trial or a further trial conducted in January 2010 (ICES 2011).

Acoustic mitigation of depredation.

A number of studies have investigated the effectiveness of pingers at reducing bottlenose dolphin depredation of static nets in various regions of the Mediterranean Sea. (Gazo *et al.* 2001; Northridge, Vernicos & Raitsos-Exarchopolous 2003; Brotons, Grau & Rendell 2008; Buscaino *et al.* 2009). While all these studies reported an increase in catch and decrease in damage to catch in nets with pingers deployed, interactions with bottlenose dolphins were not completely stopped by using pingers.

A study was conducted to investigate the behavioural response of bottlenose dolphins to Dukane NetMark 1000 deployed on a Spanish mackerel gill net in North Carolina, USA (Cox *et al.* 2004). Results showed that the pingers displaced dolphins in a subtle manner from the net. The authors suggest that the use of pingers may result in an increase in interactions between bottlenose dolphins and these nets if exposure to these sounds is positively enforced with an opportunity to depredate directly from a net or forage on discards from a hauled net.

A further trial (Burke 2004) of pingers in this fishery deployed SaveWave pingers which have been specifically designed to reduce dolphin depredation of fishing nets. During the study overall depredation rates were too low to assess whether these devices had any effect on mitigating this behaviour. However, observation on the behaviour and proximity of bottlenose dolphins to the nets was found to be similar when active pingers were deployed to when no pinger was present. The authors conclude that the SaveWave pingers did not dissuade animals from engaging closely with these nets.

A study in the Baltic sea found that the use of acoustic harassment devices in a salmon-trap fishery resulted in a decrease in the amount of seal damage of catch, and an increase in target catch (Fjalling, Wahlberg & Westerberg 2006). However, as the fishing season progressed, damage to catch was also noted in nets with acoustic harassment devices deployed. The acoustic harassment devices used were purpose built for this study.

Behavioural responses of marine mammals to the deployment of acoustic deterrent devices.

A number of studies have been conducted to investigate the behavioural responses of cetaceans to pingers. Unlike trials in commercial fisheries, these studies have used different experimental set ups, and have either used simulated nets, just pingers with no nets, or they have been investigated on captive animals. An area of exclusion around different makes of pingers has been shown for harbour porpoises (Koschinski 1997; Laake, Rugh & Baraff 1998; Gearin *et al.* 2000; Cox *et al.* 2001; Carlstrom, Berggren & Tregenza 2009), Hector's dolphins (Stone *et al.* 2000) bottlenose dolphins and tucuxi (*Sotalia Fluviatilis*) (Monteiro-Neto *et al.* 2004). Other studies have focused on whether cetaceans may habituate to pingers, as such habituation may result in an increased probability of entanglement. Habituation of wild harbour porpoise to pingers, defined as a reduction in the exclusion effect of pingers over time has been shown (Koschinski 1997; Cox *et al.* 2001). A study on captive harbour porpoise found that displacement to sound playback waned over multiple sessions and in some sessions the animals were observed very close to the sounds source (Teilmann *et al.* 2006). Kastelien et al. (2006) tested the effects of an experimental pinger on a captive striped dolphin and harbour porpoise. While the harbour porpoise was displaced by the active pinger, an effect which did not wane over the 15 minute test period, no change in distance to the active pinger was noted for the striped dolphin (Kastelein *et al.* 2006).

An ongoing study is investigating the distances at which AQUAmark100 pingers affect the behaviour of harbour porpoises and whether habituation occurs after prolonged exposure, using data collected by an array of CPODs deployed at different distances from the pinger. The first trial was conducted in the Great Belt, Denmark and preliminary results showed a significant effect on harbour porpoise behaviour out to a distance of 1600 m from the pinger. Some degree of habituation behaviour was also reported. A further trial using the same pinger has been conducted in St Andrews Bay, Scotland (see above). A further trial using a DDD pinger is also planned (ICES 2011) .

Despite indication of some reduction in porpoise aversiveness to pingers over time, the long term deployment of pingers in US Atlantic gill net fisheries and a Danish bottom-set gill net fishery have not resulted in an increase in harbour porpoise bycatch (Vinther & Larsen 2004), which indicates that if there is any waning in the aversive reaction of harbour porpoises to pingers, such a change is not great enough to result in an increase in bycatch rates.

Finally a field trial on the effects of BASA pingers on dugong in Moreton Bay, Australia found that there was no change in either the behaviour or nearest approach of dugong when pingers were active or inactive (Hodgson *et al.* 2007).

Gear modifications: gill nets.

The effect of hanging ratio on the bycatch rates of harbour porpoises and seals was investigated in a two year study conducted in the USA. Bycatch rates of both cetaceans and pinnipeds were similar in gill nets hung on a 3:1 and 2:1 ratio (Inc 2010).

The use of tie downs is mandatory for specified gill nets in the US north Atlantic as they have been associated with a reduction in harbour porpoise (Palka 2000) and common dolphin bycatch rates (ICES 2011). Tie downs are lines that are shorter than the height of the fishing net and are connected to the float line and lead line of the net at equal distances along the net. Tie downs reduce the profile of the gill net, and also make the net webbing more baggy.

A number of studies have focused on the development and testing of nets made with nylon filled with Barium Sulphate or Iron Oxide to increase the density of the net and therefore the detectability of gill nets to echolocating cetaceans ((Trippel *et al.* 1996; Mooney, Au & Nachtigall 2004; Koschinski *et al.* 2006; Larsen, Eigaard & Tougaard 2007; Mooney *et al.* 2007)). Studies investigating acoustic properties of both barium sulphate and iron oxide net using generated broad band dolphin like clicks and narrowband porpoise click found that the target strength of both nets was greater than comparable nylon nets at or near perpendicular angles, but predicted detection ranges of animals would decrease greatly with an increased angle of incidence to the net ((Mooney, Au & Nachtigall 2004; Mooney *et al.* 2007). Mooney et al. (2007) also found that although iron oxide nets had a higher density, they had a lower target strength than barium sulphate nets. In comparison a separate study comparing experimental iron-oxide cod nets and standard cod nets found no significant difference in target strength between the two materials Larsen, Eigaard & Tougaard 2007). Although results of some field trials have shown a reduction in harbour porpoise bycatch in chemically enhanced nets (Northridge *et al.* 2003; Trippel *et al.* 2006; Larsen, Eigaard & Tougaard 2007) others have shown no such reduction (Northridge *et al.* 2003).

A recent study in Argentina also found no significant reduction in the bycatch rates of Franciscana dolphins in either barium sulphate nets, or chemically stiffened nets. A second trial with this species is currently being conducted in Brazil. Furthermore a study to investigate the echolocation behaviour of harbour porpoise around chemically enhanced gill nets found no difference in the echolocation rates of porpoises around these nets compared to standard commercial gill nets, and concluded that observed reductions in bycatch in these nets was likely to be due to the mechanical properties of these nets rather than their acoustic properties (Cox and Read 2004). It is clear that cetaceans will only detect acoustically enhanced nets if they are echolocating.

Plans are currently underway in the USA to test the effect of net height on porpoise bycatch rates (Milliken Pers. Comm.)

Excluder devices.

Excluder devices are commonly referred to in the literature as SEDs (seal excluder devices), SLEDs (sea lion excluder devices) or MMEDs (marine mammal excluder devices) according to the species interacting with the fishery. They generally consist of a grid placed in an extension in front of the codend, which prevents marine mammals and other large vertebrates from passing into the codend, and instead deflects them towards either a top or bottom opening escape hatch in front of the grid. Studies to assess the performance of excluder devices at mitigating cetacean bycatch have had mixed results (Northridge & Mackay 2005; Stephenson, Wells & King 2006a; Lyle & Willcox 2008). However, they have been shown to significantly reduce the bycatch rates of bottlenose dolphins in a bottom trawl fishery in Western Australia and are now mandatory in this fishery (Stephenson, Wells & King 2006b).

Sea lion excluder devices (SLEDs) are compulsory in a squid fishery that operates around the Auckland Islands in New Zealand. However sea lions bycatch rates were not significantly reduced by the use of these devices between 2004 and 2007 (Chilvers 2008).

Gear modifications: pot, trap and line fisheries.

Modifications to fyke nets have been shown to reduce depredation by grey seals in a study in Sweden (Konigson *et al.* 2007). A separate study in the northern Baltic Sea found that the modification of salmon and whitefish trap nets resulted in a reduction in the amount of sea damage to target catch. Highest reduction in catch damage was achieved by the use of a fish bag made of a tensioned double layer of netting (Suuronen *et al.* 2006).

Bycatch rates of Australian sea lions (*Neophoca cinerea*) in the Australian west coast rock lobster fishery were reduced by fixing a simple t-bar structure inside the pots, which prevented sea lions from depredating catch and from getting trapped in pots (Campbell *et al.* 2008). Bottlenose dolphin (*Tursiops truncatus*) depredation in a king mackerel troll fishery in the US was reduced using a prototype low cost simple modification to gear which dissuaded dolphins from interacting with the catch (Zollett & Read 2006).

10. Linking stranded animals to specific gears.

Introduction.

The original intention of this part of the project was to examine a number of stranded animals to try to measure aspects of gear scars or impressions on carcasses for which it might be possible to determine specific gear types. Specific gears may be identified from rope or twine structure or diameter and knot impressions than may reveal a mesh size.

In fact it was not possible to examine any beach cast animals during the duration of the present project. Logistical issues precluded members of our team from examining any beach cast animals at the Polwhele veterinary centre where many of the UK's stranded and bycaught animals are examined for post mortem.

We had examined two animals in collaboration with UK-CSIP staff at the Institute of Zoology prior to the start of the present project, and it was these examinations that led us to believe that it is possible in some circumstances to deduce specific gear types associated with entanglement if the right cues are looked for.

Workers in the USA have also addressed this issue to some extent, but have been mainly focused on trying to identify the origins of ropes involved in large whale entanglement. Burdett and colleagues ((Burdett, Adams & McFee 2007) describe a method of using a geographical information system to model the patterns (analogous to landscape mapping) made by the impression of rope on whales skin, which they claim can be used to help identify the type and nature of the rope involved. Several other US reviews have examined ways of identifying lacerations and impressions as being associated with fishing gear in general (Hare & Mead 1987; Haley & Read 1993; Read & Murray 2000). Most recently a handbook is under preparation in the US to help identify gear related injuries on stranded animals (Barco & Touhey 2007). None of these deals in much detail with the specifics of lesions or impressions left by specific fishing gear types.

Linking marks on animals to specific gear types.

The characteristics of fishing gear that may be important include the mesh size, which is specific for particular gill net types, and is also characteristic according to particular trawl types, the twine diameter of any rope or twine that is part of the gear, and the fine scale details of the twist of ropes or multifilament twines and of the knots associated with them.

It is also important to have some understanding of what types of lesions are likely to be found on bycatch animals. An analysis of our observer records has shown that the leading edge of the tail flukes as well as the rostrum and dorsal fin of bycaught animals are the regions most frequently marked. Other areas frequently marked include pectoral fins, the caudal peduncle and trailing edge of the flukes. Results of one such analysis of 48 bycaught porpoises are shown below (Table 46 from (Ball 2006)). Typically, gill net meshes will leave lesions on the leading edges of dorsal fins, pectoral fins and or flukes. Ropes associated with gill nets will often leave marks around the peduncle (though these may also be caused post mortem, but a high proportion of entanglement involve the headline of a gill net).

Table 46: Incidences of visible linear lesions on a sample of 48 bycaught animals

Marked	Location of linear lesions									n
	Nose Line	Head Line	Mid Body	Pectoral Fin (le)	Pectoral Fin (te)	Tail Stock	Tail (le)	Tail (te)	Dorsal Fin	
Yes	31	19	8	27	22	25	35	27	31	48
No	12	24	37	14	12	15	2	2	7	
Indeterminable	5	5	3	7	14	8	11	19	10	

The twine diameter can be assessed most easily by having to hand a selection of twine types used in local candidate fisheries. These can be compared with lesions in the skin and a twine of the correct diameter can be identified (see Figure 19)

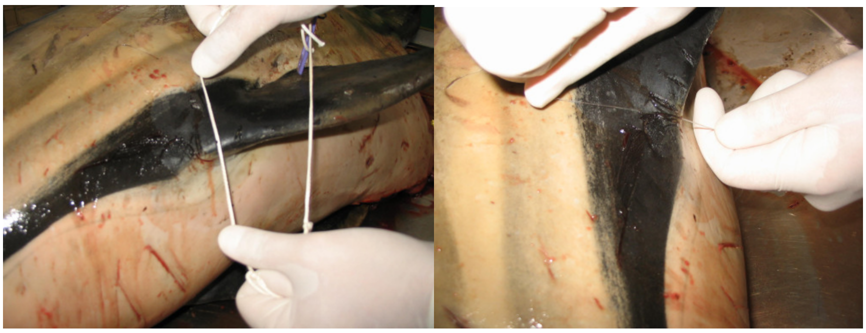

Figure 17: Representative twine types can be used to match lesions

Ropes marks – either lesions or simply impressions on the skin may be indicative of entanglement in fishing gear, but can also be caused post mortem. Sub-cutaneous haemorrhaging or bruising can indicate that the animal came into contact with the rope when still alive (Figure 20).

Figure 18: Sub-cutaneous haemorrhaging shows this rope mark was caused before death

Netting lesions are often found around the rostrum or head of an entangled dolphin or porpoise. Measuring the diameter of the circumscribing lesion will give a good idea of the primary or secondary mesh size, where the secondary mesh size is the size of four meshes after a single knot has broken in a net. Clear differences in primary mesh size can be seen among bycaught porpoises with circumscribing net marks around their rostrums and heads.

Netting can also leave impressions rather than lesions on the skin, where the skin records the pattern if the net. These can be detected on relatively fresh animals that have drowned in fishing gear. Here an important thing to quantify is the distance between junctions or knots, as this will reveal the bar mesh size of the gear involved. It may also be possible to use the impressions to gauge the twine diameter, though this is more difficult.

Ways to take this work forward.

Further work in this area will require collaboration between those with a detailed knowledge of fishing gear types and their use and those that perform necropsies on animals that strand. Additional information may be obtained through more detailed collection of data from animals reported by observers, but photography of such animals is difficult because of the risk of such photos being used inappropriately.

Examination of photographs of live animals may also shed some like on the likelihood of entanglement and escape, and this is a task that is being undertaken at present with regard to minke whales in Scotland with funding from Scottish Government.

11. Issues and Considerations.

Bycatch of protected species is becoming an increasingly important consideration in fisheries management, not just from an ecosystem management perspective, where optimising net benefits from the marine system may require management of fisheries to maintain non-target species at some predefined levels, but also from a marketing perspective. Increasingly the European buyer is being made aware of the collateral effects of fishing, and certification schemes that insist on bycatch assessment and mitigation are becoming prevalent. It is important therefore that industry, regulators, certifying bodies and indeed the general public have reliable and quantified information with which to make informed decisions about the need for bycatch mitigation.

Dolphins and porpoises have been the 'poster children' of this emerging concern, and much of the work that this project has addressed concerns these species. It is far from clear yet the extent to which fisheries represent a conservation threat to populations of these species in the waters immediately adjacent to the UK, largely because of the limited information on neighbouring European States' impacts on shared cetacean populations. Nevertheless, conservation status is not the only driver in this context, and public concerns have been raised even when bycatch levels are too low to cause serious conservation concern. Welfare issues have come to the fore.

Neither are concerns about cetacean conservation the only issues surrounding fishery bycatch. Increasingly other species, including sharks and seabirds are being considered as species that may be vulnerable to fishery bycatch. We have summarised information on these groups that we have collected so far, but we are still some way from being able to make an overall assessment of the scale of the bycatch of these species. It is clear that seals are subject to bycatch rates that are in general not much lower than those of porpoises. Anecdotal evidence suggests that this is largely related to depredatory activities. Among birds, guillemots are most frequently taken in static gear, and they appear vulnerable mainly to smaller meshed nets, mainly gill nets rather than tangle nets. Among elasmobranchs, tope are widely recorded taken in most static gears in the North Sea and the Southwest, though none was reported in Division VI west of Scotland. Shads (European protected species) are also widely recorded in gill nets in the North Sea, but less so in the Southwest.

Cataloguing the nature and scale of such bycatches is important mainly to identify those areas and species where some form of mitigation work is required. The current project has worked in a complementary manner to the on-going monitoring scheme in order to develop mitigation measures, specifically for cetaceans. To this end it is now clear that the acoustic deterrent devices that we have been testing (DDDs) – which are much louder than other devices currently being used – are effective in reducing porpoise bycatch in gill net and tangle net fisheries and they appear to satisfy the stated requirements of the Industry. Two aspects still need to be worked on. One is to develop an affordable multi-charging system and the second is to agree with regulators what an appropriate spacing might be for using DDDs. Theoretical and behavioural studies suggest that such devices may be effective out to around 2 km distance. However, bycatch reports suggest that some limited bycatch does occur as close as 1.2 km and there is no reason to believe that when used more widely bycatch might not be recorded even closer. It is important therefore to weigh the as yet unquantified risk of entanglement at distances of less than 2 km against the Industry's requirement for a practical mitigation measure. Despite these reservations, by the end of the present project, we anticipate that most of the >12m fleet of gill net boats in the Southwest will have access to DDDs.

Dolphin bycatch mitigation in gill nets remains a moot point, as we have not recorded sufficient bycatch events to be clear about the effectiveness or otherwise of DDDs for this species. However, DDDs do appear to be effective in minimising dolphin bycatch in pelagic trawl fisheries, and industry is keen to adopt these devices as a bycatch mitigation strategy. Indeed all the vessels involved have asked for supplies of DDDs to this end. Unequivocal evidence of the actual level of effectiveness of DDDs in the pelagic trawl fishery is still tantalisingly hard to define, as few control tows have been made without DDDs in this fishery in recent years. Nevertheless overall bycatch rates are substantially reduced and several key operational strategies have been identified that could form the basis of an as-yet unwritten code of conduct for best practice in this fishery.

Despite these positive steps in mitigating cetacean bycatch, concerns still remain about the use of acoustic deterrent devices in general. It would make sense to continue to investigate the nature and causes of cetacean bycatch, because it is by no means clear that it will be feasible to ensure all boats using gill nets are equipped with and use DDDs. This is particularly the case in regions of high gill net effort such as Iberia and the eastern English Channel, but also outside Europe in less developed countries. Two potential avenues for research in this area include an experimental examination of how net height and twine diameter influence bycatch rates. The former experiment is being planned in the USA, and the SMRU has the facilities and equipment to address the latter question.

Of more fundamental interest may be a more detailed study of how animals behave around actively fishing gear, using passive acoustic monitoring, to try to better understand how and why they get caught.

For many species of cetaceans, population numbers are low, and bycatch events so rare that it does not make sense to try to monitor their frequency with fishery observers. In such cases a better approach to assessing the scale of the interaction may be to examine live and freshly dead animals for evidence of typical lesions and skin marks. Some progress has been made with regard to large whale entanglement in the USA, and a similar approach has been adopted in Scotland with funding from Scottish Government. Further work in collaboration with sightings networks and the Cetacean Stranding's Investigation Programme could help develop this area of work.

Finally further work at integrating European bycatch observations, not just for cetaceans but for all potentially vulnerable species is required in order to identify any other areas where bycatch mitigation may be required. Mitigation techniques for other species, including sharks and seabirds, are being addressed in other parts of the world, and some of these approaches may translate into effective measures in UK fisheries if required.

It is critically important that if and when further mitigation trials are to be developed for cetaceans or for other species, that the fishing community is included in discussions of the merits of such trials from the outset, and that their pro-active engagement is facilitated. Vapid criticism of the industry will do nothing to benefit conservation.

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ANNEX: Pinger exclusion distance trial in St. Andrews Bay.

Preliminary Findings

By Lotte Kindt-Larsen, DTU-Aqua, Copenhagen

This study has investigated how porpoises reacted to a deterrent device (Aquamark100). Two problems have been assessed: First, is at which distances and time will porpoises habituate to pingers. Secondly, at which distances do pingers have a significant effect on the absence of a pinger. The expected result of this work will be an estimate of how large areas porpoises will be excluded from by use of pingers, thus making it possible to analyze the consequences of pinger use in harbor porpoise protected areas.

Methods

The UK Trail was collected in St. Andrews Bay between 20 September and 7dec 2010. A total of 14 C-pods were deployed in a triangle array (Figure 1) at 10-15m depth and placed 1,5m above the sea bed. The AQUAmark100 pinger was deployed in the center of the array together with two C-pods. The other 12 pods were deployed in distances of 200, 400, 800, 1600, 2400, and 3000 meters, two on each distance.

The *AQUAmark100* pinger emitted eight different signals, in random order (20 -160kHz) two with constant frequency and six with frequency sweeps. The mean source level and duration was 145db re 1µPa@1m (RMS) and 200-300ms respectively. The pinger was running by an internal clock in cycles of 23 hours on and off to simulate gill net fishery. The 23 hour cycle also reduced the effect diel variation since the time of ping start changed every day. The trial was initiated with a control period before and after measuring the porpoise's presence before introduction of the AQUAmark100 pinger.

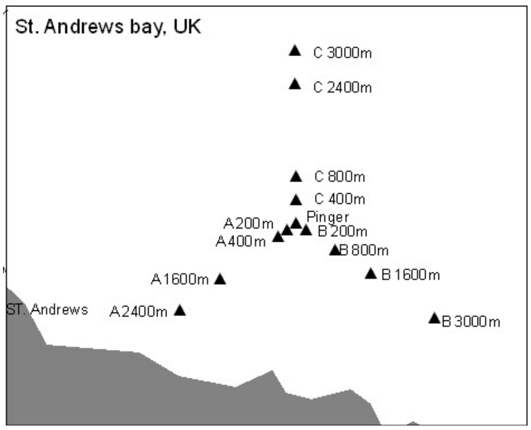

Figure A-1: C-pods and pinger placement in St. Andrews Bay, UK

Porpoise activity classification

The series of recorded clicks from the C-pods were classified as porpoise echolocation clicks by use of the C-pod software CPOD.exe (V1.054 Chelonia Ltd.) that filters the data for porpoise clicks automatically by use of a detection algorithm. Trains classified into quality classes Hi (high-probability cetacean trains) and Mo (Moderate-probability cetacean trains) were used as indicators for porpoise activity. The data were exported both as clicks in trains and detection positive minutes per hour. The hour when the pinger was changing from on/off were eliminated from the data set in order to remove recordings of porpoises which both had been exposed to pingers sounds and silence (control period).

Preliminary results

	Model 2
0 m ping7	0.002257 **
0m ping2	0.0001715 ***
A 200 m	1.406e-05 ***
A 400m	0.00692 **
A 1600 m	0.3113
A 2400 m	0.1373
B 200 m	
B 800m	0.4244
B 1600m	0.7538
B 3000m	0.6507
C 400m	0.3655
C 800m	0.2851
C2400m	0.09261
C3000 m	0.3536