Management of fisheries in harbour porpoise (Phocoena phocoena) marine protected areas

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Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
PhD Thesis
Management of fisheries in harbour porpoise (*Phocoena phocoena*) marine protected areas

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Management of fisheries in harbour porpoise (Phocoena phocoena) marine protected areas

Submitted April 2015

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TO EMIL & PERNILLE
Acknowledgements

Luckily, my Ph.D. has been filled with people who have helped me and whom I need to thank. I have been honoured with three excellent supervisors, and I want to thank you all. About 14 years ago, I meet Finn. You have been an outstanding mentor, a hard critic of my work, a fantastic sharer and a true friend. We have done so many things together over the years; I hope they will never end. Thank you. Bjarne you are probably the most enthusiastic teacher I ever had. You believe in the young like nobody else. With you around, everything is possible! Thank you for your support, weird solutions to problems, amazing discussions - but always with happy endings! Simon Northridge and your team, Alice Mackay and Alexander Coram, at the Sea Mammal Research Unit in Scotland. You are indeed a busy man and I truly admire your work. You have been a real inspiration.

There are also so many other people here at Aqua who have been a part of my Ph.D. and to whom I owe a great thank you. These include Jørgen Dalskov and Eskild Kirkegaard. Thank you all for introducing me to fisheries management and for trusting me with huge datasets and outreach from the beginning of the implementation of REM. Thomas Kirk Sørensen for insights into SAC, discussions and great travel and office companionship: you are one of the most dedicated people I know. Casper Berg for always trying, with great patience, to guide my teetering steps in the world of statistics. Rasmus Nielsen for the “battle” of having this Ph.D. recognised at DTU Aqua. Kerstin Geithner for your patience, great laughs and magic fingers during my work in GIS. Nina Qvistgaard for handling all the Ph.D. administration and for encouraging talks. My section leader Anna Rindorf and the staff of my section Ecosystem Based Marine Management and other colleagues at the institute for professional discussions, support and friendship.

A great thank you to all the fishers who participated in the projects, without you this Ph.D. would not have been possible. Nick Tregenza, POD father, for always sorting out POD questions. Jakob Tougaard for your support in modelling porpoise data, and I look very much forward to our future work. Thank you to Henning Bach and his crew from the Marine Home Guard, for their assistance in field work, encouraging talks and dedication to protecting our marine resources.


Alaska Sea Grant for inviting me to the 29th Lowell Wakefield Fisheries Symposium to present my work. NaturErhvervsstyrelsen, in particular Anja Boye. Mogens Schou for professional discussions on fisheries management and support during the years.

Brian Morton, I am so thankful. Thank for your words and thoughts, it has been a true pleasure. I hope we will meet one day. Kirsten Lindegaard Bovbjerg, Morten Tange Olsen, Jeppe Dalgaard Balle, Jacob Linnemann Rønfeldt, Grete Dinesen and Mads Rosenkilde for help along the way, input, long talks, technical discussions, friendship and helping hands. Especial thanks to my Dad for being so creative, my Mum for just being Mum and last but not least, Emil, for all the happy smiles, kisses and giving life a another perspective during the hard times.

Hellerup, April 7th, 2015

Lotte Kindt-Larsen
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Summary

The harbour porpoise (*Phocoena phocoena*) is the focus of a range of conservation efforts and policies aiming at reducing bycatch of the species in gillnet fisheries. In European waters, the harbour porpoise is protected within the Habitats Directive (Annexes II and IV), implying that the population has to be maintained at a favourable conservation status and the deliberate actions of killing and disturbance and habitat deterioration shall be prohibited in accordance with the directive’s aims. A spatial network, Natura2000, will further protect all Annex II species. According to Natura2000, Member States are obliged to nominate candidate protected areas in their waters to the EU Commission and within six years establish legislation to implement them as special areas of conservation and prepare management plans. Up to this point in time, however, no such management plans exist.

This Ph.D. thesis focuses on research methods and management tools, which can contribute to a better scientific understanding in the preparation of fisheries management plans for Natura2000 sites designated for harbour porpoises.

Firstly, it investigates the potential use of CCTV cameras to document bycatch of marine mammals. Here it is shown that Remote Electronic Monitoring (REM) systems installed on commercial fishing vessels can provide video footage, time and position of all net hauls and record bycatches of marine mammals. Comparisons between the visual analysis of the REM data and fishers logbooks showed that the REM system gave more reliable results since fishers did not, in many instances, observe the bycatch while working on the deck because it dropped out of the net before coming on board. Furthermore, REM provided high percentage coverage at low cost, compared to on-board observers.

Secondly, the suitability of using high-resolution spatial and temporal data on porpoise density and fishing effort data from the Danish Skagerrak Sea as a method to predict harbour porpoise bycatches was examined. The results showed that a simple relation between the two could predict bycatch and that the final model can thus be used as a tool to identify areas of porpoise bycatch risk and thereby support the management of both fisheries and harbour porpoises in accordance with the Habitats Directive.

Thirdly, the behaviour of porpoises in relation to two different pinger types with different acoustic properties was studied at three different locations. The results showed that at one location, the AQUAmark100 pinger had a significant effect on porpoise echolocation behaviour at 0 and 200 m distances, whereas another trial showed a significant reduction in such behaviour for up to 400 m. In none of the studies of the AQUA100 did the behaviour reveal any signs of habituation. Studies of the AQUAmark300, however, revealed clear habituation effects.

Fourthly and finally, the thesis describes the governance process and analyses its mechanisms and conflicts surrounding ongoing fisheries management planning with a focus on two Natura2000 sites in the Danish part of the Skagerrak Sea designated to protect harbour porpoises.
**Resumé**


Denne PhD fokuserer på implementeringen af Natura2000 i Danmark samt de metoder og forvaltningsværktøjer, der kan bidrage til den videnskabelige baggrund for udarbejdelsen af en forvaltningsplan for Natura2000 områder for marsvin.

Først beskriver afhandlingen den potentielle anvendelse af overvågningskameraer til at dokumentere bifangst af havpattedyr. Her er det vist, at elektroniske fjernovervågningssystemer (REM) installeret ombord på kommercielle garnfartøjer kan levere videooptagelser, tidspunkter samt placering for alle garnhal samt optage bifangster af havpattedyr. Sammenligne mellem den visuelle analyse af REM data og fiskernes bifangstregistreringer i logbøger viste, at REM-systemet gav mere pålidelige resultater, da fiskerne i mange tilfælde slet ikke opdagede de bifangede marsvin. Årsagen var, at marsvinene faldt ud af garnene før fiskeren nåede at registrere dem. En meget høj dækningsprocent kunne opnås til lave omkostninger ved REM sammenlignet med at have observatører ombord.

For det andet, bliver marsvins akustiske adfærd i relation til to forskellige typer af pingere med forskellige akustiske egenskaber på tre forskellige lokaliteter undersøgt. Resultaterne viste, at på en lokalitet havde AQUAmark100 pingeren en signifikant effekt på marsvins ekkolokalisering ud til 200m, mens en anden lokalitet viste en signifikant reduktion i ekkolokalisering ud til 400 m. I ingen af undersøgelserne af AQUAmark100 viste marsvinene tegn på eventuel habituering. Undersøgelserne af AQUAmark300 viste derimod tydelige tegn på habituering.

For det tredje blev egennetheden af detaljerede data om marsvinetætheder og fiskeriindsats undersøgt som en metode til at forudsige bifangst af marsvin i Skagerrak. Resultaterne viste, at et meget enkelt forhold mellem de to parametre kunne forudsige bifangster og den endelige model kan således anvendes som et redskab til identificere områder med høj risiko for bifangst af marsvin, og hermed støtte forvaltningen af fiskeriet og marsvin i overensstemmelse med Habitatdirektivet.

Til slut beskriver afhandlingen implementeringsprocessen og analyserer de mekanismer og konflikter, der eksisterer i forbindelse med fiskeri. Herunder er der særligt fokus på to Natura2000 områder i den danske del af Skagerrak, der er udpeget til beskyttelse af marsvin.
Aims of this PhD thesis

The Ministry of Environment has selected 16 marine areas (Natura2000 areas) to protect the population of harbour porpoise (*Phocoena phocoena*) in Danish waters. Since many of the areas are used by Danish commercial gillnet vessels, there is: (i), a need for knowledge on how such fisheries interact with porpoises in the areas and (ii), a need for ideas on how such fisheries can be managed to ameliorate any detected negative interactions. This Ph.D. was thus put forward to contribute to scientific knowledge relating to the management of fisheries in harbour porpoise Natura2000 areas.

The first aim was to find a cost efficient method of monitoring porpoise bycatch in gillnet fisheries since this is essential for identifying the magnitude of the bycatch problem and evaluate the potential effects of management regulations. A study was therefore undertaken, under the European Fisheries Fund (EFF), to collected data on the feasibility of using electronic monitoring, with video cameras, to determine the levels of harbour porpoise bycatches in Danish waters.

The second aim was to develop a model that could identify areas of high harbour porpoise bycatch risk. This study examined whether porpoise density and gillnet fishing could be used to identify high-risk areas for observed bycatches in the Danish Skagerrak Sea. The study was part of a larger project, MESMA (Monitoring and Evaluation of Spatially Managed marine Areas), financed under the European Union’s Seventh Framework Programme (FP7).

The third aim was to investigate different aspects relating to the use of acoustic alarms (pingers). The main focus of this study was habituation trials and investigations of the effective range from two different pinger types since, at present, these are the only methods used to reduce harbour porpoise bycatches without affecting fishing effort. The study was conducted as part of a larger pinger project, funded under the EFF and DEFRA (Department for Environment, Food and Rural Affairs, UK) programmes.

The last aim was to describe the governance process and analyse the mechanisms and conflicts surrounding ongoing fisheries management planning in Danish Natura2000 sites designated for harbour porpoise protection. The project was part of a larger governance work package conducted under MESMA and MYFISH (Maximising Yield of FISHeries while balancing ecosystem, economic and social concerns) also financed under FP7.

Based on the four aims listed above, the Ph.D. was structured into four parts. Each part has resulted in one of four papers that together have contributed to a better scientific understanding on issues relating to the management of fisheries and harbour porpoise protected areas. The thesis, however, sets the four papers into a more general introduction about: (i), harbour porpoises; (ii), the relevant policies implemented to protect them; (iii), bycatches and bycatch monitoring; (iv), mitigation tools; (v), Natura2000 plans for Denmark and other EU countries; (vi), regulatory tools and, finally,(vii), in a set of management recommendations and conclusions.
List of papers

The four papers listed below, will uncover tools and opportunities relevant for the management of harbour porpoises in marine protected areas. Paper I supports science and managers with a tool to monitor porpoise bycatch. Paper II identifies areas of high porpoise bycatch risk. Paper III provides information on the behaviour of porpoises in relation to acoustic alarms and, finally, Paper IV describes governance mechanisms in relation to the implementation of Natura2000 areas for harbour porpoises in Denmark. The papers will be referred to in the thesis by their respective roman numbers.


IV. Sørensen TK, Kindt-Larsen L & Jones P. Uncovering governance mechanisms surrounding harbour porpoise conservation in the Danish Skagerrak Sea. (Manuscript, ready for submission as a part of a special issue of European Policy).

(This paper was written as part of a Special Issue devoted to Marine Policy. The issue contains 13 papers each representing a different case study from the MESMA (Monitoring and Evaluation of Spatially Managed marine Areas) Project. The papers describe governance issues such as conflict analysis, degrees of integration, participation, transparency and accountability, equity and justice and uncertainty. The paper thus follows a defined structure for all papers submitted to the special issue to follow. A synthesis paper uniting all case studies is in progress. The submission of Paper IV, therefore, has to wait for the completion of this.)
1 Introduction
Marine habitat conservation for cetaceans has lagged behind land conservation. Even though habitat conservation for cetaceans may be featured increasingly in marine spatial planning, the identification, monitoring and management of such protected areas is challenging in the marine environment. Many of the species are highly mobile and difficult to monitor and whether or not their needs are being adequately met can thus be difficult to assess.

1.1 Cetaceans in Danish waters
The harbour porpoise (*Phocoena phocoena* [Linnaeus, 1758]) is distributed widely throughout the northern hemisphere and is the most common cetacean in Danish waters (Hammond et al. 2002, 2013). The harbour porpoise has a dark grey face and back, with a white or light grey belly. The species is well adapted to cold waters by having a robust body shape (normal length 110-130cm), thick blubber and no beak. Compared to other cetaceans they have relatively little room to store food and cannot, therefore, deposit energy efficiently and need to be in close proximity to their prey (Read et al. 1997, Bjørge & Tolley 2002). They are not, therefore, anatomically specialized and are, in general, believed to be opportunistic feeders. They prey on a variety of species although the Atlantic herring (*Clupea harengus*), has been documented to be one of the important prey species following analyses of the stomach contents of porpoises’ either bycaught or stranded in Scandinavian waters (Aarefjord & Bjørge, 1995; Börjesson et al. 2003).

Several populations and sub-populations of harbour porpoises are thought to exist in the North Atlantic and North Sea. In Danish waters, at least two populations have been recognized based on genetic studies; one in the southern part of the Kattegat, the Belt Seas and Western Baltic denoted as inner Danish waters and one in the North Sea including the Skagerrak (Andersen 2003, Wiemann et al. 2010). Accurate population estimates are difficult to obtain, although two large surveys have been conducted, that is, SCANS I and II (Small Cetacean Abundance in the North Sea and Adjacent waters) (Hammond et al., 2002, 2013). SCANS I (1994) estimated 36,634 porpoises in the inner Danish waters (strata I, X) and 169,348 porpoises in the North Sea (strata C, F, G, L, H, Y), where SCANS II (2005) estimated 19,129 (strata S) and 157,925 (strata V, U, L, Y, H) porpoises, respectively. Even though the estimate was lower in 2005 for inner Danish waters the two numbers were not significantly different. The lower estimate has, however, caused concern and in 2012 a mini SCANS was conducted covering only inner Danish waters. The mini SCANS monitored a slightly different area, as it did not include the Skagerrak Sea. Mini SCANS revealed a population estimate of 40,475 harbour porpoises (Viquerat et al. 2014) indicating no significant population trend in the area.

A third subpopulation exists in the Baltic Sea. This population has declined dramatically and sightings of these porpoises are rare in here (Berggren & Arrhenius 1995, Kochinski 2001, Berggren et al. 2004). Even though porpoise sightings in the Baltic are few and far between, a new project, SAMBAH (Static Acoustic Monitoring of the Baltic Sea Harbour porpoise), collecting data on their abundance using acoustic monitoring has, however, revealed that around 447 individuals exist in the proper Baltic (SAMBAH, 2014). Population numbers and structure in the Baltic are, however, still debated (Palme et al. 2008, Wiemann et al. 2010, Galatius et al. 2012).
1.2 Harbour porpoise conservation status and possible threats

Over the last 20 years, the International Union for Conservation of Nature (IUCN) has assessed the status of species, subspecies, varieties, and even selected subpopulations of cetaceans on a global scale in order to highlight taxa threatened with extinction, and therefore promote their conservation. IUCN has classified the Baltic Sea subpopulation of harbour porpoises as “critically endangered” whereas the other subpopulations, such as the North Sea are of “least concern” (Hammond et al. 2008).

The populations of harbour porpoises face several potential risk, such as noise, constructions at sea, pollution and their incidental bycatch in gillnets, as follows:

Noise can influence the detection range of any sonar system and there is an increasing concern about the effects of human-induced underwater sounds upon marine mammals (Richardson 1995, Popper 1980 NRC, 2000, 2003, 2005). Noise may also mask natural sounds, impair communication and affect prey detection negatively (Au 1993). Harbour porpoises are, however, often observed in areas with heavy ship and boat traffic (Sveegaard et al. 2011a). The constructions of offshore wind farms and the potential impacts of these on harbour porpoise echolocation activities have been investigated and showed that the species’ habitat use changed considerably in a construction area (Carstensen et al. 2006, Tougaard et al. 2009).

The uncontrolled use of persistent organochlorine chemicals like PCBs (polychlorinated biphenyl) in the 1960’s and 1970’s have been described as one of the reasons for the population decline seen in the Baltic Sea (Teilmann & Lowry 1996). PCB and pesticides like DDT are relatively poorly metabolised and excreted by animals. As a consequence, species higher up the food chain tend to accumulate these organic pollutants resulting in them being sequestered in the blubber and concentrated in the maternal milk with adverse impacts upon suckling infants (Parsons 2004). PCBs have also been claimed to be responsible for immunological deficiencies and reproductive abnormalities (Bruhn et al. 1999) and organic pollutants such as organochlorines have been recorded in marine mammal tissues (Reijnders 1992). No evidence has been identified for pollution effects on harbour porpoise survival, although they should still be regarded as a potential threat (Reijnders 1992, Breggren et al. 1999).

The incidental bycatch in gillnets is regarded as the largest threat to small cetaceans. Monitoring of marine mammals bycatch has therefore been conducted worldwide (Read et al. 2006). Records of marine mammal bycatch in Danish waters have been collected from 1992-1998 for the bottom-set gillnet fisheries in the North Sea. Extrapolation of the observed data gave an estimated total annual bycatch of 5.591 porpoises in the period 1994-1998 (Vinther 1999, Vinther & Larsen 2004). Since then, no annual bycatch estimates have been obtained for Danish waters. Bycatch rates of porpoise have, however, recently been estimated by ICES WGBYC (Working Group on BYCatch). The estimation revealed a yearly bycatch between 110 and 219 (min/max) porpoises in the Kattegat and Belt Seas and 1235 and 1990 (min/max) porpoises for the North Sea (ICES 2015). These estimates, however, cover other waters as well as Danish seas. New initiatives on porpoise bycatch monitoring in Danish waters have been established (Paper 1) and projects collecting information on this are ongoing.
1.3 Nature conservation in EU


1.3.1 The Habitats and Birds Directives and Natura2000

In order to ensure the survival of Europe’s most endangered and vulnerable species, EU governments adopted the Habitats Directive in 1992. Together with the Birds Directive, it sets the standard for nature conservation across the EU and enables all 27 Member States to work together within the same strong legislative framework in order to protect the most vulnerable species and habitat types across their entire natural range within the EU. The Habitats Directive protects around 1200 European species other than birds, which are considered to be endangered, vulnerable, rare and/or endemic. Included in the Directive are mammals, reptiles, fish, crustaceans, insects, molluscs, bivalves and plants. The protection provisions for these species are designed to ensure that the species listed in the Habitats Directive reach a favourable conservation status within the EU (EC 1992).

The concept of favourable conservation status in the Habitats Directive was derived from the Bonn Convention (CMS 1979). In this, the favourable conservation concept is applied only for endangered migratory species included in Appendices I or II, while in the Habitats Directive it is used for both habitat types listed in Annex I and species listed in Annexes II, IV and V. Not surprisingly, the two definitions of FCS for species are practically identical.

The key criteria for FCS of habitats are: (1), a stable or increasing natural range; (2), the long-term survival of its specific structure and functions and (3), the favourable conservation status of its ‘typical’ component species. The criteria for FCS of species are: (1), the population dynamics of the species indicate good chances for the long-term survival in its natural habitats; (2), the natural range of the species must be stable or increasing; (3), there is, and will continue to be, a sufficiently large habitat to maintain its populations on a long-term basis.

FCS belongs to a family of environmental concepts closely related to the precautionary principle or precautionary approach. The precautionary approach is a means to respond to and act upon a perceived conservation threat in the absence of information or scientific proof. The concept behind this definition is that beyond some threshold level the risk of serious or irreversible changes is thought to markedly increase, although the scientific evidence for such an increase may not yet be conclusive. Setting a target conservation level, such as the FCS of a habitat type or a species is, thus, inevitably a precautionary act, as it is assumed that failing to maintain or achieve the targeted level may result in a potentially irreversible loss, that is, an extinction. It is also typified by the notion that scientific consensus as to what constitutes the optimal target level in conservation is lacking (Berrens 2001).

Furthermore the Habitats and Bird Directive require the establishment of a network of designated sites, named Natura2000. Under the Habitats Directive these are termed as Special Areas of Conservation, SACs under the Birds Directive Special Protection Areas, SPAs. The Directives contain annexes with
habitats and species listed, and whose conservation requires the designation of sites by Member States. Habitats and species for which Natura2000 sites are designated must be maintained in a ‘Favourable Conservation Status’ (FCS) (EC 1979, 1992).

Even though the Habitats Directive lay down certain goals that must be achieved, each Member State is free to decide how to transpose directives into national laws. The Habitats Directive has thus been transposed into Danish National Law as “Naturbeskyttelsesloven” – or, the “Nature Protection Law”. This law aims to protect nature, with its population of wild animals and plants and their habitats and the scenic, historical, scientific and educational values that enhance, restore or create areas that are of importance for wild animals, plants, landscape, cultural and historical interests, and provide access for people to move and reside in the countryside and improve opportunities for outdoor recreation.

1.3.2 Council Regulation 812/2004
EU member states are further obliged to fulfil Council Regulation 812/2004, which lays down measures concerning the incidental catches of cetaceans in fisheries (EC 2004). In short, the regulation promulgated, that Member states should minimise the impact of fishing activities on marine ecosystems, monitor the incidental captures and killings of protected cetaceans and ensure that the captures do not have a significant impact on the species concerned. It also requires that Member states collect scientific information and techniques on developments to reduce the incidental captures of cetaceans, implement acoustic deterring devices in areas and fisheries with known or foreseeable high levels of cetacean bycatch and establish the technical specifications for the efficiency of such devices. Furthermore, it prohibits the use of drift nets in the Baltic Sea from 2008.

In Denmark, Council Regulation 812/2004 proclaims that acoustic devices (pingers) should be prescribed in ICES-area IV and section IIIa. The pingers are obligatory for vessels larger than 12m in all gillnet fisheries with net fleets of ≤400m and on gillnets with mesh sizes of ≥220mm (EU 2004).

Different from directives, regulations are legally binding throughout every Member State and enter into force on a set date in all Member States.

1.3.3 ASCOBANS
ASCOBANS (Agreement on the conservation of small cetaceans of the Baltic and North Seas) entered into force in 1994 (ASCOBANS 1994). This is a regional agreement on the protection of cetaceans under the Bonn Convention. ASCOBANS covers all species of toothed whales (Odontoceti) in the agreement area, with the exception of the sperm whale (*Physeter macrocephalus*). In February 2008, an extension of the agreement area came into force, which changed the name to “Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas”. The agreement is signed by Belgium, Denmark, Finland, France, Germany, Lithuania, Netherlands, Poland, Sweden and United Kingdom and does thus not cover the whole EU. The aim of the ASCOBANS agreement is to achieve a favourable conservation status for small cetaceans. Different rules are described in the agreement regarding habitat conservation and management. Over the years ASCOBANS has adopted various resolutions. The most cited is, however, the one on incidental take that aims to reduce bycatch to levels not exceeding 1.7% of the population.
Further three action plans for harbour porpoises specific to the situation in different parts of the agreement area have been concluded to date.

1. Jastarnia Plan, a Recovery Plan for Baltic Harbour Porpoises (ASCOBANS 2009a)
2. Conservation Plan for Harbour Porpoises in the North Sea (ASCOBANS 2009b)
3. Conservation Plan for the Harbour Porpoise Population in the Western Baltic, the Belt Sea and the Kattegat (ASCOBANS 2012)

The main difference between the ASCOBANS agreement and the Habitats Directive and Regulation 812/2004 is that the ASCOBANS agreement is not legally binding.
2 Monitoring of bycatch

As described, the various populations of harbour porpoises face several potential risks and incidental bycatch in gillnets is, in many cases, regarded as the largest threat to small cetaceans (Section 1.2). Monitoring of marine mammals bycatch has therefore been conducted worldwide (Read et al. 2006).

Bycatch monitoring can be conducted using a number of different methods but, in most cases, on-board observers are recommended as a means of collecting accurate data (IWC 1994). The use of on-board observers is, however, costly (EP 2010), and new methods using CCTV (Closed-Circuit Television) to monitor bycatch of marine mammals have showed promising results in lowering costs and increasing coverage (Paper I). The implementation of CCTV-based monitoring in Denmark began in 2008. Here, the Danish Government suggested that utilization of marine resources in the revised EU Common Fisheries Policy (CFP) should follow a results-based approach, with the simple requirement that the fisher accounts for his total removal of fish from the resource rather than the landed catches (FVM 2009). By introducing full accountability through catch quotas instead of landing quotas, the fisher’s incentive to optimise the value of his catch by discarding less valuable fish would be replaced by his incentive to use selective fishing methods and thereby optimise the value of his catch and reduce total removals from the fish stocks. To achieve this objective, the fisher should receive increased quotas (catch quotas) to ensure that all fish are accounted for. A catch-quota management system with a fully documented fishery provides assurance that quotas can actually be administered within an absolute limit, so that catch limits become an exact expression of set fishing mortality. To test whether a catch-quota management system could work and whether full documentation of fisheries is possible using electronic monitoring systems, the National Institute of Aquatic Resources (DTU Aqua) carried out a scientific trial from 2008 to 2009 deploying remote electronic monitoring (REM) systems on board six Danish commercial fishing vessels including one gillnetter, four trawlers and one Danish seiner. Using an arrangement of CCTV cameras, hydraulic sensors and GPS tracks, the REM systems provided video footage and time and position data for all net hauls, which were analysed for discards of cod (*Gadus morhua*). The results showed that the REM system could provide the documentation required to support the catch quota management system (CQMS) and that it was an incentive for participating fishers to avoid discarding cod (Kindt-Larsen et al. 2011).

After the project finished, Danish fishers have had the opportunity to voluntarily become part of the CQMS. This is now managed by the Danish AgriFish Agency and, today, eighteen vessels participate in the scheme (the total national commercial fishing fleet is approximately 1600 vessels).

2.1 REM to monitor bycatch of marine mammals

The video footage collected under the CQMS indicated that bycatch of marine mammals could be monitored using REM (Kindt-Larsen et al. 2011). Consequently, a pilot trial was conducted to evaluate the feasibility of using REM to observe incidental bycatch of marine mammals and test if it could increase monitoring levels and reduce the cost of bycatch observations (Paper I).

In the trial, six Danish commercial gillnetters, 10 to 15 m in length overall (loa) operating under CQMS, were equipped with REM systems. The trial was conducted from 1 May 2010 to 31 April 2011 in the North Sea, Skagerrak and Øresund. The REM systems recorded time and position of all net sets and video footage of all net hauls including the bycatches of marine mammals. The enrolled fishers filled out a daily supplementary logbook noting down trips (start and end), hauls (soak time and number of nets), gear (mesh size), catch and incidental bycatches of cetaceans and seals. The spatial and temporal parameters of
each haul and all video footage were analysed by staff trained in the EMI software (Europe release, Archipelago Ltd. V.11.3. 11189) (Paper I).

The results from the trial revealed that, in general, the REM system worked well. When comparing the hours at sea from official logbooks with hours collected from the sensor data, a mean coverage of 86% of the REM fishery was achieved and the bycatch of marine mammals was easily detected on the video footage. A total of 36 porpoises were recorded on the video footage (Fig. 1). The fishers’ supplementary logbooks reported only 25 porpoises caught. Three porpoises, which were reported in the logbooks, could not be found in the video footage. Fourteen porpoises were not reported in fishers’ logbooks but were identified in the videos; seven of these were not seen by the fishers. This indicated that the REM system gave more reliable results, since fishers in many cases did not observe the bycatch while working on the deck because the porpoise had dropped out of the net before entering the hauler (Paper I). In contrast, the REM system recorded the gillnet hauls continuously.

![Figure 1: Positions of porpoise bycatch and gillnet hauls. Grey dots = haul positions, stars = porpoise bycatch positions.](image)

Even though the pilot trial documented that the REM system was stable and useful for documenting porpoise bycatch, there are both strengths and weaknesses in using such systems. For example, the system control box was sensitive to unstable power supplies. Installation of uninterruptible power supplies could, therefore, minimize such fallouts. In addition, water droplets, waves and glare lowered the quality of the video but never, however, to such an extent where bycatch detection became impossible. Analysis of the
video footage revealed different numbers of bycatches compared to the fishers’ logs. Missing bycatches were due to either forgetfulness or because the porpoise had dropped out of the net before the fishers saw them. From the videos, it could be verified that many porpoises tended to drop out when they broke the surface, due to their heavier weight in air than in water. It is, however, possible that porpoises could drop out of the net while still under water and therefore be missed on the videos. We believe, however, that the REM system will have a similar detection rate as observers looking over the side of the vessel watching all net hauls. It is important, therefore, that the cameras cover the position where the net breaks the surface since, as noted above, some porpoises fall out at that specific point (Paper I).

One of the major concerns when working with large datasets of video footage is the time needed for analysis. The EMI programme restricted the video review to the hauling periods only, thereby limiting the time spent on data review. When comparing the price of the REM system to on-board observers, the use of the latter in Denmark costs approximately 6.7 times more than the former (Paper I).

In conclusion, the REM proved to be valuable and reliable for documenting marine mammal bycatch on board commercial gillnetters. Furthermore, high coverage percentages at low cost, compared to on-board observers, could be obtained with REM (Paper I).

2.1.1 REM in relation to other methods

Monitoring of marine mammal bycatch has been addressed by a variety of different methods. In Danish waters, and elsewhere, the main data on bycatches have been collected by on-board observers (Bravington & Bisack 1996, Trippel et al. 1996, Vinther 1999), as this was regarded to be the most reliable way to obtain information on catch composition and on biological aspects of the catch (IWC 1994). Many observers, however, have additional tasks while working on board (e.g. observers working under the EU Data Collection Framework), making it impossible to watch all net hauls from the moment they break the water surface. The results from the REM trial (Paper I) documented the importance of constantly watching the point where the nets break the surface, since many porpoises drop out there. This implies that observers who have other on board tasks will miss some of the bycatch.

Another important advantage of the REM system, compared to using on-board observers, is that it allows observations of bycatch on vessels that are unsuitable for on-board observers. On-board observers tend to be placed on larger vessels that are able to accommodate them, but this group of vessels often fishes in different ways than smaller ones, e.g. further offshore. This could introduce a bias if data from the larger vessels are extrapolated to also cover smaller boats as was done, for example, by Vinther (1999). There is another difference between on-board observer and REM data, which deserves mentioning. On-board observers, at least in Denmark, have tended to collect data from many different vessels during the course of a year, but REM data tend to include much longer time series from a smaller number of vessels because of the time and costs involved in moving the REM systems between them. Although the longer time series of the REM system provides better insights into the fisheries that the so-equipped vessels are pursuing during the course of a year, care, however, needs to be taken to ensure that they are indeed representative of the fleet that is the subject of monitoring.

Another common method of obtaining information on bycatch is from fishers’ voluntary reporting schemes (Read & Gaskin 1988, Berggren 1994, Kock & Benke 1996, Rubsch & Kock 2004). The main concern with this method has been whether fishers are willing and able to report correctly what they observe. The results from the REM trial showed that fishers did not always report porpoise bycatch. The reason for this was mainly due to a significant part of the actual bycatch not being observed by the fishers,
because the porpoises dropped out of the nets before coming on deck (Paper I). Fishers reporting schemes are thus believed to be biased.

2.2 Identification of high risk areas
Limited financial resources often lead to common questions from environmental and fisheries managers as to where bycatch monitoring should be focused and in which areas porpoises are particularly exposed to high risks of entanglement in fishing gear. A tool to identify such areas and/or seasons would therefore be valuable. In Paper II, data on porpoise density and gillnet fishing effort were examined to determine if it could be used to identify high-risk areas for bycatch in the Danish Skagerrak Sea. Porpoise density data were obtained from 66 satellite tracked harbour porpoises in the years 1997-2012. These provided detailed information on individual porpoise movement. The study area was divided into a grid consisting of 1x1 km cells. Assuming errors of longitude and latitude are distributed normally (Vincent et al. 2002), the most likely number of true positions within each grid cell can be computed from the positions inside it and adjacent ones. The values assigned to the grid cells therefore reflect the likelihood that they were visited by porpoises equipped with satellite transmitters. By assuming that the behaviour of the tagged animals is representative of the porpoises in the area in general, these grid values can be used as a proxy for density (for further information see Paper II). The fishing effort data and actual porpoise bycatch incidents were obtained from vessels monitored by REM systems (Paper I). Based on effort data and seabed topography, three fishing grounds were selected for analysis, that is, areas A, B and C. Area A and C were further divided into two sub-areas each (A1, A2, C1, C2) since large variations in porpoise density were observed within them (Fig. 2).

When building the model to predict bycatch, we assumed the following general relationship between the response, which is the number of porpoise bycatches \((N_i)\) caught in the \(ith\) haul, porpoise density \((P_i)\) at the \(ith\) haul position, and the effort pertaining to the \(ith\) haul described by the soak time \((ST_i)\) and net length \((NL_i)\) as well as the target species \(s_i\) (which is used as a proxy for additional differences in gear characteristics, such as mesh size). The model was built with a Poisson GLM after a log-transformation:

\[
\log(E(N_i)) = \log(\alpha(s_i)) + \beta(s_i) \log(ST_i) + \phi(s_i) \log(NL_i) + \gamma \log(P_i)
\]

where \(\alpha(s_i)\), \(\beta(s_i)\) and \(\phi(s_i)\) corresponds to a categorical effect for each possible target species for haul \(i\). The results showed that the best model included both porpoise density and effort data (soak time). The model was selected in terms of AIC (Akaike Information Criterion) which is a measure of the relative quality of a statistical model. The model was therefore reduced to

\[
E(N_i) = \alpha ST_i P_i
\]

Figure 2 shows the results of the modelled bycatch rate and that large difference in porpoise bycatch were identified in relation to area and season (precise bycatch values can be found in Paper II, Figure 6). In the winter, area A1 had the highest bycatch followed by areas A2, C2, B and C1. In the spring, area A1 had the highest bycatch followed by B, A2, C2 and C1. In the summer, the bycatch was generally lower compared to the other seasons, although the largest value was again identified for area A1 followed by B, C1, C2 and A2. In the autumn, bycatches were high in area A1 followed by C2, B, A2 and C1.
Figure 2: Map of predicted harbour porpoise bycatch in five areas and four seasons. The unit of the bycatch legend is the number of bycaught porpoises per 1000 hauls. The black lines indicate boundaries of Natura2000.

In conclusion, high resolution information on fishing effort, porpoise densities and bycatches have allowed a fine scale analysis of such data and identified and verified a correlation. The correlation has resulted in a method to predict potential areas of bycatch risk when spatial data on fishing effort and porpoise densities are available. The model predictions can function as a starting point for investigations of harbour porpoise bycatches and should be of considerable influence with respect to fisheries management and bycatch mitigation in general, and in relation to the design and implementation of effective conservation measures for protected areas in particular.
3 Mitigation methods
As bycatches of harbour porpoises have been recognised in many fisheries and are considered to be one of the main threats to the species, much research has been conducted in order to prevent such events. Bycatch can be prevented in two ways. As the total bycatch by a given gear is the product of (i), the total effort of the gear and (ii), the bycatch per unit effort of that gear, bycatch can thus be mitigated by reducing either effort or bycatch per unit effort or both (Hall 1996). To reduce either of the two, several methods exist. These will be described and discussed below.

3.1 Reducing bycatch per unit effort
This section describes methods to reduce bycatch per unit effort. One such method involves deploying acoustic alarms, so called “pingers” or “ADDs” (Acoustic Deterrent Devices) on the nets and another is by gear modifications.

3.1.1 Traditional pingers
Traditional pingers work by modifying the behaviour of porpoises. Pingers emit acoustic signals, which are believed to be generally aversive and act to displace animals from its vicinity (Dawson et al. 2013). Kraus et al. (1997) conducted an experiment in the Gulf of Maine gillnet fishery, which gave the first significant results about pinger effects on porpoise bycatch. The study was designed as a blind controlled experiment testing if pingers could reduce the bycatch of harbour porpoises. Dukane NetMark1000-pingers (source level 132dB re 1 µPa@1m, 10kHz) were used. The results showed a significant reduction (89%) in porpoise bycatch. Trippel et al. (1999) also showed a bycatch reduction (77%), when using Dukane NetMark1000 pingers in the Bay of Fundy and Gearin et al. (2000) recorded an 88% reduction when testing a modified version of the Lien-pinger (source level 121.7-124.7dB re 1 µPa@1m, 20kHz). Larsen and Eigaard (2014) tested the LU-1 pinger (a predecessor to the AQUAmark100, source level 145 dB re 1 µPa@1m, 40-120kHz) in the Danish cod gillnet fishery and found a 90% reduction. Larsen et al. (2013) tested the similar AQUAmark100 pinger in the Danish hake (Merluccius merluccius) net fishery and obtained a reduction of 100% and 78% when spacing the pingers at 455m and 585m, respectively (Table 1).

Table 1. Trials conducted on the effectiveness of pingers

<table>
<thead>
<tr>
<th>Location</th>
<th>Brand</th>
<th>Source level</th>
<th>Pinger spacing</th>
<th>Effect (%)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulf of Maine</td>
<td>Netmark1000</td>
<td>105–139</td>
<td>90</td>
<td>89</td>
<td>Kraus et al. (1997)</td>
</tr>
<tr>
<td>Washington State</td>
<td>Lien</td>
<td>122–125</td>
<td>17</td>
<td>88</td>
<td>Gearin et al. (1999)</td>
</tr>
<tr>
<td>Bay of Fundy</td>
<td>Netmark1000</td>
<td>139-145</td>
<td>100</td>
<td>77</td>
<td>Trippel et al. (1999)</td>
</tr>
<tr>
<td>Black Sea</td>
<td>Netmark1000</td>
<td>132</td>
<td>200</td>
<td>98</td>
<td>Gönenber &amp; Bilgin (2009)</td>
</tr>
<tr>
<td>North Sea</td>
<td>Aquamark100</td>
<td>136-145</td>
<td>455</td>
<td>100</td>
<td>Larsen et al. (2013)</td>
</tr>
<tr>
<td>North Sea</td>
<td>Aquamark100</td>
<td>136-145</td>
<td>585</td>
<td>78</td>
<td>Larsen et al. (2013)</td>
</tr>
<tr>
<td>North Sea</td>
<td>Lu-1-prototype</td>
<td>145</td>
<td>140</td>
<td>90</td>
<td>Larsen &amp; Eigaard (2014)</td>
</tr>
</tbody>
</table>

Dawson et al. (2013) reviewed a total of 14 controlled experiments all testing the effect of pingers on porpoise bycatch and concluded that three of these did not have the statistical power to determine any bycatch reducing effect of the instruments. The reasons for the missing effect were a lack of bycatch on both pinger and control nets (Carlström et al. 2002), the former having several faults (Northridge et al.
Due to the many positive results in reducing the bycatch of porpoises in gillnets fisheries, however, the IWC (2000) and Dawson et al. (2013) concluded that pingers do reduce such catches and that further experimentation was unnecessary.

Even though pingers have been shown to be effective in reducing harbour porpoise bycatch, there are some important issues that needs to be considered before installing them, that is, effective range, habituation, habitat exclusion, functionality, implementation and enforcement. These will therefore be described and discussed below.

**3.1.1.1 Pinger effective range**

The effective range of a pinger is the maximum distance at which it can affect porpoise behaviour. The effective pinger range is important in relation to bycatch reductions, costs and habitat exclusion. Spacing the pingers too widely will increase the risk of bycatch, spacing them too narrowly will increase the costs for fishers and have unnecessary acoustic impacts on the habitat.

To study the impacts of pingers on porpoise behaviour, including their effective range, the behaviours of porpoises were investigated with respect to two different pinger types (AQUAmark100, 20-40 kHz, 145dB re 1µPa@1m (RMS), 200-300ms at random intervals, and AQUAmark300, 10 kHz, 132dB re 1µPa@1m (RMS), 300ms every 4 sec) (Paper III). The study utilized an adaptive design whereby results gained in one trial would feed into the design of the next. The experiments were conducted in coastal waters at three different locations: (1), Jammerland Bay, Great Belt, Denmark; (2), St Andrews Bay, North Sea, Scotland and (3), Gilleleje Flak, Kattegat, Denmark (Fig. 3). The first trial (Jammerland Bay) had a modified AQUAmark100 pinger, running in cycles of 23 hours on and off, attached above the first C-POD (porpoise click detectors) in an array of five C-PODs. The next four C-PODs were deployed at distances of 200, 400, 800 and 1600 m from the pinger (Fig. 3.1). The preliminary results from Jammerland Bay indicated a pinger effect outwards of 1600 m (which later turned out to be incorrect). To measure the effective pinger range one needs to map out the distances at which the pinger has no effect. To ensure, therefore, that the station furthest array from the pinger in the UK trial had no pinger effect, the array was extended to contain stations at longer distances (2400 m and 3000 m). Another concern about the Jammerland Bay setup was that the array only recorded porpoises in one direction from the pinger (northern direction, Fig. 3.1). If, for example, the porpoises only visited the pinger area from either a southern or eastern direction, the northern stations would be biased, since all individuals would only encounter the 0 m station before they would be scared away by the pinger. The UK study was thus established as a triangle array to detect porpoises from three directions. A total of 14 C-PODs were deployed in the array (Fig. 3.2). The same aforementioned modified AQUAmark100 pinger was deployed in the centre of the array together with two C-PODs. The other 12 PODs were deployed, in replicates, at distances of 200, 400, 800, 1600, 2400 and 3000 m. The Jammerland and St Andrews Bay trials were both initiated with a control period measuring the porpoises’ presence before introduction of the AQUAmark100 pinger. At Gilleleje Flak two C-PODs were deployed with a 300 m spacing. At one station, a single modified AQUAmark300 pinger, likewise running in cycles of 23 hours on and off, was attached to the C-POD (Fig. 3.3). The main reason for the different pinger used at Gilleleje Flak was habituation issues, which will be discussed below (Section 3.1.1.2).
In terms of effective pinger range, the results showed that in St Andrews Bay, the AQUAmark100 significantly reduced the recorded porpoise clicks at distances of 0 and 200 m, whereas a significant reduction was identified at 0, 200 and 400 m distances to the AQUAmark100 pinger in Jammerland Bay. The reasons for the differences in the effective range of the AQUAmark100 may be several. One possibility is that insufficient data were collected during the UK trial, since the study was conducted over a shorter time period compared to the Danish one. The shorter time period reduced the power to detect low-level differences between on and off periods, which should be expected at longer distances from the sound source. It is, therefore, possible that a significant effect would have been found at 400 m in the UK study if the experimental period had been longer. A second possibility for the above discrepancy is that it could be due to differences in the ambient noise levels between the Danish and UK study areas. If an area has a high background noise level, it could lower the signal to noise ratio significantly (Urick 1983), making it more difficult for the porpoises to detect pinger signals. High sediment (sand) noise was detected at several of the UK stations, caused by large sand migrations due to high tidal movements (5 m) at the time of the experiments. This discrepancy could, thirdly, be caused by differences in seafloor morphology and water depths at the two study areas since the pinger sound field is highly dependent on this. The Danish trial was conducted in shallow waters, which might lead to multi-path sound propagation.
(Shapiro et al. 2009) whereas the UK trial was conducted in deeper waters with longer distances to reflecting boundaries, that is, the sea floor and water surface. All the above factors may influence the obtained results and differences in effective pinger range are thus expected to vary between different locations.

The studies of the AQUAmrk300 showed a significant effect only at the pinger. In a similar set-up, Carlström et al. (2009), however, showed that Dukane NetMark 1000 pingers (10 kHz) were comparable to the AQUAmrk100 - affecting porpoise click rates out to 500 m. Again, the reasons for such differences may be many but are most likely the result of the above mentioned factors.

Effective pinger range has also been studied in commercial gillnet fisheries. Studies investigating AQUAmrk100 efficacies have documented that the pingers can be spaced at 585m and still have a significant reduction effect (Larsen et al. 2013). Studies examining increased spacing of 10 kHz pingers like the AQUAmrk300 have not been conducted. Palka et al. (2008) and Carretta and Barlow (2011), however, showed that when 10 kHz pingers were set at 200 m spacings they reduced the bycatch of porpoises significantly. Palka et al. (2008) also suggested that in situations where a single pinger was non-functional, the bycatch increased by 2.5 times compared to nets with fully functional instruments and in sets where more than one pinger was non-functional the bycatch was increased by a factor of 10.

The effective range of a pinger will thus depend on: frequency, source level, depth, bottom type and background sound level and determining the right spacing thus needs to take these factors into consideration.

3.1.1.2 Habituation

Habituation is one of the main concerns when using traditional pingers since it might lead to increasing bycatch rates over time (Gearin et al. 2000, Cox et al. 2001). Habituation is defined as ‘a decrease in response to a stimulus after repeated presentations’ (Bouton 2007). In relation to bycatch, pingers represent a case of repeated presentations of a stimulus where no reinforcement is imposed on the porpoises to avoid entanglement. One may say that they are rewarded for swimming away from the device by a reduction in received sound pressure levels of the pinger sounds. A failure response is, however, not connected with a learning experience since porpoises most likely will be entangled and drown. Porpoises that have been repeatedly exposed to the same pinger sounds would, therefore, be expected to show a decrease in avoidance responses.

In the trials presented above (Paper III) the studies from Jammerland Bay and St. Andrews Bay, both using the AQUAmrk100 (20-160 kHz in random order) revealed no signs of habituation. Other authors, however, have observed habituation effects in relation to 10 kHz pingers. Carlström et al. (2009) investigated porpoises’ acoustic spatial and temporal responses to Dukane NetMark1000 pingers. They identified an increased echolocation rate over time as evidence of habituation and, likewise, Cox et al. (2001) showed a habituation effect when studying porpoise echolocation in relation to a Dukane NetMark1000. The study at Gilleleje Flak was thus conducted to test if a similar habituation effect was observed in relation to the AQUAmrk300 pinger. The results revealed an apparent habituation effect over time at the sound source. The most obvious reason for the different behavioural responses observed between the two pinger types is that porpoises react differently to simple tonal signals (AQUAmrk300) compared with more complex ones with more energy at higher frequencies (AQUAmrk100). As described earlier, the AQUAmrk300 pinger emits the same 10 kHz signal every 4 sec. In contrast, the
AQUAmark100 emits eight different signals at 20-160 kHz in random order. The signals and play order of the AQUAmark100 were designed to try to avoid any habituation and this aim seems to have been achieved according to the results obtained in this study. That is, these results indicate that porpoises may habituate more easily to a constant signal compared to a mixture of different signals like those of the AQUAmark100. Since only one experiment was carried out with the AQUAmark300 pinger, the risk of observing a spurious habituation effect is substantial and we, therefore, recommend that further experiments will be carried out.

Even though habituation in relation to the 10 kHz pinger types have been identified by trials in commercial fisheries in the USA, habituation occurring at a level where pingers no longer reduce bycatch have not been detected (Carretta & Barlow 2011). In the EU, pingers have only been used to a limited extent in gillnet fisheries (EC 2004, ICES 2015) and habituation has not been observed. Habituation will, however, only be a problem if the effective range becomes so small that the porpoises cannot avoid entanglement.

3.1.1.3 Habitat exclusion

As pingers act to displace animals from their vicinity, they will most likely create areas around the nets, which the porpoises are excluded from exploiting. Whether this exclusion will have an appreciable effect on porpoise populations exposed to pingers will depend both on the geographical extent and longevity of such exclusion areas as well as on whether these areas are of critical importance to the porpoise populations (Larsen & Hansen 2000). The studies conducted and reported upon in Paper III showed differences in the effective range that will cause differences in potential habitat exclusion. The extent of the habitat exclusion zone will therefore be dependent on either the effective range, the circumstances and the level of habituation since all these will affect the zone. An important fact to note in our results is that even though the porpoise clicks may be considerably reduced in the vicinity of a pinger when it is “on”, they are not absent, meaning that the instruments do not wholly exclude porpoises from their vicinity (Paper III). One should, however, keep in mind that PODs record clicks from a wide area meaning that clicks could be recorded from areas were the pingers have had little effect. Similarly, some low level of bycatch is usually reported upon even when nets are fully equipped with pingers (Table 1) and impacts from pingers currently in use have not, up until now, had any known effects on the presence of porpoise in wider areas (Carretta & Barlow 2011). The question about habitat exclusion, therefore, remains a concern if pingers are to be used at high densities in areas of preferred porpoise habitat (Dawson et al. 2013).

3.1.1.4 Functionality

The functionality and practical use of pingers is important since this will influence their abilities to reduce bycatch. The practical implementations of deploying pingers in gillnet fisheries have thus been evaluated (Seafish 2003, Cosgove et al. 2005, Larsen & Krog 2007). Tested pingers were shown to be time-consuming to attach to the nets, short in battery life, high in failure rates, and problematic when storing since they occasionally entangled the gear as they fell through the meshes when lying in the net pounder. In 2006, a meeting on acoustics alarms for use on gill and tangle nets was held to share information on handling and functionality. A set of recommendations was made: (1), Pingers should have low weight to minimise injuries while handling. (2), Have easy attachment and must be able to turn freely around the head rope without getting tangled in the net, in the same way as the head rope floats do. (3), Pingers should be shaped not to cause net tangling during either fishing operations or during handling. (4), In the
case of violent impacts, pingers should not break up into pieces, which could hit and injure fishermen in their vicinity. (5). Contain a basic system, easily checkable, reporting on the condition of the pinger, would facilitate the replacement of the devices and would, thus, make the system more effective (DIFRES 2006). Similarly, EU Member States using pingers have concluded that further work is needed to improve the reliability, effectiveness and the practical handling of the devices in current use (EC 2011). Even though pingers have shown positive results regarding bycatch reduction, they are not widely accepted by fishermen due to handling problems and costs.

In recent years, pinger manufacturers have made new improved versions and new companies have entered the market. New pinger versions from some brands have, for example, implemented lights, indicating their battery status. Previous functionality tests may, therefore, be outdated and newer pingers may prove easier to handle. Dawson et al. (2013) suggested that an independent accreditation system might improve confidence in pinger quality.

### 3.1.1.5 Implementation and enforcement

Pinger use has been mandatory in certain areas and fisheries for a number of years. In the north eastern USA (New England and the Mid-Atlantic waters), the Harbour Porpoise Take Reduction Plans (HPTRP) have been adopted as has the Pacific Offshore Cetaceans Take Reduction Plan (POCTRP) in California to minimise bycatch of short-beaked common dolphins (*Delphinus delphis*) and other marine mammal species (FR 1997, 1998). The implementation of the HPTRP resulted in a 60% reduction in the bycatch of harbour porpoises (Palka et al. 2008) and the POCTRP in an 82% reduction (Barlow & Cameron 2003). In Europe, EU countries adopted Council Regulation 812 in 2004 (EC 2004) mandating pingers in certain gillnet fisheries and areas. According to Council Regulation 812/2004, Member States should report annually on the use of pingers and include all information collected on the incidental capture and killing of cetaceans in fisheries (EC 2004). The ICES Working Group on Bycatch has annually reviewed reports from EU Member States on these issues. Pingers have, however, only been used to a limited extent in gillnet fisheries within EU waters (ICES 2012, 2015) and long term effects have therefore not been recorded from them. Despite the limited use of pingers in EU, implementation of pinger use in the USA has revealed large reductions in harbour porpoise bycatch. The fact that bycatch rates, however, appear to increase when nets are only partially equipped compared to fully pingered nets (Palka et al. 2008, Carretta & Barlow 2011) stresses the need for enforcement of a successful implementation plan.

Enforcement is important in relation to pingers. Increased enforcement would lead to better compliance, which would result in reduced porpoise bycatches. Pinger use has, hitherto, been enforced by national authorities. Different methods have also been used to test the functionality of the pinger. Since pingers not only need to be tested for their presence, the National Marine Fisheries Service (USA) developed a tester, which determined their functionality. The implementation of the tester in observer programmes has, however, been limited (Orphanides et al. 2009, Orphanides & Palka 2013). German and Danish authorities have also developed a monitoring device, which permits inspection of pingers at sea (EC 2011). Even though pinger enforcement is important, it is a costly task. CCTV data have, however, shown that pingers can be recognised easily on video footage. Videos will, however, have to be analysed at lower speeds, compared to, for example, video analysed for porpoise bycatches, since pingers are smaller and thus difficult to detect. If EM systems are to be implemented for pinger enforcement, the EM systems or pingers would benefit from being modified for such purposes. Either the system should be able to register the signals from the pingers, or the pingers should have lights indicating their functionality.
The effective implementation of pingers in gillnet fisheries is, however, difficult and compliance is likely to be variable, even in developed countries. Education, outreach and enforcement are all critical components of effective implementation plans (Dawson et al. 2013). In the EU, many countries have not implemented pingers. Even in areas where pingers are assumed to be used, the level of compliance, that is, the percentage of vessels actually deploying operational instruments, is difficult to assess as the national enforcement strategies (including the frequency and coverage of the enforcement) is not reported upon (ICES 2014).

### 3.1.1.6 Advantages and challenges of traditional pingers

At this stage, pingers have been shown to be effective in reducing the bycatch of harbour porpoises. There are, however, several issues that need to be considered before full implementation into gillnet fisheries.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Effective at reducing bycatch of porpoises</td>
<td>- Pingers are not 100% effective, meaning that bycatch can occur even though they are deployed correctly.</td>
</tr>
<tr>
<td>- Use of pingers will allow the fisheries to continue.</td>
<td>- If pingers are not deployed correctly, an increase in bycatch can be expected.</td>
</tr>
<tr>
<td></td>
<td>- The effective range of pingers can vary depending on area and noise level.</td>
</tr>
<tr>
<td></td>
<td>- Some degree of habitat exclusion is to be expected.</td>
</tr>
<tr>
<td></td>
<td>- Habituation can occur in relation to certain pinger types.</td>
</tr>
<tr>
<td></td>
<td>- Costs of purchasing (and maintaining) the pingers can be high.</td>
</tr>
<tr>
<td></td>
<td>- Pingers can have impacts on other species.</td>
</tr>
<tr>
<td></td>
<td>- Increased background noise.</td>
</tr>
</tbody>
</table>

### 3.1.2 Alerting pingers

The reason for the incidental bycatch of harbour porpoises in gillnets is not known, although several hypotheses exist. One is that porpoises have their sonar locked on other targets and consequently do not discover gillnets. It has, therefore, been discussed whether alerting sounds can make porpoises aware of gillnets and thereby avoid entanglement (Pleskunas & Tregenza 2005). Alerting sounds are artificial porpoise-like sounds simulating the clicks porpoises often use when detecting targets (Møhl & Andersen 1973). The idea behind the alerting pingers is that porpoises will be stimulated to echolocate towards the pingers that are positioned on the nets, become aware of the net barrier ahead and, thereby, avoid entanglement. This concept was tested in 2006 by deploying custom made alerting pingers, called PAS pingers (Porpoise Alerting Sound pingers), on gillnets from a Danish vessel targeting hake. Alerting sounds in this case were artificial porpoise click trains (series of 110 kHz clicks, SL = 125-138 dB peak-peak re 1μPa @ 1 m, 50-2500 clicks per sec). Conventional net fleets had either PAS pingers or dummy pingers attached at intervals of 180m. On-board observers collected data on fishing activity, fish catches and porpoise bycatch. The trial had a total bycatch of 17 porpoises in PAS nets and 15 in the control nets with dummy pingers. Statistical analyses showed no difference in bycatch rates of harbour porpoises between the PAS pinger nets and the controls. The results indicate, therefore, that this type of alerting sound would not reduce the bycatch of harbour porpoises (Kindt-Larsen et al. 2007). Kindt-Larsen (2008)
concluded that the reason for the negative result was that the signal emanating from the PAS pinger had not worked as intended, that is, it had failed to increase the porpoise click rate.

Another trial followed up on the alerting idea using alternative alerting sounds. The sounds used in this pinger type have been recorded as aggressive signals from porpoises in captivity (Clausen et al. 2011) and field tests have shown that these do increase porpoise click rates (Culik et al. in press). Trials on the effectiveness of these alternative alerting sounds in relation to porpoise bycatch are currently being conducted (Culik et al. 2015). The ICES Working Group on Bycatch has raised concerns that if the final results from the new trial show that the alerting sounds cannot reduce porpoise bycatch, there could be an endless search for a new alerting sound. The Working Group therefore stressed the importance of testing the principle of whether higher click rates would, of necessity, result in a lower bycatch (ICES 2014).

### 3.1.2.1 Advantages and challenges of alerting pingers

If alerting pingers are eventually shown to reduce bycatch, they can serve as an alternative to the traditional pinger. Since they are non-aversive they will not act to displace porpoises and could be implemented in fisheries without having any displacement effects. At this stage, however, no clear bycatch reducing effect has been identified. A table of their advantages and challenges has been produced below.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Reduce porpoise bycatch.</td>
<td>- Bycatch can occur even though the pingers are deployed correctly.</td>
</tr>
<tr>
<td>- Use of pingers will allow the fisheries to continue.</td>
<td>- If pingers are not functional, an increase in bycatch can be expected.</td>
</tr>
<tr>
<td>- Do not have displacement effects.</td>
<td>- The effective range can vary depending on area and noise level.</td>
</tr>
<tr>
<td>- Habituation is suspected to be less compared to traditional pingers as the sounds are not aversive.</td>
<td>- No studies exist in relation to habituation</td>
</tr>
<tr>
<td></td>
<td>- Costs of purchasing and maintaining the pingers are high.</td>
</tr>
<tr>
<td></td>
<td>- Pingers may have impacts on other species.</td>
</tr>
<tr>
<td></td>
<td>- Increase background noise.</td>
</tr>
</tbody>
</table>

### 3.1.3 Modification of gillnets

An idea to keep porpoises from becoming entangled in gillnets is to make them more acoustically reflective and thereby more detectable to porpoises. Porpoises use echolocation and thus navigate by detecting echoes from their surroundings (Mohl & Andersen 1973, Au et al. 1999). It has been calculated that porpoises only can detect gillnets at short distances (5-15 m) (Kastelein et al. 2000, Mooney et al. 2004, Villadsgaard et al. 2007). How well an echo is reflected does, however, depend on the target strength (acoustic reflexivity) of the object. Different kinds of objects and materials have therefore been attached to gillnets to increase detection. None of these experiments, however, have shown clear reductions in bycatch rates without compromising the fish catch (Hembree & Harwood 1987, Goodson et al. 1994, Koschinski & Culik 1997).

Other studies have tried to make the nets more acoustically reflective by adding barium sulphate (BaSO₄) or iron oxide to the nylon (Northridge 2003, Larsen et al. 2007, Trippel et al. 2009). Two of the studies
(Larsen et al. 2007, Trippel et al. 2009) showed a reduction in porpoise bycatches. In one case, however, this was also associated with a large decrease in fish catches (Larsen et al. 2007). Because of these results, Larsen et al. (2007) investigated the acoustic target strength of the iron oxide-enhanced nets compared to regular nylon nets. The analysis revealed that the two net-types did not differ significantly in target strength, and the difference in both porpoise bycatch and fish catches between the two net types was explained by an increase in stiffness of the iron oxide nylon, caused by the chemicals embedded in it. Mooney et al. (2007) also compared the target strength of barium sulphate and iron oxide nets to control ones. They showed an increased target strength at certain angles of the enhanced nets but concluded that both the stiffness and the target strength were likely important in reducing porpoise bycatch. To further investigate the relationship between stiffness and acoustic reflectivity, Bordin et al. (2013) compared franciscana (Pontoporia blainvillei) bycatch rates in standard gillnets to those with one of two modifications: increased acoustic reflectivity by infusion of barium sulphate or increased flexural stiffness of the nylon twine. The results showed that a total of 77 dolphins were captured incidentally in 807 monitored gillnet hauls and no significant difference in franciscana bycatch rates or target fish catches were identified among the three net types. Since the results did not lead to a reduction in franciscana bycatch rates, the authors concluded that other methods are needed to reduce the impact of incidental captures (Bordin et al. 2013).

As mentioned earlier, the reason for chemically enhancing gillnets was to increase their target strength since porpoises might discover gillnets at too short distances to avoid entanglement. New research has, however, revealed that porpoises can detect gillnets at much longer distances (50-80 m) (Nielsen et al. 2012, Wahlberg 2014). It is thus believed that the reason for porpoise entanglement is not that they cannot detect the barrier at a sufficient distance and thus that entanglement must be due to other reasons, for example lack of attention to the net barrier.

Other modifications, such as hanging ratios, mesh size and tie downs have been analysed as possible methods to reduce bycatch (Orphanides 2009, Schnaittacher 2010, Fox et al. 2011, Mackay 2011). Nets with large mesh sizes (> 23.2 cm) were shown to have higher bycatch rates compared to small mesh sizes (<16.6 cm) (Orphanides 2009), while other studies identified mesh size to be insignificant in some areas (Mackay 2011). None of the other factors showed any clear significant reduction effect, however, and, in many cases, the lack of conclusive results was related to low sample sizes.

3.1.3.1 Advantages and challenges of gillnet modification

If net modifications such as changing TS, hanging ratios, mesh sizes and tie downs were able to reduce bycatch, they could be easy and cost-efficient to implement. Since no clear bycatch reducing effect has been identified in relation to gear modification without affecting the catch rate of target fish, however, net modifications are not at this stage considered as viable methods to reduce bycatches.

3.2 Effort changes

As mentioned above, another way of reducing total bycatch is by reducing gillnet effort. Several methods exist to reduce this, including time/area closures and a change to alternative gear. These mitigation methods will be discussed below.

3.2.1 Time/area closures

The objective of time/area closures is to take advantage of naturally occurring variations in the degree of co-occurrence between target and bycatch (Murawski 1994). Time/area closures have been used in many
areas to conserve different species (Pastoors et al. 2000, Murray et al. 2000, Ye et al. 2000, Niemi et al. 2012). In 1994, the United States National Marine Fisheries Service implemented a series of time/area closures for the gillnet fisheries in the Gulf of Maine to reduce the bycatch of harbour porpoises (Murray et al. 2000). The results showed that the closure was not effective since the number of bycatches in the Gulf of Maine rose from 1,400 (1993) to 2,100 (1994) (Bisack 1997). This failure was mainly due to temporal and spatial variations in bycatch patterns and displacement of fishing effort to areas outside the closed area, where porpoise bycatches likewise occurred (Murray et al. 2000). Subsequently, the time/area closures have been expanded spatially and temporally to reflect the inter-annual variability in harbour porpoise migration patterns, and pingers were required on gillnets to prevent porpoises from interacting with the gear (Orphanides and Palka 2013).

Another example of time/area closures is that of the vaquita (*Phocoena sinus*) in the Upper Gulf of California, Mexico, which is considered to be critically endangered (Rojas-Bracho et al. 2008). To protect the vaquita, the Mexican Government created, in 1993, a protected “Biosphere Reserve” wherein gillnet fishing was prohibited in a small part (SEMARNAP 1995) and, in 2005, an additional “Refuge Area” was created. Gillnet and trawl fishing in the Refuge Area was prohibited, although with little enforcement the fishing ban was widely ignored (Gerrodette & Rojas-Bracho 2011). It was not until 2008, with the introduction of a Species Conservation Action Plan for Vaquita (SEMARNAT 2008), that a comprehensive protection and recovery effort was introduced. Although efforts to implement the plan probably slowed the vaquita’s decline, the goal of eliminating bycatch by 2012 has not been attained (Rojas-Bracho & Reeves 2013).

In relation to other marine mammals, time/area closures have been used to protect both dolphins and sea lions (Wilson et al. 2004, Chilvers 2008, Slooten 2013). An example of area-based management in reducing the bycatch of the New Zealand (NZ) dolphin (*Cephalorhynchus hectori*) is given by Slooten (2013). In 1988, the first protected area for NZ dolphins was established. Management regulations closed the area for gillnet fishing, although in some areas the gillnet fishery was exempted in order to reduce the economic impact on the fishery. The closures only slowed the decline. In 2003, the closures were therefore expanded to include trawling, again in some areas, but again too, the population decline was only slowed. In 2008, a Threat Management Plan was thus implemented, providing protection in most areas where the dolphins occurred. Again gillnet and trawl fisheries were closed in some areas but still the population declined (Slooten 2013).

### 3.2.1.1 Shaping appropriate time/area closures

Determining the appropriate closure size or season is difficult since marine mammals are often widespread and move over large distances (Wilson et al. 2004) and fishing effort likewise changes over seasons (Paper II). The right closure size is, however, extremely important since incorrect closures may just relocate the bycatch problem either spatially or temporally (Murray et al. 2000, Diamond et al. 2010) and impose unnecessary socio-economic impacts on stakeholders (Murray et al. 2000, Harley & Suter 2007). Most area closures are focused on key site selections, although the area that needs protection might change over time. Thus in order for time/area closures to succeed, bycatch rates must be consistent over time and space.

Identification of high risk areas for porpoise bycatch, such as described in Paper II, may help managers to find the most appropriate closure in relation to time and area - since both are incorporated into the prediction of bycatch - or at least function as a starting point for bycatch investigations.
3.2.1.2 Economic costs
Time/area closures are often unpopular in the fishing industry since they can potentially cause longer steaming times, increased fuel costs, lost fishing opportunities and/or reduced catches (O’Keefe et al. 2013). In the example from the Gulf of Maine provided above, concern was raised by the fishing industry that the closure placed an unfair burden on the fishers with small vessels, which were not able to fish far from land (Murray et al. 2000). In contrast, the conservation and scientific communities argued that the closures were too small and would exclude important areas and thereby only displace the fishing effort and not reduce the bycatch (Read 2013). Understanding the trade-offs between conservation benefits and economic costs are, thus, crucial for developing well-informed policies and management strategies. In some cases there is, however, little room for compromise when, for example, the loss of one individual threatens the population’s survival (Slooten 2013).

3.2.1.3 Enforcement
Although establishing a time/area closure might seem like the optimal conservation choice, without a convincing enforcement mechanism the measure is clearly pointless. If the fishers do not comply with the closures, they will not have an effect. Only when fishers support the measure can there be a strong incentive for self-policing, which can make enforcement relatively straightforward. In other circumstances, however, particularly when a fishery operates over a large or remote area, the practicalities and costs of enforcement can be prohibitive. It seems likely that, in some cases, satellite surveillance techniques could be used to good effect. In all EU countries, vessels above 12 m loa must carry a Vessel Monitoring System (VMS). The system sends positioning data about the vessel every hour and in relation to closed areas, the VMS signals are used in Denmark as part of a tool called Geofencing. Geofencing enables remote monitoring of geographic areas surrounded by a virtual fence (geofence) that automatically detects when VMS tracked vessels either enter or exit them (Reclus & Drouard 2009). Another way would be by use of REM systems, which, in addition to monitoring bycatch, can monitor the position of the vessel in relation to closed areas.

3.2.1.4 Advantages and challenges on time/area closures
The experiences collected in different areas in relation to time/area closures have been diverse. Time/area closures have, nevertheless, been shown to be effective in reducing the bycatch of porpoises. There are, however, several issues that need to be considered before the wider implementation into gillnet fisheries.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Can reduce bycatch if the bycatch rate, for the area, is consistent over time and space and higher compared to outside the area.</td>
<td>- Time/area closures can only function if the bycatch rate for the area is consistent in time and space and higher compared to outside the area.</td>
</tr>
<tr>
<td></td>
<td>- Time/area closures need to be adaptive due to variations in species’ densities and area use.</td>
</tr>
<tr>
<td></td>
<td>- Time/area closures can result in displacement of fishing effort into areas with unknown bycatch rates.</td>
</tr>
<tr>
<td></td>
<td>- Time/area closures can have high economic costs for the industry in terms of lost catching opportunities.</td>
</tr>
</tbody>
</table>
3.3 Alternative fishing gear

Another way of reducing fishing effort is by changing into gear types that do not cause risk of porpoise bycatch. Longline and pot fisheries can often be pursued by gillnet vessels, have not had any problems with porpoise bycatch and can thus serve as alternative methods to such detrimental fishing activities.

3.3.1 Longline

Longline fishery is used worldwide and in many countries represents a substantial part of the fishery. Although longlines are simple devices, set-up and rigging procedures vary widely. Catch rates for longlines are largely dependent on the type of hooks, lines, bait, fishing depth, fishing practices and a variety of biotic and abiotic factors. All of these factors will affect fishing success and whether it can be viable commercially.

The species that can be caught in a Danish longline fishery are, primarily, cod and haddock \((\textit{Melanogrammus aeglefinus})\), but catfish \((\textit{Anarhichas lupus})\), tusk \((\textit{Brosme brosme})\), ling \((\textit{Molva molva})\) and hake can also be caught. The Danish Fishermen’s Association conducted a trial in 2000-2002 testing four automatic longline systems in national waters. The longline trial set for cod showed that in the North Sea the catch consisted of 70-80% cod while the remainder comprised haddock, catfish and ling. In the Baltic Sea, all catches were cod. In the Baltic Sea, a specific longline fishery for turbot \((\text{\textit{Psetta maxima}})\) was tested but proved to be unsuccessful (Krog 2003).

Several studies have compared catch rates from longlines with other gear types (Huse et al. 2000, Santos et al. 2002) discovering that longlines had higher catch rates compared to gillnets. Several fish size comparison studies have, however, shown that gillnets catch larger fish than longlines (Huse et al. 1999, 2000, Santos et al. 2002).

Despite the many positive results from longline fisheries, information obtained from the Danish trial showed that the fishery was dependent on season. The largest catches were taken from December to April while the lowest were from May to July. The catches were highest when current speeds were low. In areas with high current speeds (e.g. the Skagerrak), the fishery could only be performed in the summer periods with low current effects. Major problems with ‘lice’ (isopods and amphipods) and hagfish (Myxinidae) were also seen at depths greater than 60 m. Vessels able to switch between gillnet and longlining were shown to be the most profitable due to the possibility of removing the latter system during periods when the former seemed more profitable. Krog (2003) stressed the importance of experience and expertise if a longline fishery should be developed in Denmark.

Despite the absence of porpoise bycatch in longline fisheries, the technique does have problems with the bycatch of other species, such as seabirds and turtles. Seabirds come into conflict with longlines when they forage behind vessels for bait and fish waste. Little is known about bycatch of seabirds in Denmark and bycatch data in relation to any longline fishery are not available. In a global review Anderson et al. (2011), however, estimated that at least 160,000 seabirds were killed annually. The most frequently caught species were albatrosses \((\textit{Diomedeidae})\), petrels and shearwaters \((\textit{Procellariidae})\) with current levels of mortality liable to be unsustainable for some species and populations. Since none of these taxa are resident in Danish waters, the interactions with any local longline fishery would be minimal. Interactions with other seabirds, however, must be expected.
3.3.1.1 Advantages and challenges of the longline fishery

Longline fisheries do not have bycatches of porpoises and therefore serve as good alternatives to the gillnet fishery. Despite this, longlines do have certain limitations and several issues needs to be considered before fishers can be expected to change gear.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Gillnet vessels can easily be used as longline ones.</td>
<td>- Longlines are limited in relation to catchable species.</td>
</tr>
<tr>
<td>- High quality of fish catches.</td>
<td>- There can be large seasonal variations in catch rates.</td>
</tr>
<tr>
<td>- No bycatch of porpoises.</td>
<td>- Reduced functioning in areas with strong currents.</td>
</tr>
<tr>
<td></td>
<td>- Possible bycatch of other species including seabirds.</td>
</tr>
</tbody>
</table>

3.3.2 Pots

Pot fisheries account for only a small part of worldwide commercial fishing. In some countries, however, there has been a long tradition of pot fishing. Pot fishing has been used to catch roundfish (Furevik & Skeide 1994, Conners et al. 2004), lobsters (Homarus gammarus) (Miller 1990) and Alaskan red king crab (Paralithodes camtschaticus) (Zhou & Shirley 1997). With pot fishing, desired species and sizes can be targeted through trap design and the choice of bait. Catch size is affected by trap size, bait quantity and quality, time between setting and hauling and preventing escape through the entrance.

In Denmark, a pilot fishery with cod pots was conducted from 1996 to 1997. The results showed that the catches mainly included cod while tusk and ling could be caught around wrecks and at low depths. The catch varied from 0.2 kg to 6.8 kg/pot and individual fish size was in general low. Furthermore, the pot fishery had large problems with ‘lice’ since these consumed the bait fast. The material (aluminium) of which the pots were constructed was also too light, implying that other materials are needed to increase the catch rate (Krog 1998).

A more recent trial has been conducted in Sweden evaluating cod pots versus gillnets and longlines in the Baltic Sea. During a three-year study, cod pots were used by commercial fishermen in two areas in the south central Baltic. The comparison of catches with other gear types showed that during the first half of the year the pot fishery generated lower daily catches than the gillnet and hook fisheries with comparable fishing efforts. During the second half of the year, however, catches by the pot fishery either exceeded or were equal to catches by gillnet and hook fisheries. In addition to the time of year, the catches in the pots varied according to the number of soak days, water depth and the direction of the water current in relation to that of the string of pots (Königson et al. 2013).

In relation to both longlines and pots, a change from one gear to another can be costly. If a gillnet fisher were to change to pot fishing, he/she would need around 200 pots, corresponding to a cost of ~€100,000. Clearly, this would be a huge task for a fishery sustaining only a small profit. If such an investment were to be made, the fishers would need to be sure that the catches were potentially high enough to sustain a profitable fishery.
### 3.3.2.1 Advantages and challenges of a pot fishery

Due to the absence of porpoise bycatch by a pot fishery, it could serve as an alternative method of fishing in certain areas. There are, however, a number of issues that need to be considered before implementation of a pot fishery.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>- No bycatch of porpoises.</td>
<td>- A pot fishery is limited with respect to catchable species.</td>
</tr>
<tr>
<td>- High quality of fish catch.</td>
<td>- There are large seasonal variations in catch rates.</td>
</tr>
<tr>
<td>- No bycatch of seabirds.</td>
<td>- Low functioning in areas with strong currents.</td>
</tr>
<tr>
<td></td>
<td>- Low catch rates in Danish waters.</td>
</tr>
<tr>
<td></td>
<td>- Ample vessel deck space needed to stow and handle the pots.</td>
</tr>
</tbody>
</table>
4 Management strategies

In terms of bycatch management, one of the most important issues is to have a clear conservation goal before deciding on a strategy, since this will make it possible to evaluate the effects of the implemented tools.

In relation to Natura2000, Article 2 in the Habitats Directive (EC 1992) says that the overall aim of the Directive is to contribute towards ensuring biodiversity through the conservation of natural habitats and wild fauna and flora. The measures taken under the Directive are with a view to ensuring that the species and habitat types concerned achieve FCS and that their long-term survival is secured across their entire natural range within the EU. In its most general sense, therefore, the conservation objective for Natura2000 areas is to contribute to either maintaining or reaching FCS. It is, however, important to distinguish between the conservation goal of individual sites and the overall goal of achieving FCS. Site level conservation objectives are a set of specified goals to be met in a site in order to ensure that it contributes in the best possible way to achieving FCS at the appropriate level. Once the goals have been set, several management strategies exist to obtain this. In most cases, mitigation tools such as the ones described in Section 3 are prescribed. Examples are the earlier mentioned Council Regulation 812/2004, which implements pingers in certain fisheries and areas within the European Union (EC 2004) and the pinger and time/area closure implemented within the Gulf of Maine (Murray et al. 2000). In both cases, however, the authorities were responsible for the choice of mitigation tools. An alternative to prescribing certain mitigation methods is a results-based approach, where a limit is set on allowable bycatch, while the mitigation methods needed to stay below that limit are left open to the fishermen. An example of result-based management is thus given below.

4.1 Bycatch quotas

One results-based approach is the use of bycatch quotas. Implementing these would allow a certain level of bycatch although it is up to the industry itself to determine how this would be kept within the defined limits. Quotas can be applied either individually or fleet-wide and allow for their transfer, purchase and lease (Alverson et al. 1994, O’Keefe et al. 2013). Quotas have not been used as a management tool to reduce bycatch of harbour porpoises, although Bisack and Sutinen (2006) published the results of a study where individual transferable quotas (ITQ) and time/area closures were compared as management tools. To study ITQs as a management tool, these authors developed a numerical bioeconomic model of harbour porpoise bycatch in the New England sink gillnet fishery. The model incorporated spatial and temporal patterns of fish species and marine mammals over several seasons and years. The results showed that the ITQ was less costly to the industry compared to the season-port closures. The difference between the two changed depending on the bycatch limit although, in all cases, the ITQ had the lowest costs (Bisack & Sutinen 2006).

ITQs have been used mainly for fish but an ITQ study has been published on the protection of Hooker’s sea lion (Phocarctos hookeri) in the New Zealand squid fishery. Because Hooker’s sea lions are protected, a bycatch limit has been set each year starting in 1992, based on population models of sustainable mortality levels. The results showed, however, that the squid fishery is much more sensitive to bycatch limits than the sea lions, that is, the fishery showed much greater losses than the sea lion population showed gains under the closures (Maunder et al. 2000). A positive example was, however, provided by the purse seine tuna fishery. Here dolphin bycatch was allowed until a certain level, which led to a large reduction in the total dolphin bycatch (Hall 1998, Gosliner 1999).
In 2004, a review was made on the effectiveness of bycatch quotas as management tools (Diamond 2004). Therein, it was stated that a successful bycatch quota programme would have to include the following.

1. Individual accountability in the form of individual bycatch quotas (IBQ). This would make individual fishers accountable for their own fishing practices and incur both the benefits and costs of high bycatch rates. If the quotas were fleet quotas, this would induce fishermen to fish as quickly as possible so they can make their profit before the bycatch quota is reached.
2. 100% observer coverage. Without complete observer coverage, much of the data would have to be either estimated or interpolated, making enforcement difficult, if not impossible.
3. Relatively small, manageable fleets. The larger the fleet or the territory that must be covered, the more difficult and expensive observation and enforcement becomes.
4. A limited number of landing ports that can be readily monitored, particularly if observer coverage is less than 100%.
5. Reliable enforcement.
6. Penalties that are true disincentives and
7. Some flexibility in the system for fishers to have alternatives to manage their bycatch.

In addition, fisheries with unpredictable bycatches are unlikely to be successful under quota management because the only way that fishers can avoid bycatch is to stop fishing. In these instances, gear modification to increase either selectivity or effort reductions may be the best solutions to bycatch problems (Diamond 2004).

5 Economic compensation

If the implementation of management measures results in considerable industry losses, a way of “sweetening the pill” is by economic compensation. This works by compensating fisheries that are affected by, for example, area closures and encourages fishers either to stop fishing or to change gear. In relation to the protection of porpoises, economic compensation has been used as part of a conservation effort in the upper Gulf of California, Mexico, for protection of the vaquita. In addition to the area closures described above (Section 3.2.1), the Mexican Government employed a set of economic incentives to eliminate shrimp drift nets and finfish gill nets from the vaquita distribution area. This voluntary programme offered different options for the fishers to either: 1) rent-out: an annual payment to stop fishing, where the fisher is paid US$3,500 annually; 2) switch-out; an agreement on using alternative gear not having vaquita bycatch, in which the fisher is paid US$25,000 and given a new fishing permit or (3) buyouts; turning in boat, nets and fishing permits and thereby gaining US$25-35,000 (SEMARNAT 2008). In 2008-2010, modifications were applied to the programme to make the buyout less appealing and the rent-out more. The switch-out option was also blurred by offering temporal switch-out, in order to make it more attractive (CNANP 2008, 2009, 2010). Analysis of the fishers’ participation in the programme showed that those with skills in alternative economic activities were more likely to halt fishing, and those with less productive vessels were more likely to switch to vaquita-safe fishing methods. Overall, however, only 15.5% of the total fleet either stopped or permanently changed into vaquita-safe fishing gear as part of the programme (Avila-Forcada et al. 2012).

As many countries do not have a tradition of economic compensation in relation to the management of marine mammals the examples are few. Swedish fishers have, however, been compensated for damages to fish catch or fishing gears caused by seals (HVm 2014).
6 Lessons to be learned from elsewhere

In many ways, the story of the implementation of management measures for protection of porpoises in the USA can be compared to the upcoming management measures of Natura2000. Read (2013) has listed the lessons learned in the Gulf of Maine and clearly emphasized the need for:

1) a clear conservation goal,
2) adequate information,
3) stakeholder involvement, and
4) implementation of monitoring programmes.

(1) If no goal is set, the plan may fail since no level of bycatch is set for example triggering an area closure. An example of a missing goal is the harbour porpoise conservation plan in the Bay of Fundy (DFO 1994) which included a provision to close an area of the western bay to gillnet fishing effort if ‘a high incidence of incidental catch is observed’. More measurable goals like a potential biological removal (PBR) level are more preferred.

(2) In the Gulf of Maine, adequate information on, for example, fishing effort allowed managers to estimate benefits and costs thereby allowing stakeholders to evaluate different mitigation measures and to offer compromise, substitution or alteration (Read 2013).

(3) Engagement of stakeholders in management decision-making has gained acceptance worldwide (Berkes et al. 2001) and many scientists and resource managers agree that the involvement of stakeholders is a key factor for a successful management regime in the marine environment. By being involved in the process, stakeholders are forced to address different issues related to the management measures (Pomeroy & Douvere 2008).

(4) Monitoring programmes documenting the effect of the mitigation measure is essential since it allows an evaluation of either success or failure. In cases where the measure is either costly or unpopular, a monitoring programme can further ensure compliance (Read 2013).
7 Implementation of harbour porpoise Natura2000 areas in Denmark

In Denmark, the Danish Ministry of the Environment has the overall national responsibility for the implementation of the Habitats Directive. This responsibility is placed within the Ministry’s Nature Agency that designates sites, develops and publishes management plans for each site so designated, and carries out public hearings. Danish Natura2000 areas for porpoises have mainly been designated on the basis of density data derived from the satellite tracking of captured and tagged individuals (Sveegaard et al. 2011a). It is the intention that designated areas are those with the highest densities of harbour porpoises, which is also in accordance with the Habitats Directive. In several areas, however, porpoises have been added to areas selected for other reasons such as reef structures (pers comm, Krawack 2015). In total, 16 areas have been selected, resulting in approximately 940,796 ha becoming protected for harbour porpoise conservation (Figure 4).

![Figure 4. Natura2000 sites selected for harbour porpoise conservation in Danish waters.](image)

The Danish Ministry of the Environment has legally delegated implementation of Natura2000 responsibility to various sectoral ministries. As a result, the Ministry of Food, Agriculture and Fisheries of Denmark and its AgriFish Agency have been given the legal responsibility to ensure that fisheries and aquaculture in Danish seas are not a hindrance to the achievement of a favourable conservation status for species and habitats. If it is deemed necessary, the AgriFish Agency must formulate and implement measures to protect the species and habitats from any threats originating from fishing activities. This legal obligation was written into Danish fisheries legislation in 2008 and any issues pertaining to fishing in relation to the Habitats Directive are therefore centred within the AgriFish Agency (Paper IV).

7.1 The process of porpoise management measures in Danish Natura2000

As a result of the relatively recent designations of many sea areas for porpoise conservation, the AgriFish Agency will not develop formal management measures for the sites before 2015. The initial work is, however, ongoing and in order to foster an open and effective dialogue between stakeholders, the Danish AgriFish Agency has invited fisheries and environmental organizations and other relevant institutions to
join a *Dialogue Forum*. The underlying philosophy behind these dialogues is that stakeholders will benefit from each other’s knowledge and experiences through a series of meetings, each addressing a range of relevant topics, which are mainly identified by the Danish AgriFish Agency. During each meeting, the group discusses selected areas, issues or species, thereby directing the meetings towards specific and detailed goals on these pre-defined topics. In preparation for these meetings, the Danish AgriFish Agency relies on scientific background documents provided by independent research institutions such as DTU Aqua and Aarhus University. The Dialogue Forum must not be mistaken for an attempt to either reach consensus or achieve co-decision on management issues. There are no stated guarantees that viewpoints expressed will be taken into account and once the meetings are over, the decision-making process continues behind the closed doors of the AgriFish Agency until management decisions are proposed. In addition to the Dialogue Forum and in specific relation to porpoises, the AgriFish Agency has established an expert group to support it in relation to scientific advice about porpoises and their interactions with fisheries (Paper IV).

7.1.1 Setting goals
Looking back on the lessons learned from Read (2013) (Section 6), one of the most important issues for porpoise conservation is the need for a clear goal in order for Natura2000 to succeed. As described under the management goals of Natura2000 (Section 1.3.1 and 4), the goal is to contribute to maintain or reach FCS. It is, however, essential to distinguish between a conservation goal for individual sites and the overall goal of achieving FCS. Site level conservation objectives are a set of specified goals to be met for a site in order to ensure that it contributes in the best possible way to achieving FCS at the appropriate level.

When setting the goals for the individual sites, it is important to keep the diversity of the different areas in mind. Some of the areas have been selected due to their high densities of porpoises while others have been selected due to the presence, for example, of reef structures, and porpoises have later been added due to their presence in the area. It is, therefore, important that the sites are considered on a case-by-case basis and it might not, therefore, be appropriate to have the same goals for all sites even though this is probably the easiest way in terms of management.

In addition to the goals of Natura2000, Denmark has to comply with EU Council Regulation 812/2004 laying down measures concerning incidental catches of cetaceans in fisheries and the ASCOBANS agreement even though this is not legally binding (Section 1.3.3).

Setting the goals of the Natura2000 sites is, however, a political decision and will depend on how the Danish AgriFish Agency decides to interpret the Habitats Directive. As stated by Read (2013), however, a measurable goal is important to allow assessments of when that goal is reached.

7.1.2 Stakeholder involvement
Stakeholder participation and involvement in the management decision-making process is important and has gained acceptance worldwide (Berkes et al. 2001, McConny et al. 2003). It is one of the main issues discussed by Read (2013). As described in Paper IV, Danish stakeholders participate in meetings in relation to Natura2000. One disadvantage of such proposed meetings may be, however, the lack of a local presence when developing fisheries management measures for Natura2000. Although several fishers’ associations are represented in the AgriFish Agency’s Dialogue Forum, the absence of local government bodies that can interact directly with (especially small scale) fisheries stakeholders who might be affected...
directly by management decisions may fuel the idea that the management approach is purely top-down and that local concerns are not taken account of.

7.1.3 Interviews (MESMA - Monitoring and Evaluation of Spatially Managed marine Areas)
- Collected by Lotte Kindt-Larsen 2012

The EU FP7 project MESMA has focused on marine spatial planning and aimed to produce integrated management tools (concepts, models and guidelines) for monitoring, evaluation and implementation of spatially managed marine areas, based on European collaboration. As part of the MESMA project, views from fishers have been collected through interviews. The main focus of the interviews was to contact those fishers using the two Natura2000 areas “Skagerrak and Skagens Gren” and “Store rev” since these have high fishery importance.

The fishers were asked about: vessel length; number of persons working onboard, years as a fisher and gear used. The fishers were then given a map on which to draw fishing positions according to target species, mesh sizes, sea days and months. Questions relating to Natura2000 and porpoise bycatch are listed in Table 2 below. A total of 20 fishers were interviewed, twelve from Hirtshals and eight from Skagen. Table 2 gives a summary of the most important results obtained from the interviews.

Table 2. Summary of interviews

<table>
<thead>
<tr>
<th>Questions</th>
<th>Result</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Had they heard about the Natura2000 plans</td>
<td>95% answered yes</td>
<td></td>
</tr>
<tr>
<td>Had they seen the Natura2000 map</td>
<td>73% answered yes</td>
<td>Many of the fishers in Skagen had participated in a Natura2000 meeting held by their organization</td>
</tr>
<tr>
<td>Had they been fishing in the areas</td>
<td>100% answered yes</td>
<td></td>
</tr>
<tr>
<td>How much of their income was from the two areas</td>
<td>65% (mean) ranging from 0-100%</td>
<td>Only one fisher had no fishery within the areas.</td>
</tr>
<tr>
<td>Did they consider gillnet fishery as a threat to porpoises in the areas</td>
<td>100% answered no</td>
<td></td>
</tr>
<tr>
<td>Did they believe Natura2000 would protect porpoises</td>
<td>90% answered no 10% did not know</td>
<td>Comments from fishers: Porpoises move around too much so they will not be protected within these areas. A better protection would be to find where the problems are and protect them there.</td>
</tr>
<tr>
<td>What would happen to their fishery if the areas was closed</td>
<td>84% would have to close 10% would be able to change area 5% would not be affected</td>
<td></td>
</tr>
<tr>
<td>Question</td>
<td>Response 1</td>
<td>Response 2</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Had they any management ideas for the areas</td>
<td>47% had ideas on how the areas could be managed</td>
<td>Most answered that pingers should be mandatory in the area.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Stop gillnet fishery with trammel nets since they can hold the porpoises.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Implementation of CCTV to be able to fish.</td>
</tr>
<tr>
<td>Would they be willing to take CCTV cameras to continue fishing</td>
<td>30% would be willing to take CCTV cameras</td>
<td>Some fishers would only be willing to take CCTV if they got additional quotas</td>
</tr>
<tr>
<td>Point out fisheries with high bycatch risks</td>
<td>78% answered the Lumpsucker fishery</td>
<td>The reason why these fisheries has the highest bycatch is due to their long fishing time (Lumpsucker) and many nets and large meshes (Turbot)</td>
</tr>
<tr>
<td></td>
<td>42% answered the Lumpsucker and Turbot fishery</td>
<td></td>
</tr>
<tr>
<td>What can be done to avoid bycatch</td>
<td>36% answered that pingers could be used</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5% answered that the time the net was in the water could be reduced</td>
<td></td>
</tr>
<tr>
<td>Had they done anything to avoid bycatch</td>
<td>100% answered no</td>
<td>Since they did not think there was a bycatch problem they did not do anything to avoid it</td>
</tr>
<tr>
<td>Had they heard about pingers</td>
<td>84% answered yes</td>
<td></td>
</tr>
<tr>
<td>Had they ever used pingers</td>
<td>10% answered yes</td>
<td>The main reason for them not to use pingers was that none of the fishers felt obliged to use them in their fishery</td>
</tr>
<tr>
<td>Had they any further comments</td>
<td></td>
<td>- Several answered that the problem will solve itself. Many gillnetters are old and will stop within the next 5 years.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- There are no problems with bycatch in these areas, but there are in other locations in Denmark, so why are they not stopped there instead?</td>
</tr>
</tbody>
</table>

The fishers were generally positive and took time off from work for the interview and many hoped that the interview results could be used as a way to present their knowledge and views to the AgriFish Agency. They were confident when speaking about their fishing activities in Natura2000 areas and provided information on fishing positions on the maps. With regards to the implementation of Natura2000, the fishers disagreed with the boundaries of the areas since they did not think that there were any bycatches within them. Many interviewees asked the question “why not regulate in the areas or fisheries with bycatch problems if you want to save porpoises?” and did not see the point in implementing Natura2000 areas. Many also raised concerns about possible closures of, especially, the Store Rev site. The fishers believed that the persons who had made the boundaries of Store Rev must have known where
the gillnet fishery is conducted since it exactly encompasses their fishing areas. They were told that the areas were made on the basis of porpoise density maps, but they remained sceptical. Their point was that gillnet fishers are limited to fishing in areas where the trawl fishery is difficult/impossible; otherwise trawlers would interfere with their gear. Store Rev serves as such as a site due to its reef construction, which excludes the trawlers (see Paper IV).

Concerns about using CCTV cameras as a requirement to fish/ document bycatch within the areas were also raised. The idea of CCTV was in general rejected due to ethical problems about being video monitored. Furthermore the gillnet fishers thought that they had been allocated additional quotas that were too low under CQMS (Section 2) and that the gillnet fishery had been treated unfairly under the distribution of cod quotas within the CQMS and that, therefore, they did not want to take cameras on-board. Concerns on registrations of porpoise bycatch did not seem to be a problem. They were asked what they would do if they were the AgriFish Agency having to make regulations in the area. Some had no answer to this question while others tried to put themselves in the situation and tried to come up with solutions that would both protect porpoises and not close down all gillnet fishing. The most frequent solution was to implement pinger use in the area even though few had ever used them. Many pointed out that it would be too costly for the industry to implement and only found it fair as a regulation if the EU was willing to co-finance the pingers. Concerns on the quality of the current pinger types were also raised. Other fishers suggested excluding some fisheries from pinger regulations, for example, the sole fishery, and only regulate the ones having the risks of bycatch such as the lumpsucker fishery.

In summary, therefore, there is no doubt that any regulations within the Natura2000 areas will affect gillnet fishers and they fear what will happen to them when these are implemented. Many fishers are economically dependent on retaining access to the Natura2000 areas such as both Store Rev and Skagens Gren since many of them do not have either the possibility or motive for moving or changing their gear. They were wholly aware of the fact that management measures for the areas will come into force in the near future but hoped that their opinions would be taken into account by the AgriFish Agency. If the management measures for Natura2000 are to be accepted and implemented successfully, it is critical that even more involvement by local fishers is obtained in the process within Denmark.
8  Natura2000 management measures in other EU countries
As mentioned in the above Introduction, EU Member States are, according to Natura2000, obliged to nominate candidate protected areas in their waters to the EU Commission and, within six years, establish legislation to implement such areas as special areas of conservation and prepare appropriate management measures (EC 2007). The EU Member States have, however, chosen different approaches in terms of selecting areas and they are likewise in different stages in relation to management plans. A short review of where some of the Member States are in their processes of developing management measures is presented below. All notes are based on either interviews or email correspondence with persons working with different aspects of Natura2000 in the respective countries.

8.1  Belgium
(Ellen Peccau - ILVO Institute for Agricultural and Fisheries Research)
No area in Belgium is designated to specifically protect the harbour porpoise. In 2008, Belgium was reprimanded by the EU for taking insufficient measures to protect harbour porpoise. In response to that, the government prohibited the use of gillnets at sea by the recreational fishery. In 2009, a decree related to the protection of species was developed. Nevertheless, enforcement is lacking as the implementing legislation is not in place. In September 2013, the EU again questioned the management measures for porpoises in Belgium.

8.2  Finland
(Heikki Korpelainen - Ministry of the Environment (YM))
In Finland no Natura2000 areas has been designated for harbour porpoise. Few registrations of porpoises have been recorded during the SAMBAH project (SAMBAH 2014), however, the Finnish Ministry of the Environment and the Commission agreed that registrations of porpoises in Finnish waters were so rare that Finland should not designate Natura2000 areas for their protection.

8.3  Germany
(Christian Von Dorrien- Thünen Institute of Baltic Sea Fisheries)
In 2011, Germany was the first country to put forward a public international hearing on fisheries management proposals for Natura2000 areas. The hearing covered 10 Natura2000 areas in the German EEZ of the North Sea and Baltic Sea, where the Federal Government is responsible. The proposals contained closures and restrictions on mobile bottom contacting gears due to their impact on reefs and sandbanks, as well as on the gillnet fisheries due to their risk of bycatch of both porpoises and birds. In June 2013, the Federal State (Bundesland) of Schleswig-Holstein held a national hearing concerning areas that are within 12 nm and therefore fall under its jurisdiction. The management plan was however, rejected due to criticism from Denmark, which has historical fishing rights up to 3 nautical miles from the coast, and partly due to strong opposition from the affected local fisheries. Finally, an agreement between Schleswig-Holstein and two local fisheries organisations was made agreeing to voluntarily reduce the length of gillnets in summer and to ad-hoc fishing closures in certain areas in winter when high densities of seabirds are observed.
At this stage, Germany has no dedicated management measures for harbour porpoise protection in German Natura2000 areas. The only exceptions are those areas where there is some overlap with a National Park, like the Wadden Sea and one area on the coast of the island of Rügen.

8.4 Holland

(Robbert G. Jak - IMARES Institute for Marine Resources & Ecosystem Studies)

In Holland no Natura2000 areas have been selected specifically for porpoises. Porpoises have, however, been added to other Natura2000 areas which have been selected for other reasons, e.g., habitats. The reason for this is that it has been impossible to identify areas or regions of particular ecological significance for harbour porpoises for any significant length of time. Thus in 2011 Holland adopted the current Harbour Porpoise Conservation Plan, which more generic rather than area-orientated (Camphuysen & Siemensma 2011).

8.5 Italy

(Caterina Fortuna - National Institute for Environmental Protection and Research, Rome)

No porpoises exist in Italian waters. Italy has, however, designated few Natura2000 areas which includes bottlenose dolphins (Tursiops truncatus) on the list of species for protection. These areas have been selected based on confirmed regular presence of bottlenose dolphins. To date, however, no management plans have been implemented.

8.6 Poland

(Krzysztof E. Skóra - Faculty of Oceanography and Geography - University of Gdansk)

Poland has selected four Natura2000 areas for porpoise protection. The designations are based on high density and stranding data and have been agreed upon by the Commission. No management measures specifically for the areas exists, however, a new Harbour Porpoise Conservation Programme is waiting for approval (PL 2015).

8.7 Portugal

(Ana Marçalo - Portuguese Wildlife Society & Dep. Biology, Universidade AVERIRO)

Portugal has not selected any Natura200 areas for harbour porpoise or any other cetaceans yet. The project LIFE MARPRO (Conservation of Marine Protected Species in Mainland Portugal) will, however, elaborate both proposals for Natura2000 areas and management plans for harbour porpoise and bottlenose dolphins. MARPRO ends in 2016 and expectedly areas will be submitted to the European Commission be then.

8.8 Sweden

(Erland Lettevall & Lena Tingström - Swedish Agency for Marine and Water Management)

In Sweden six Natura2000 sites have been selected for harbour porpoises, among other species and habitats. Some coastal County Administrative Boards (CAB) have been asked to propose additional Natura2000 sites for porpoise protection before 1 May 2015. The designations will be based on high density areas of porpoises, similar to the Danish approach. The proposals for new Natura2000 sites for porpoises should be based on density data collected under SAMBAH (Section 1.1). Once the CABs have
proposed the areas, they need to be approved by the Swedish Environmental Protection Agency and designated by the Government before they can be submitted for approval by the European Commission.

8.9 UK
(Mark Tasker - The Joint Nature Conservation Committee)

Harbour porpoise conservation in UK waters is currently carried out under a number of regulations that implement several EU Directives and Regulations. JNCC has recently begun work on a more focused management plan that will be published in 2014-15. This plan is aimed at maintaining the populations of harbour porpoises at a favourable conservation status but will take knowledge on bycatch in relation to different fisheries and areas into account.

The UK has, at present, only one Special Area of Conservation for harbour porpoises. This is the Skerries and Causeway site off Northern Ireland. Analysis is underway at present to determine if there might be further areas essential to the life and reproduction of the species that could be suitable for designation. In two earlier attempts to find such sites, the JNCC did not find any areas suited for Natura2000 due to the widespread and mobile nature of the species’ occurrence in UK waters. The European Commission has recently encouraged the UK to try again to find suitable areas.

Estonia, France, Latvia, Lithuania and Spain are also covered by Natura2000 but have not been interviewed.
9 **Suitability of bycatch mitigation tools in Natura2000 areas**

Denmark is now at a stage where Natura2000 sites for porpoises have been selected and approved by the European Commission and the next step is preparing management measures. Ensuring that the conservation goals of the sites are met could potentially mean, however, that restrictions in fisheries are needed in order to minimize porpoise bycatch. As described above, several mitigation methods to reduce bycatch numbers already exist (Section 3) and their suitability for implementation within Danish Natura2000 sites will be discussed below.

9.1 **Reducing bycatch per unit effort as a mitigation tool**

This section describes the suitability of using pingers as a bycatch mitigation tool within Natura2000 areas (see also Section 3.1 for information on pingers).

9.1.1 **Mitigating bycatch using pingers**

As described earlier (Section 3.1.1), pingers are effective in reducing porpoise bycatches. Because of the positive results obtained with pinger use in gillnet fisheries, the European Commission has concluded that currently there are no alternative technical mitigation measure that have been proven to be effective in reducing the incidental catches of cetaceans (EC 2011). In order to reduce bycatch of porpoises within Natura2000 areas, implementing pinger use would thus be an obvious solution. There are, however, a number of issues that need to be addressed in relation to pinger use in Natura2000 areas.

9.1.1.1 **Effectiveness in terms of porpoise protection**

Since pingers are developed to displace porpoises from their vicinity, they will have an effect on the distribution of porpoises in the area. By how much, however, will be influenced by area, background noise, habituation level and pinger signal types (Paper III). Depending on the level and distribution of fishing effort, pinger use in Natura2000 areas could potentially reduce the presence of porpoises in it. It is, however, possible that larger Natura2000 areas could encompass both porpoises and gillnet fisheries required to use pingers at the same time, provided the fishery occupied only limited parts of the Natura2000 area and porpoises could use other parts of the area when pingers were deployed.

In relation to minimizing the level of pinger displacement effects, the results obtained in Paper III are important. The experiments revealed differences in impact radii by different pinger types. If pingers are to be implemented within Natura2000 sites it could therefore be beneficial to advocate the use of pinger types that have the lowest impact radii in order to displace the porpoises as little as possible. The results described in Paper III further revealed that porpoises do not appear to habituate to all pinger types. Habituation is most often interpreted as something negative. It can, however, also be beneficial as long as it does not lead to increased bycatch rates, since this would reduce the pinger displacement effect. Another possibility could be implementation of pingers with even shorter impact radii than the types that exist today, since a short-range pinger would, in theory, limit displacement effects on porpoises. Whether a short-range pinger could function in terms of bycatch reduction should, however, be tested in the gillnet fishery since such a pinger might not deter the porpoises sufficiently to avoid entanglement.

9.1.1.2 **Impact on fisheries**

Many of the porpoise Natura2000 sites serve as important fishing grounds for the gillnet fishery (Paper II). Since pingers do not affect the catch rates of fish, fishers will not have any loss in terms of catch opportunities if pingers are implemented. Fishers, however, will incur capital costs in terms of purchasing the pingers. The total cost will depend on the numbers of nets used and pinger type. Some pingers can be
spaced at larger intervals than others, and pingers also vary in price (€40–130 each). Implementation of pingers in Natura2000 areas would not, therefore, influence the fisheries’ income, but they will have recurrent expenses in addition to the initial capital costs in terms of maintenance of the pingers. Pingers are, however, the only bycatch mitigation method, that will allow gillnet fisheries to continue fishing at the current level within Natura2000 sites and they will thus have the least financial impact on the fishery.

9.1.1.3 Enforcement demands
Pingers need to be inspected for their functionality and correct spacing. If pinger use is not enforced, it is possible that the fishermen will not attach the pingers correctly, nor will they replace those that are malfunctioning. Both of these factors would influence the pingers’ abilities to reduce bycatch. In order to avoid this, the use of pingers within Natura2000 areas would require extensive enforcement.

9.1.1.4 Other issues relating to pinger use
As pingers displace porpoises, their suitability for use in Natura2000 areas depends on the interpretation of the Habitats Directive (Danish Nature Protection Law) since their use requires that some level of displacement is accepted. The Danish Nature Protection Law states, however, that Annex 3 species, which includes porpoises, may not intentionally be disturbed with adverse effects on either the species or the stock.

In conclusion, the level of displacement in Natura2000 sites due to pinger use will depend on the size of the area, its importance for porpoises, the level of fishing effort, the level of pinger use, the effective range of the pinger and effort distribution in such waters. This means that the evaluation of pinger use, in terms of porpoise protection within Natura2000 sites, needs to be assessed on a case-by-case basis.

9.2 Mitigating bycatch by changes in effort in Natura2000 areas
This section describes the suitability of using effort related tools, such as time area closures and alternative gears as bycatch mitigation tools within Natura2000 areas (see also Sections 3.2 and 3.3 for more information on time/area closures and alternative gear types).

9.2.1 Mitigating bycatch by time/area closures
Having Natura2000 areas closed for gillnet fishers would obviously reduce the bycatch within them. There are, however, a number of issues that need to be addressed in relation to time/area closures in Natura2000 areas.

9.2.1.1 Effectiveness in terms of porpoise protection
Time/area closures will be beneficial for porpoise protection since they will be protected against the risk of entanglement within the site. The re-distribution of fishing effort could potentially, however, increase the bycatch risk elsewhere. If, for example, effort is re-distributed into areas with higher bycatch rates compared to the site. If time/area closures should function without increasing bycatches elsewhere, Natura2000 sites need to have higher bycatch rates compared to areas outside them. If this is not the case, the bycatch of porpoises will be re-allocated to waters outside Natura2000 ones. This may not interfere with the goal of the specific site, but with the overall goal of the Habitats Directive.

The effectiveness of a potential time/area closure also depends on the possibilities of adapting the areas to variations in porpoise distribution. If not, the time/area closures could potentially result in higher bycatch rates elsewhere, since the concentrations of porpoises may have moved into areas not covered by Natura2000. High density porpoise areas in Denmark have, however, been shown to be rather stable over
time (Paper II Appendix 1, Sveegaard et al. 2011b). If such changes were to occur, however, changing the designation of areas would be a time consuming process since the EC most likely would have to approve them. Whether Natura2000 designations will be able to adapt to incorporate changes in porpoise distribution or fishing effort in a timely fashion thus remains unknown.

9.2.1.2 Impact on fisheries
If time/area closures are implemented within Danish Natura2000 sites, it will have an impact on the gillnet fishery. How much will depend on the importance of the areas for the fishery and the level of closure. As mentioned above, several Natura2000 areas serve as important fishing grounds. Re-allocation of gillnet fisheries is, therefore, to be expected if traditional fishing areas are to be closed. The redistribution of displaced fishing effort can be assessed by modelling (Bastardie et al. 2010). It is, however, not always clear where the re-distribution will occur, but it still remains a critical step in assessing the impacts of any closure. Taking the areas identified and discussed in Paper II as an example, a limitation of the fishery in the two Natura2000 areas (covered by areas A and B) would lead to the re-distribution of the gillnet fishery. The question would then arise: is it possible to re-distribute such high fishing efforts? Particularly, of course, bearing in mind both competition with the trawl fishery and the lack of other suitable gillnet fishing grounds. During conducted interviews (Section 7.1.3), fishers were asked about their economic dependence on “Store Rev” (Area B, Paper II) as a fishing ground. In reply, it was said that, on average, 65% (0-95%) of their total income came from that specific area. Thus, if time/area closures are implemented within Danish Natura2000 areas, such as the two discussed in Paper II, it will most likely result in increased costs for the gillnet fishery. The costs will be both in terms of lost catch opportunities and an increase in fuel costs resulting from steaming to fishing grounds further away, and some fishers would potentially have to cease their activities.

9.2.1.3 Enforcement demands
As described earlier, time/area closures can be monitored by use of VMS (Section 3.2.1.3). Since 2012, all Danish vessels >12m loa carry VMS, thereby making it possible to check if the vessels are fishing either inside or outside a closed area. Since, however, approximately 90% of the Danish gillnet fleet comprises vessels of <12m loa and thus do not carry VMS it would be difficult to enforce time/area closures by this method. Enforcement could therefore only be conducted by fisheries inspections at sea. These would, however, not be as frequent as the VMS system since this registers the vessel position every hour.

9.2.1.4 Other issues relating to time/area closures
Another possibility could be to rule out gillnet fisheries in areas with the highest bycatch rates (Section 3.1.4). Even though little data on bycatch rates in relation to target species exists, and most such information is non-significant, there might be potential in regulation through target species for example. The fishing industry itself has several times pointed at the lumpsucker (Cyclopterus lumpus) fishery as one with large porpoise bycatches (Section 7.1.3) and many porpoise strandings have been recorded from Danish beaches during the months when the lumpsucker fishery is active. At this stage, however, insufficient data are available on this fishery and, because of this, exclusions of fisheries with high bycatch rates as a tool to mitigate bycatch within Natura2000 areas is not a viable option.

In conclusion, time/area closures could work as a mitigation tool within Natura2000 sites. If, however, bycatch rates are not shown to be higher within the sites compared to outside such closures, the total
bycatch could potentially increase. If time/area closures are to be implemented it is, thus, important to monitor which areas the gillnet fisheries relocate to, if total bycatches are not to increase.

9.2.2 Mitigating bycatch by only allowing alternative gear
The catch potentials of alternative gears such as longlines and pots are presented in Section 3.3. Mitigation of bycatch by only allowing alternative gear can be regarded as time or area closures of gillnet fisheries, since the areas need to be closed for gillnet in order to protect porpoises. The effectiveness and impact on fisheries in relation to Natura2000 are discussed below.

9.2.2.1 Effectiveness in terms of porpoise protection
The main advantage of both longline and pot fisheries is that they do not have porpoise bycatches. Since not all gillnet fisheries are replaceable by alternative gears, however, it is most likely that a part of the gillnet fleet will re-allocate to areas not covered by Natura2000 plans. Restrictions on fishing gear might thus contribute to low bycatch levels within the sites but increase the bycatch elsewhere. Re-allocation of non-replaceable gillnet fisheries should thus be considered before implementation of alternative gears.

9.2.2.2 Impact on fisheries
Only allowing certain gear types within Natura2000 sites will have major impacts on the fishing industry, since fishers would be unable to continue their usual activities. They will have to reorganise their vessels and learn how to fish with other gears. Even though most gillnet vessels are suitable for longline fishing, for example, many fishers have spent decades fishing with gillnets and changing into another gear type would be a challenge many could not contemplate as an option.

Furthermore, both pots and longlines have shown to be difficult to operate under strong currents and several of the Natura2000 sites are positioned in areas with strong currents, including the Skagerrak Sea. In addition, longlines and pots will only be suitable for a small number of species since plaice (Pleuronectes platessa), for example, for which there is a major gillnet fishery in Denmark, cannot be caught by either longlines or pots.

If Natura2000 sites were, therefore, open only for fisheries with no risk of porpoise bycatch, it would result in increased costs for the fishery both in terms of capital costs for new gear but also in terms of recurrently reduced incomes because of reduced catching opportunities.

9.2.2.3 Enforcement demands
Enforcement of alternative gears could be conducted by at-sea inspections and will, as with time/area closures, be far less demanding compared to the enforcement of pinger use, for example.

In conclusion, it is doubtful whether gears such as longlines or pots can generally be implemented in Natura2000 sites as a replacement for the gillnet fishery. In some areas, with low current speeds, longlines or pots could potentially replace a part of the gillnet fishery for roundfish. In areas with high currents, however, such as the Skagerrak, a change into longlines or pots would not be feasible. Whether longlines or pots could function as an alternative fishing method for the gillnet fishery within Natura2000 sites thus depends on whether sufficiently high catch rates of the target species can be achieved within them.
10 Recommendations

10.1 Key research and technological development recommendations

i. Investigate the causes of porpoise entanglement, as this is still unknown. With this information, scientists would be able to better focus research into the development of effective mitigation tools. If, for example, porpoise bycatch is caused by lack of attention to the net barrier, testing the principle of alerting sound pingers would be important.

ii. Identify the effects of habitat exclusion on porpoise populations. If pingers are used for porpoise protection in Natura2000 areas, it is important to know what the consequences would be at the population level. Furthermore research on minimising the area affected by pinger sounds is needed. Investigating, for example, how short the effective pinger range could be and still avoid bycatch would be valuable. Also a clear definition of pinger effective range including a standard procedure for measuring it is needed.

iii. As habituation may minimise habitat exclusion, investigations into porpoise habituation behaviour in relation to different pinger types would be valuable. Habituation trials have, hitherto, only been conducted to a limited extent and more trials are needed to ascertain if porpoises are more likely to habituate to certain pinger signals.

iv. The further development of tools to identify areas of high bycatch risk. Paper II has developed one such tool, but more research is needed on the model employed and its general applicability, particularly to evaluate if the relationship identified between effort, porpoise density and bycatch is applicable to other fisheries.

v. The use of CCTV to monitor bycatch is becoming accepted, but the systems and analysis tools need to be expanded and particularised for specific bycatch monitoring purposes. The development of tools to easily identify soak time, net length, mesh size and pinger functionality would also be valuable. Procedures to more easily move systems between vessels would be advantageous. Further research on the development of automated image recognition software should also be conducted.

10.2 Key management recommendations:

1. Decide on goals for Natura2000 management plans and how these should feed into the overall protection of harbour porpoises.

2. Assessment of the magnitude of porpoise bycatch risk as this forms the basis for management measures. Porpoise bycatch risk should not only be assessed for Natura2000 areas but for all waters. Such assessments should, ideally, be updated yearly as fishing effort may change from year to year.
3. The Danish harbour porpoise Natura2000 sites differ in size, porpoise density, fishing effort and reasons for designation and, thus, protection measures should be prepared on a site-specific basis and where data from fisheries and porpoise densities/usage are taken into account.

4. If pingers are to be implemented within Natura2000 sites, they should have the least adverse impact on porpoises. Management measures should thus allow only pingers with the shortest impact range as this would help to minimize porpoise displacement.

5. If the fisheries management plans for Natura2000 areas are to be accepted and implemented successfully, it is critical that more involvement in these processes is obtained by local fishers within Denmark.

6. In relation to the fisheries management of Natura2000, it is important not only to focus on such designated areas but on all waters where porpoise bycatch risk is identified. Management measures should be implemented in all risk areas regardless of whether they have Natura2000 status, or not, as this will protect not only the most porpoises but it would also make the most sense for the fishers.
11 Conclusion

The overall aim of this Ph.D. was to examine and evaluate different tools that could contribute to the scientific knowledge required when preparing fisheries management plans for harbour porpoise conservation in Natura2000 areas.

The four papers have each contributed towards different issues. Paper I, has provided scientists and managers with a novel tool to monitor harbour porpoise bycatch in gillnet fisheries. The use of CCTV-cameras has both increased monitoring levels and reduced the costs of direct observations. Paper II has provided scientists with a new tool to identify areas of high risk of porpoise bycatch, as a correlation has been identified between porpoise densities, fishing effort and harbour porpoise bycatch. Paper III has revealed new knowledge on porpoise behaviour in relation to acoustic alarms. Research has shown that porpoises exhibit different behaviours depending on pinger type, both in terms of habituation and within distances at which porpoises approach the pinger. Finally, Paper IV has described the governance mechanisms in relation to the implementation of Natura2000 sites for porpoise conservation in Denmark’s waters.

The thesis has, furthermore, reviewed methods to mitigate porpoise bycatch and discussed their feasibilities as management measures for Natura2000 sites. The review has revealed that there are several methods that can reduce the level of porpoise bycatch. They do differ, however, in relation to their impacts on fisheries, effectiveness in terms of porpoise protection and enforcement requirements. All methods have some kind of cost for gillnet fisheries in terms of either the purchase of equipment and/or lost catching opportunities. Of the methods reviewed, pinger use is, however, the method that least affects any gillnet fishery since fishers can continue their activities with the same effort within Natura2000 sites. In relation to the effectiveness of porpoise protection, the reviewed methods could all reduce bycatch. They all, however, have some potentially negative side effects such as disturbance or possible increases in bycatch elsewhere.

All methods had costs in terms of enforcement. Pinger use, however, had the highest enforcement needs. Such instruments require to be inspected regularly and if fishermen do not attach the pingers correctly, nor replace malfunctioning pingers, their effectiveness would be diminished. In conclusion, there are no solutions to the bycatch problem that do not have some kind of cost. At this stage, pingers seem, however, to be the most appropriate tool for reducing porpoise bycatches. If they are to be implemented within Natura2000 sites, however, porpoise displacement must be expected and accepted.

This thesis has focussed on the management of fisheries within Natura200 sites and, thus, the bycatch of harbour porpoises. The main difference between Natura2000 sites and other protected areas focusing on reducing bycatch is, however, the manner in which they are selected. Most porpoise protected areas have been selected due to high bycatch rates, whereas Natura2000 sites have been selected mainly due to the high densities of resident porpoises. Bycatch is, therefore, necessarily a problem within Danish Natura2000 sites. Focussing on porpoise bycatch, one could thus argue that the areas should have been selected based on bycatch rates and not porpoise densities. Areas with high densities of porpoises will, however, always have a potential risk of bycatch if gillnet fishing is either introduced into or conducted within the area. Furthermore, the goal of Natura2000 is not only to protect porpoises from bycatch but
also to avoid habitat deterioration and species disturbance in general. These issues should therefore be discussed in relation to the future management plans for Natura2000 sites.

It is, however, my hope that the information and research results presented both within the research papers and within this thesis will serve as a resource for managers, working on fisheries related issues, in developing management plans for porpoises within proposed Natura2000 sites in Denmark and other EU member states.
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PAPER I

Observing incidental harbour porpoise (Phocoena phocoena) bycatch by Remote Electronic Monitoring
Kindt-Larsen L, Dalskov J, Stage B, Larsen F (2012)
Endangered Species Research 19:75-83
Observing incidental harbour porpoise *Phocoena phocoena* bycatch by remote electronic monitoring

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**ABSTRACT:** Quantification of marine mammal bycatch is important in the context of conservation and management of protected species. Hitherto, using on-board observers has been the most reliable and accurate method; however, observer programs can be prohibitively expensive. To investigate the potential of closed-circuit television cameras to document bycatch of marine mammals, 6 Danish commercial gillnetters (10 to 15 m in length) operating under the Danish catch quota management system were equipped with remote electronic monitoring (REM) systems. The REM systems provided video footage, time and position of all net hauls and bycatches of marine mammals. Comparisons between REM results and fishers' logbooks showed that the REM system gave more reliable results, since fishers, in many cases, did not observe the bycatch while working on the deck because the bycatch had already dropped out of the net before coming on board. Furthermore, very high coverage percentages at low cost, compared to on-board observers, could be obtained with REM. Alternative means of conducting the video analysis were tested; they were, however, not found to be very efficient.

**KEY WORDS:** Bycatch · Harbour porpoise · Remote electronic monitoring · Closed-circuit television

**INTRODUCTION**

Monitoring of marine mammal bycatch has been conducted worldwide due to growing concerns regarding the population status of many marine mammal species. In 1992, the Council of the European Community (CEC) adopted the Habitats Directive on conservation of natural habitats and of wild fauna and flora, which obliges member states to estimate incidental bycatch of marine mammals (CEC 1992). Furthermore, the European Commission implemented Council Regulation No. 812 in 2004, which specifies measures concerning incidental bycatch of marine mammals, including specific requirements for bycatch monitoring (EC 2004). Assessment of both the Habitats Directive and Council Regulation 812/2004 has nevertheless shown that many monitoring tasks have not yet been fulfilled, mainly due to lack of funding (EP 2010). Bycatch monitoring can be conducted using a number of different methods, but in most cases on-board observers are recommended as a means of collecting accurate data (IWC 1994). However, on-board observer programs are expensive, particularly in high-wage countries like Denmark, and can be difficult to implement. Since the implementation of Council Regulation 812/2004 approximately 6 million Euros have been spent in countries of the European Union (EU) on marine mammal observer programs in which 135 cetaceans have been reported as bycatch (EP 2010).

In 2008 the Danish government suggested that utilization of the marine resources in the EU in the revised Common Fisheries Policy (CFP) should follow a results-based approach, with the simple requirement that the fisher accounts for his total removal of fish from the resource rather than the landed catches (Ministry of Food and Agriculture 2009). By introducing full accountability through catch quotas instead of landing quotas the fisher's
incentive to optimize the value of his catch by discarding less valuable fish would be replaced by his incentive to use selective fishing methods to optimize the value of his total removals from fish stocks. To achieve this objective the fisher should receive increased quotas (catch quotas) to reflect that all fish are accounted for and he should be given the freedom of choice of method in conducting his fishery, to make his own methods work for the best result.

The present CFP with its quota and effort restrictions, high-grading ban and other restrictions contributes to a complex management system with a considerable incentive to discard unwanted catches. A catch-quota management system, with a fully documented fishery, provides assurance that quotas can actually be administered with an absolute limit, so that catch limits become an exact expression of the set fishing mortality.

In order to test whether a catch-quota management system can work and whether full documentation of fisheries is possible using electronic monitoring systems, the National Institute of Aquatic Resources (DTU Aqua) carried out a scientific trial from 2008 to 2009 deploying remote electronic monitoring (REM) systems onboard Danish commercial fishing vessels including 1 gillnetter, 4 trawlers and 1 Danish seiner (Kindt-Larsen et al. 2011).

The REM systems recorded videos of every catch event, which were analysed for discard of cod. The video footage from the gillnet vessel indicated that bycatch of marine mammals could be monitored using REM. Consequently, a pilot trial was conducted to test the REM’s abilities to record marine mammal bycatch onboard commercial gillnetters. This paper reports on this pilot trial and evaluates the feasibility of using REM to observe incidental bycatch of marine mammals, increase the monitoring levels and reduce the cost of observations.

MATERIALS AND METHODS

Vessels and fishery

The trial was conducted from 1 May 2010 to 31 April 2011 in the North Sea, Skagerrak and Øresund (Fig. 1).

Six Danish commercial gillnet vessels targeting cod Gadus morhua and plaice Pleuronectes platessa participated, using trammel nets and bottom set gillnets. One of the vessels fished mainly over shipwrecks and stone reefs, whereas the other 5 vessels fished mainly over sand, stone and gravel. All vessels had a wheelhouse, partly roofed sorting areas and a net hauler. Vessel length, gross tonnage (GT) and engine power varied from 10 to 15 m, 7.7 to 21 GT and 74 to 171 kW, respectively. Five vessels had 220 V power supplies, while one had a 24 V power supply. Half of the vessels were operated single handed; the others had 1 to 2 crew members working on deck.

REM system and installation

Vessels were equipped with the REM system developed by Archipelago Marine Research Ltd, Canada (McElderry et al. 2003, Ames et al. 2007). The system comprised a control box with a 500 GB replaceable hard drive, a hydraulic pressure sensor, a position sensor (global positioning system; GPS) and 4 waterproof armoured-dome closed-circuit television (CCTV) cameras. The control box included a computer that monitored sensor status and activated image recording. All components were connected to the control box placed in the wheelhouse. In most cases, existing gooseneck entrances were used for cabling; however, on 2 vessels, holes had to be made in the wheelhouse to accommodate cabling. The
hydraulic pressure sensor was mounted on the high-pressure side of the hydraulic system recording the pressure activity in the net drum. Cameras were mounted in most cases on existing structures. However, in some cases additional mounting brackets had to be installed for correct positioning of the cameras. On each vessel, 1 of the 4 cameras was positioned to view the net when it was breaking the water surface prior to the entry of the hauler. To ensure that the nets stayed in the frame this camera viewed a larger area than where the nets would normally break the water, since the net changed position during hauls. The other cameras recorded catch sorting, discards and fishery overview. The lenses of the CCTV cameras varied from 2.6 to 8 mm and frame rates from 2 to 9 frames per second (fps) depending on focus area. Cameras filming hauling and catch sorting were in general set with 6 to 9 fps, while overview cameras only recorded 2 fps. The size of each recorded frame was 640 x 480 pixels. The REM system on all vessels was programmed to switch on the system when leaving port and off when entering port, determined by the GPS positions of the outer range of the harbours. When the hard drive was 70 to 95% full, the fishers contacted DTU Aqua staff, who exchanged it for a new one.

Fishers’ data

In the mandatory official logbook, Danish fishers are obliged to register date and time of departure and arrival, gear type, mesh size, amount of fish obtained by species, area and ICES (International Council for the Exploration of the Sea) rectangle. In addition, fishers were asked to fill in a supplementary logbook with information on trips, hauls, gear used, catch, discard and marine mammal bycatch. Trip characteristics included vessel name and number, date sailed, date landed and home port. Haul characteristics included latitude, longitude, time of the beginning and end of the haul, soak duration, presence and quantity of fish kept and discarded, as well as the number of incidental catches of cetaceans and seals. Gear characteristics included net type, mesh size, length of string and number of nets.

Sensor analysis

Spatial and temporal parameters for the beginning and end of each fishing trip and haul were analysed by use of the REM Interpret (EMI) software (Europe release, Archipelago Ltd. V.11.3.11189). EMI displays time series of GPS tracks on a map and hydraulic pressure and vessel speed on a time line. EMI also integrates synchronized playback of all camera views to the visual map of sensor data, permitting viewers to watch both GPS tracks and the time-linked video footage concurrently.

Video analysis

Before review of the video data the DTU Aqua viewers were given 15 video test files to test their abilities to detect porpoises *Phocoena phocoena*. Ten of the 15 video files contained porpoise bycatch and 5 did not. The scores of all viewers were recorded. Subsequently all video footage containing net hauls was examined by the DTU Aqua viewers for bycatches of marine mammals. The videos were played back at a rate 10 to 12 times faster than real time, depending on catch mixture and image quality. Notations were made if the viewers believed the fishers had seen the bycatch either by cutting loose the carcass before it entered the hauler, looking over the side when the carcass was visible, or disentangling the carcass onboard. If a porpoise dropped out of the net before entering the hauler and the fishers were sorting fish or otherwise engaged on deck, the porpoise was registered as not seen by the fishers. All hours spent on data processing were added up to calculate the total cost of sensor and video analysis.

To explore efficient methods for the detection of bycatch from video footage, additional computer-aided techniques (programmed in MATLAB) were tested. Method A reduced the original video frames in size and arranged 143 frames (11 rows of 13 frames) in image montages (Fig. 2). Each montage corresponded to 5.72 s of video footage. Method B overlaid 15 video frames into a single image in the montage. The overlays were produced by continuously creating a median background removing all objects from the image. By subtracting the median image from the current video frame, varying objects (e.g. white foam, nets, porpoises) stood out from the background. Objects from 15 frames were overlaid in each image of the montage. Each image montage thereby showed a total of 2145 frames (13 x 11 x 15) corresponding to 85.8 s of video footage (Fig. 2).

Trials were conducted where viewers used both methods to browse through the montages at their own pace noting down bycatch events. Time spent on montage analysis and comments on program functionality were recorded.
RESULTS

REM system

In general the REM system worked well. Fishers found the system easy to handle and only rarely needed technical staff to repair it. These repairs included a power supply that became unstable if the vessel’s own GPS plotter was turned on before the REM, causing minor data loss.

Effort

Fig. 3 shows the number of trips recorded in official logbooks, fishers’ logbooks and by EMI sensors. According to the official logbooks, the participating vessels made 925 fishing trips and were at sea for 10,055 h. In the fishers’ supplementary logbooks, 776 fishing trips and 1074 net hauls were recorded. Analysis of the sensor data resulted in 758 trips and 5096 hauls.

For all vessels the numbers of trips recorded by fishers and sensors were smaller than the number recorded in the official logbook.

Comparing the number of hours at sea from the official logbooks with hours from the sensor data a similar pattern is seen (Table 1). The mean coverage was 86%, ranging from 61 to 97%.

Bycatch

Bycatch and gillnet positions for all 6 vessels are shown in Fig. 1. A total of 36 bycaught harbour por-

![Graph](image-url)

Fig. 3. Number of fishing trips recorded in official logbooks, fishers’ supplementary logbooks and by the sensor system

Table 1. Number of hours spent at sea as recorded in official logbooks and by sensor data, including the coverage (%) of the sensor data in relation to the official logbooks

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Hours at sea</th>
<th>Coverage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Official logbooks</td>
<td>Sensor data</td>
</tr>
<tr>
<td>1</td>
<td>1373</td>
<td>833</td>
</tr>
<tr>
<td>2</td>
<td>1270</td>
<td>1215</td>
</tr>
<tr>
<td>3</td>
<td>2060</td>
<td>1613</td>
</tr>
<tr>
<td>4</td>
<td>1574</td>
<td>1358</td>
</tr>
<tr>
<td>5</td>
<td>1872</td>
<td>1812</td>
</tr>
<tr>
<td>6</td>
<td>1906</td>
<td>1806</td>
</tr>
<tr>
<td>Total/m</td>
<td>8149</td>
<td>6831</td>
</tr>
</tbody>
</table>
poises *Phocoena phocoena* were detected in the video footage, ranging from 1 to 18 porpoises per vessel. Fishers' supplementary logbooks reported 25 porpoises caught. Three porpoises, which were reported in the logbooks, could not be found in the video footage. Fourteen porpoises not reported in fishers' logbooks were found in the videos; 7 of these were not seen by the fishers (Table 2). One bycaught harbour seal *Phoca vitulina* was observed on video footage, but was not registered in the fisher's logbook.

**EMI versus image montage methods**

The success criteria for the image montage methods were to reduce time spent on analysis and to have a high detection rate of porpoise bycatch. According to time spent on analysis, Image Montage Method A (143 frames) and Method B (2145 frames) had to be faster than 0.5 and 7 s montage$^{-1}$, respectively, to be time saving in comparison with EMI viewed at 10 to 12 times normal speed. However, both methods were highly time consuming (>>0.5 s for Method A and >>7 s for Method B), and, consequently, the image montage methods were rejected. Method A, however, showed the same number of porpoise bycatches as detected within EMI, whereas viewers using Method B registered fewer.

**Monitoring costs**

The costs of systems and installation for all 6 vessels were 61 200 € (Table 3). The running costs for the project period (811 d of fishing) were 18 900 €, including video and sensor data analysis, technical support and maintenance. A total of 913 h were spent on sensor and video analyses (analysing video footage of hauls at 10 to 12 times normal speed). All video footage reviews were done by student workers to minimize costs. The cost of a student worker in Denmark is 16 € h$^{-1}$, while technical staff cost 36 € h$^{-1}$. If all video and sensor analysis had been carried out by technical staff, the cost of video and sensor data analysis would have been 32 868 €.

**DISCUSSION**

This is the first paper to document the use of REM to record incidental bycatches of marine mammals, and the discussion will thus focus on the strengths and weaknesses of this method relative to other more common methods.

**The REM system**

The control box was found to be sensitive to unstable power supplies, causing minor computer failures. In situations where this occurred, installation of an uninterruptible power supply (UPS) could minimize data loss. No failures of sensors (GPS and hydraulic pressure) were found, which resulted in high-quality sensor data. In general, the video footage was of high quality, but dew, water droplets, waves, glare and lighting conditions occasionally lowered the quality, although never to a level where bycatch detection became impossible. Only rarely did the net shift out of the frame view during hauls. None of the vessels were found to be unsuited for camera observation; camera fixtures were easily welded to the vessels and mounted in the right positions.

**Data collection**

The number of trips and hauls recorded in the official logbooks, fishers' logbooks and sensor data
showed some discrepancies. There are several reasons for the differences. First, Vessel 3 had problems with power failures, and a hard drive from Vessel 1 was damaged in the mail, explaining their low number of trips recorded in the sensor data. None of the systems were found to be tampered with, missing data were simply due to electrical problems. Second, the number of trips recorded by sensors would almost always be fewer than in the official log, since fishers must report a trip every time they leave port. If they do not make any hauls, the trip would be classified as a trip in the official log, but not by the sensor viewer. The missing trips from the fishers' logbook data are mainly due to the fishers forgetting to fill in the logbooks, and on 1 occasion several sheets were lost in the mail. Another reason is the way the logbooks were filled in. The official logbook was filled in on a daily basis, whereas the fishers' logbook was supposed to be filled in haul by haul, making it difficult for some fishers to keep track of what is registered where. With respect to hauls, the numbers recorded in the sensor data were much larger for all vessels than the numbers recorded in the skippers' logbooks. The reason for this difference was that the fishers recorded nets set in a line or at approximately the same position as a single haul, while the REM viewer separated them into minor hauls. If the vessel stopped hauling in the middle of a net and continued some time after, it was still considered as only 1 haul by the viewer, since a haul is defined from buoy to buoy. It was, however, too much work for fishers to make logs on a single-haul basis when many hauls were carried out close to each other, since they were too busy working on deck. The differences in both hauls and trips are important to keep in mind if haul- or trip-based data from REM vessels are extrapolated to the whole fleet.

Detecting porpoise bycatch by video

A total of 39 porpoise were taken as bycatch during the REM trial. Three were recorded in the logbooks, but were not seen on the video footage, while 14 were observed on video footage, but not recorded in the fishers' logbooks. This corresponds to a detection rate of 63% in fishers' logbooks and 92% by video footage of the total number observed by fishers or video. The footage corresponding to the time at which the fishers had noted a bycatch event that was not detected on the video was carefully reexamined, but no bycatches were seen. We believe, however, that the missing bycatches are due to inaccuracies in the fishers' log notations, putting down the wrong date or time.

Inspections of the footage from the 14 observations missing in the logbooks showed that 7 of the porpoises were seen by the fishers, since they had to disentangle the carcasses from the nets, while the remaining 7 porpoises dropped out of the nets before the fishers discovered them.

Some porpoises possibly drop out while still under water and are therefore missed by the videos. Other porpoises dropped out when they broke the surface, as shown by our results, due to their heavier weight in air than in water. These results indicate 2 reasons why voluntary reporting potentially provides much lower numbers than actual bycatch. Fishers may even forget to record bycatch. Or, because the crew is normally busy during hauling, they do not watch the nets attentively as they leave the water and therefore miss the porpoises that drop out of the nets at this point. The incentive for fishers to report bycatch is also very important, since, in many cases, this is very low if there is no REM system onboard. They also often fear that the reporting of bycatch may have negative repercussions for them directly or for their industry in general.

Comparisons of detection rates between REM analysis and observers were not conducted as part of this trial. We believe, however, that marine mammal observers watching all net hauls will have a similar detection rate to the REM system, while observers who have other duties besides watching bycatch will have a lower detection rate. Detection rates from other studies comparing observers with other duties versus observers with no other duties showed lower detections in cases where observers had other tasks (Bravington & Bisack 1996). In relation to detection rates, it is very important that a camera covers the position where the nets break the surface, since a number of porpoises drop out of the net at that specific point. Cameras focused only on the net hauler will not detect all bycatches. Registration of porpoise bycatch disentanglement was previously carried out by Bravington & Bisack (1996), who showed that 58% fell out of the net before reaching the deck.

Regarding bycatch of sea birds, it was possible to detect these on the video footage. The number of seabirds were, however, not registered, since it would have been necessary to play back the video footage at a much lower speed (4 to 7 times normal speed) in order to ensure registration of all bird bycatches.
EMI versus image montages

One of the major concerns when working with large datasets of video footage is the time needed for analysis. If video footage is to be used for routine monitoring of marine mammal bycatch, it is very important to find the best possible method that, in the shortest possible time, will determine the number of animals caught. The EMI program restricted the video review to the hauling periods only, thus limiting the time spent on data review. The playback speed and video window size were easily adjustable for the viewers, making it possible to address low picture quality, and, in general, all viewers found the program easy to handle. Compared to this, the 2 methods using image montage were both very time consuming, and overwriting of bycatches was possible in Method B, making it very difficult to determine the number of marine mammals present. These 2 methods were thus rejected.

To reduce the time spent on video analysis, an automatic recognition system might be a solution. The development of such a system is, however, a difficult task since it would have to be able to recognize porpoises, the appearance of which varies with lighting and orientation. Furthermore, a porpoise would appear as 2 objects because of its black back and white belly. Adding a range camera, which measures distances to the object, could possibly resolve some of these challenges, since the porpoises would then appear as 1 object. Events in which only the tail reaches the surface would, however, be very difficult to detect, and the addition of such methods would also increase the costs of the system.

Monitoring

Monitoring of marine mammal bycatch has been addressed by a variety of different methods. In Danish waters and elsewhere the main data on bycatch have been collected by on-board observers (Bravington & Bisack 1996, Trippel et al. 1996, Vinther 1999), as this has been regarded as the most reliable way to obtain information on catch composition and on biological aspects of the catch (IWC 1994). However, many observers also have other tasks while working onboard (e.g. observers working under the EU Data Collection Framework), making it impossible to watch all net hauls from the moment they break the water surface. Our results have shown the importance of constantly watching the point where the nets break the surface, since many porpoises drop out there. This implies that observers who have other tasks on board will miss some of the bycatch.

Another common method of obtaining information on bycatch is from fishers' voluntary reporting schemes (Read & Gaskin 1988, Berggren et al. 1994, Kock & Benke 1996, Rubsch & Koch 2004). The main concern with this method has been whether fishers are willing and able to report correctly what they observe. Our results from the REM trial show that fishers will not always report bycatch that they have observed. In addition to this, a significant part of the actual bycatch, in this trial 18%, was not observed at all by the fishers, because animals dropped out of the nets before being seen. Comparing fishers' reports and the REM system, the REM system will provide bycatch data that are much closer to the actual bycatch, thereby allowing a better assessment of the population effects of bycatch.

An important advantage of the REM system, compared to using on-board observers, is that the REM system will allow observations of bycatch on vessels that are unsuitable for on-board observers. On-board observers tend to be placed on larger vessels that are able to accommodate them, but this group of vessels often fishes in different ways than the smaller vessels, e.g. further offshore. This could introduce a bias if data from the larger vessels are extrapolated to also cover the smaller vessels as was done by, for example, Vinther (1999) and Vinther & Larsen (2004).

There is another difference between on-board observer data and REM data which deserves mention. On-board observers, at least in Denmark, have tended to collect data from many different vessels during a year, but REM data tend to include much longer time series from a smaller number of vessels because of the time and costs involved in the installation of REM systems. Although the longer time series of the REM system provide better insight into the fisheries that the vessels are pursuing during the course of a year, more care needs to be taken to ensure that the vessels are indeed representative of the fleet that is the subject of the monitoring.

Costs and coverage

The total costs of an on-board observer in Denmark amount to 667 € d⁻¹, including salary, at-sea allowance and travel. The total costs for covering 811 d with on-board observers thus amount to 540,667 €. Therefore, monitoring bycatch of marine mammals by use of on-board observers is, in this case, approximately 6.7 times more expensive than
with the REM approach. In the trial, student workers were used to analyse sensor and video data. Experiences from earlier trials (authors’ unpubl. data) showed that student workers and technical staff were equally adept at detecting porpoises. In countries where the REM system is much more widely used for fisheries management (e.g. Canada), technical staff analyse sensor and video data. If technical staff had been used for REM analysis within the Danish trial, the REM system would still have been 5.4 times less expensive compared to on-board observers. It should be noted, though, that this relationship applies specifically to Denmark, and will be different in countries with other wage levels. However, in Denmark and economically similar countries, this discrepancy in costs means the REM approach will enable much higher coverage of the different fleets with the same amount of funding. Since many countries in Europe seem to be struggling to achieve the 5 to 10% coverage stipulated in Council Regulation 812/2004 and are far from the 20 to 30% coverage recommended by the US Marine Mammal Protection Act (NOAA 2007) for fisheries where bycatch is unknown, the REM approach would make these expectations more realistic.

The maintenance cost of the system was very low, because the technical staff were located very close to the vessels’ home ports. Thus, hard drives could be exchanged within a maximum of 2 h of working time. If the trial was expanded to a larger fleet, the cost of maintenance would probably increase.

The main advantage of using on-board observers is, however, that they can easily switch between vessels, while the REM system must be installed on all vessels requiring observation. However, this cost could be minimized by only installing cameras and sensors on each vessel and rotating the control box between vessels.

Advantages and challenges of the REM system

The benefits and drawbacks of using the REM system in bycatch monitoring can be summarised as follows.

Advantages

• Close to 100% coverage of all net hauls.
• Video footage can be analysed at 12 times normal speed.
• Possibility of going through the data more than once and by multiple persons.
• Marine mammals are easily recognized and can be detected.
• Finger use is easily recognized.
• Control and security of the system is high.
• Technological improvements with regards to GPS, cameras, software, etc., are very fast and quality can therefore easily be improved.
• Low costs compared to on-board observers.
• No observer effect.

Challenges

• Mechanical systems can break and/or be tampered with.
• Data storage limitations (video data demands ample storage capacity).
• Detailed information on catch, such as weights and lengths, is not automatically collected at the moment of capture.
• The number of vessels covered can be limited.
• Having fishers accept the REM system onboard and overcoming the scepticism with respect to being monitored.
• Data confidentiality issues.
• Limited availability of REM systems and thus limited competition. At present, only one company sells the REM system.

CONCLUSIONS

REM proved to be very useful and reliable for documenting marine mammal bycatch. Bycatches were easily identified on video footage, and high-resolution data could be collected on fishing effort, time and position. An important advantage of the REM systems is that the observed bycatch is probably closer to the actual total bycatch than the bycatch observations made by fishers or by on-board observers with tasks other than viewing the net full time, since REM records bycatches before they enter the net hauler. Another important advantage of the REM system is that it allows data collection on vessels that are too small to accommodate an on-board observer. We also conclude that, in Denmark and countries with a similar wage level, using REM systems for monitoring is considerably less expensive than using on-board observers and, thus, much higher coverage is possible for the same amount of funding.

Acknowledgements. This study would not have been feasible without the participation and cooperation of the captains and crews of the 6 vessels. We thank our colleagues at DTU Aqua, the technical crew and student workers for their effort
and dedication. Additionally, we thank Archipelago Marine Research Ltd for technical support with the REM system and data analysis. We are also grateful for the input of 3 anonymous referees whose comments greatly improved the quality of the final manuscript. Finally, we thank the Danish Ministry for Food, Agriculture and Fisheries and the European Fisheries Fund for funding the project.

LITERATURE CITED


Editorial responsibility: Andrew Read, Beaufort, North Carolina, USA

Submitted: May 31, 2012; Accepted: August 16, 2012
Proofs received from author(s): November 2, 2012
Identification of high risk areas for harbour porpoises bycatch by use of data from remote electronic monitoring and satellite telemetry.
Manuscript submitted to Marine Ecology Progress Series
Identification of high risk areas for harbour porpoise 
(*Phocoena phocoena*) bycatch using data from remote 
electronic monitoring and satellite telemetry


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Abstract

The incidental bycatch of harbour porpoises (*Phocoena phocoena*) is an issue of major concern for fisheries management and their conservation. With the aim of identifying areas of potential high risk for porpoise bycatch, we analyzed high-resolution spatial and temporal data on *P. phocoena* abundance and fishing effort data from the Danish Skagerrak Sea. Included in the survey were areas designated under the EC Habitats Directive (Natura 2000) for harbour porpoise protection. From May 2010 to April 2011 four commercial gillnet vessels were equipped with Remote Electronic Monitoring (REM). The REM system recorded time, position and closed-circuit television (CCTV) footage of all net hauls. The REM data were used to identify fishing grounds, quantify fishing effort and document harbour porpoise bycatch. Movement data from 66 harbour porpoises equipped with satellite transmitters from 1997-2012 were used to model population density. A simple model was set up to investigate the relationship between the response (number of individuals caught) and porpoise density and fishing effort described by net soak time, net length and target species. The results showed that a model including both porpoise density and effort data predicted bycatch better than models that only one factor. We therefore conclude that although porpoise telemetry data allows for identification of areas of potential high bycatch risk, better predictions are obtained when combined with fishing effort data. The final model can thus be used as a tool to identify areas of bycatch risk, and, thereby support the management of both fisheries and porpoises in accordance with the Habitats Directive.

Key words: Harbour porpoise, Bycatch mitigation, REM, Natura 2000, Fisheries management

Introduction

As a response to the many impacts that commercial fishing has on the marine environment, fishing activity management in EU waters has evolved towards an ecosystem approach to fisheries management. Among other aspects pertaining to marine ecosystems, this approach prescribes a reduction in fisheries' impacts on sensitive habitats and species, including the harbour porpoise (*Phocoena phocoena*) (EU 2013, EC 2004). The EC Habitats Directive (EC 1992), furthermore, obliges EU member states to protect a range of marine species and habitats including designation of an ecologically coherent network of marine protected areas (MPAs) that is termed Natura 2000. The harbour porpoise is listed in Annexes II and IV of the Habitats Directive, meaning that populations must have a so-called favourable conservation status and that the deliberate actions of killing, disturbance and habitat deterioration of the species are prohibited throughout its range (EC 1992). In 2010, 16 areas were designated as Natura 2000 sites for the protection of harbour porpoises in Danish waters. Despite this designation, the results of recent monitoring of some fisheries bycatch, and the legislative requirements to prevent this, management agencies continue to struggle to find an appropriate course of action to mitigate the impacts of fishing on porpoises. Often quantitative data on actual bycatch rates and the
impacts of these on species and subpopulations are absent (Pedersen et al. 2009). Further data on the correlation between bycatch incidents, fishing activity and harbour porpoise density and distribution are needed in order to implement effective fisheries management actions that will facilitate the achievement of the management goals related to the Habitats Directive and Natura 2000 MPAs.

Harbour porpoises and commercial fisheries interact in various ways. Some are direct, in which marine mammals come into physical contact with fishing gear and are bycaught incidentally, while others are indirect, e.g. through resource competition (DeMaster et al. 2001). Bycatch in gillnet fisheries is usually regarded as the main anthropogenic impact on porpoises and has been documented for several such fisheries (Vinther 1999, Read et al. 2006). Bycatch monitoring can be conducted using a number of different methods although, in most cases, on-board observers are recommended as a means of collecting accurate data (IWC 1994). More recently, remote electronic monitoring (REM) systems have shown great potential in documenting porpoise bycatch (Kindt-Larsen et al. 2012). Both types of observer programmes are, however, expensive and can be challenging to implement. Limited financial resources often lead to common questions from environmental and fisheries managers as to where bycatch monitoring should be focused and in which areas porpoises are particularly exposed to the high risk of entanglement in fishing gears. A tool to identify such areas and/or seasons would therefore be valuable.

This study aimed to examine whether harbour porpoise density and gillnet fishing can be used to identify high risk areas for observed porpoise bycatches in the Danish Skagerrak Sea over the course of four seasons. Porpoise density data were obtained from satellite tracked harbour porpoises, while fishing effort data and registration of bycatch incidents were obtained from vessels monitored by remote electronic monitoring (REM) systems.

Materials and methods

Study area
The study was conducted in the Danish part of the Skagerrak Sea (Fig. 1). Both trawl and gillnet fishing is carried out in the area (Sørensen & Kindt-Larsen in prep), which also contains high densities of porpoises (Sveegaard et al. 2011a). Three areas in the Skagerrak have been designated as Natura 2000 sites under the Habitats Directive for the protection of porpoises, namely “Skagens Gren og Skagerrak” (2691 km²), “Store Rev” (109km²) and “Gule Rev” (471 km²) (Fig.3). “Skagens Gren og Skagerrak” was selected due to its high porpoise densities (Sveegaard et al. 2011a) while the other two areas “Store Rev” and “Gule Rev” were selected initially because of the presence of reef structures. Harbour porpoises were added subsequently to the initial reason for designation of these sites due to the high occurrence of the species in the Skagerrak (pers. comm. Krawack 2015).

Remote Electronic Monitoring data
Data on fishing effort from four of the six commercial gillnet vessels participating in the REM trial identified above, were used in this study because their activities were typically conducted in the study area (Kindt-Larsen et al. 2012). The data were collected from 1 May 2010 to 30 April 2011 using REM systems from Archipelago Marine Research Ltd. The REM systems recorded time, position and CCTV footage of all trips (port to port) and thus represent a full census of effort by these four vessels. Video footage of all net fleet hauls was analysed using EMI software (Archipelago Marine Research Ltd. V.1.1.3.11189). Since all fleets were set in almost straight lines, their lengths were calculated as the distance between the GPS position of the start and end buoy of a fleet. Soak time was determined as the mean time the fleet had been in the water, by subtracting the mean time of setting from the mean time of hauling. Fishing effort was determined as a product of fleet length and soak time. Data from May 2010 were lost from one vessel. Data from the same vessel in May 2011 were therefore used to fill this information gap on the assumption of predictable seasonal fishing patterns.

REM effort data were divided into seasons and fisheries categories. The seasons were winter (December, January, February), spring (March,
Figure 1. The three areas and their respective gillnet effort of the 4 REM vessels. A (528 hauls), B (381 hauls) and C (1136 hauls) where each symbol represents a single gillnet haul.

Table 1. Recorded bycatch events and hauls for the three types of fisheries (cod, plaice and hake) in three areas (A, B and C – see Fig. 1) and seasons (All seasons; Winter = Dec-Feb; Spring = Mar-May; Summer = Jun-Aug; Autumn = Sep-Nov).

<table>
<thead>
<tr>
<th>Fishery and Area</th>
<th>Hauls</th>
<th>Bycatch</th>
<th>Hauls</th>
<th>Bycatch</th>
<th>Hauls</th>
<th>Bycatch</th>
<th>Hauls</th>
<th>Bycatch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod All</td>
<td>2178</td>
<td>18</td>
<td>796</td>
<td>12</td>
<td>559</td>
<td>0</td>
<td>122</td>
<td>2</td>
</tr>
<tr>
<td>A</td>
<td>528</td>
<td>5</td>
<td>87</td>
<td>2</td>
<td>199</td>
<td>0</td>
<td>72</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>296</td>
<td>5</td>
<td>145</td>
<td>3</td>
<td>55</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>844</td>
<td>8</td>
<td>365</td>
<td>7</td>
<td>51</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Plaice All</td>
<td>342</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>179</td>
<td>14</td>
<td>191</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>38</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>276</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>99</td>
<td>1</td>
<td>177</td>
<td>0</td>
</tr>
<tr>
<td>Hake All</td>
<td>65</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>65</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>A</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>47</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>47</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>16</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>16</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>2585</td>
<td>19</td>
<td>796</td>
<td>12</td>
<td>738</td>
<td>14</td>
<td>378</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2. Mean mesh size, soak time and fleet length for the different fisheries.

<table>
<thead>
<tr>
<th>Fishery</th>
<th>Mesh size (mm)</th>
<th>Soak time (hours)</th>
<th>Fleet length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>CV</td>
<td>Mean</td>
</tr>
<tr>
<td>Cod</td>
<td>154</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Plaice</td>
<td>136</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Hake</td>
<td>130</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>
April, May), summer (June, July, August) and autumn (September, October, November) (Fig.1). The fishery categories were plaice, cod and hake. Participating fishermen, furthermore, filled in a daily log which included information about the gear used including mesh sizes, which were added to the REM data on a haul basis during analysis.

The cod fishery by the four vessels was conducted in all four seasons with the greatest number of hauls in winter and the lowest in summer. The plaice fishery had most hauls in spring and summer while the hake fishery took place only during the summer (Table 1). The three fisheries differed with respect to mesh size, soak time and fleet length. The cod fishery used the largest mean mesh size (154mm) and the hake fishery the smallest (130mm). The mean soak time was shortest for the hake fishery (6 hours) and longest for the plaice fishery (12 hours). The shortest mean fleet length (671m) was identified for the cod fishery and the longest for the plaice fishery (1974m). Both the plaice and cod fisheries, however, exhibited large variability in soak time and fleet lengths (Table 2).

Based on effort data and seabed topography, three fishing grounds with homogeneous bottom types were identified for analysis: A), containing a sandbank and sandy/small stone sea bed; B), interspersed boulder reefs and reef structures created by leaking gas and C), mixed stone bottom (Fig. 1). Areas B and C were used by all three fisheries while area A was used only for cod and plaice. A total of 528, 381 and 1136 hauls were observed in areas A, B and C, respectively (Table 1). In relation to the rest of the fleet, the four gillnet vessels landed 23% of the total gillnet landings in the area (Agrifish 2010) and were responsible for 22% of the total catch value.

Harbour porpoise density data
From 1997 to 2012, 88 harbour porpoises were tagged with satellite transmitters in the Danish inshore waters and near Skagen. Of these, 66 individuals swam into the study area during the period of transmission. Inside the study area, they transmitted a total of 4590 locations (average per individual: 85, range: 1-395). For information on tagging sites, sex, age, length, weight, transmission period see Appendix I and for tagging procedure and types of transmitters used, see Sveegaard et al. (2011a). The transmitters were positioned by System Argos and the data provided detailed information on individual porpoise movement. Locations obtained through System Argos are less precise than those of GPS and may deviate from the actual location of the animal by up to several kilometers. During processing by System Argos, individual positions were classified into one of six location classes according to precise latitude and longitude estimates. To remove the most unlikely positions, locations were filtered using the Douglas Argos filter (Douglas 2006), which removes those that require unrealistically high swimming speeds or sharp turning angles by the porpoises. Even so, inaccuracies remain, and these were dealt with by the method described in Tougaard et al. (2008). In summary, the study area was divided into a regular, rectangular, grid consisting of 1x1 km cells. Assuming errors of longitude and latitude are distributed normally with a mean of zero and a standard deviation specific for each location class (Vincent et al. 2002), the most likely number of true positions within each grid cell can be computed from the positions inside it and adjacent ones. The values assigned to the grid cells therefore reflect the likelihood that they were visited by porpoises equipped with satellite transmitters. By assuming that the behaviour of the tagged animals is representative of the porpoises in the area in general, these grid values can be used as a proxy for density. This method differs from kernel density estimators often used on the same type of data (such as undertaken by Sveegaard et al. 2011a) in that results are local (i.e. do not change by extension or reduction of the total study area) and do not rely of arbitrarily selected smoothing factors. The satellite tracking data converted into the density grid are shown in Figure 2.

As the data were collected over a long time frame, one objection to the analysis of the satellite data would be whether or not the spatial patterns were stable over time, allowing for meaningful comparisons to be made of one
Figure 2. Porpoise density data estimated from satellite derived positions from the 66 porpoises tagged in the period 1997-2012 and locations of area A, B and C.

Figure 3. Map of harbour porpoise bycatch events from the four fishing vessels symbolized by triangles. The polygons are Natura2000 sites, “Skagens Gren og Skagerrak”, “Store Rev” and “Gule Rev”.
period with bycatch with a different one. This concern has been addressed (Appendix 1) and the patterns of area use over time were shown to be almost identical, thereby allowing such an analysis.

_bycatch data_

Data on the bycatch of harbour porpoises were collected from the CCTV video footage of the four REM gillnet vessels. All videos of net hauls were examined visually by trained staff who recorded the number of bycatch events. For each event, its time and position were logged using EMI software (Archipelago Marine Research Ltd. V.1.1.3.11189). A total of 33 bycaught porpoises were observed in the video footage (Fig. 2). Of these, 18 were caught in the cod, 14 in the plaice and 1 in the hake fishery, respectively, and 26 (79%) of them took place in the winter and spring (Table 1).

_bycatch model_

Fishing effort, porpoise bycatch and density data were separated into seasons. When the porpoise densities were divided into seasons, however, several of the 1x1km grid cells had a value of zero. The zero values are not, moreover, necessarily true zeros (areas with no individuals) but may be caused by a low number of tagged porpoises in those seasons. In order not to over-interpret porpoise density data, therefore, the seasonal mean of such information for areas A, B and C were used. Area A and C were further each divided into two sub-areas (A1, A2, C1, C2, Fig. 2) since large differences in densities was observed within them.

In our model, we assume the following general relationship between the response, which is the number of porpoise bycatches \( (N_i) \) caught in the \( ith \) haul, porpoise density \( (P_i) \) at the \( ith \) haul position, and the effort pertaining to the \( ith \) haul described by the soak time \( (ST_i) \) and net length \( (NL_i) \) as well as the target species \( s_i \) (which is used as a proxy for additional differences in gear characteristics, such as mesh size).

\[
E(N_i) = \alpha(s_i)ST_i^{\beta(s_i)}NL_i^{\phi(s_i)}P_i^\gamma
\]

where \( \alpha(s_i) \), \( \beta(s_i) \) and \( \phi(s_i) \) correspond to a categorical effect for each possible target species for haul \( i \). In our general relationship, we do not assume that the exponents \( \beta \), \( \gamma \) and \( \phi \) are equal to one, which would imply a linear relationship, although removal of the exponents was tested as a possible model reduction.

A Poisson GLM with a log link was used:

\[
\log(E(N_i)) = \log(\alpha(s_i)) + \beta(s_i)\log(ST_i) + \phi(s_i)\log(NL_i) + \gamma\log(P_i)
\]

Hence, a Poisson distribution is a natural choice, as we are dealing with count data in the dataset \{0,1,2\} as the maximum number of bycaught porpoises per haul was 2. Note that the log link implies the predictors should also be log-transformed when a multiplicative structure in the natural domain can be assumed. The main purpose of the model was to test whether \( \gamma \) was significantly greater than zero, i.e. whether there is a positive correlation between porpoise density and the number of individuals caught in the gillnet fishery. The model selection strategy was, initially, the full model in which insignificant terms were removed successively and tests performed to determine if any of the regression coefficients could be replaced by an offset, i.e. assuming direct proportionality in fishing effort and/or porpoise density \( (\beta = 1, \phi = 1) \). The model selection was based on Akaike’s information criterion, AIC (Akaike 1974) and was run in R (R Core Team, 2012).

An alternative model (model 3 below) with porpoise density \( P \) replaced with a free parameter for each combination of area and season (denoted AS), was also tested.

In other words, the following three hypotheses were tested:

Porpoise bycatch is best explained by fishing effort alone and, hence, the true underlying density species’ can be considered equal in all areas and all seasons.

Porpoise bycatch is best explained by a combination of fishing effort and observed densities \( (P) \) from independent satellite tracking data.

Porpoise bycatch is best explained by a combination of fishing effort and estimates of the species’ true underlying densities, where the latter are estimated as free parameters for each
AS, rather than using the satellite data. Hypothesis 1 versus 2 was tested by comparing the AIC of models with and without inclusion of P as an explanatory variable. Hypothesis 3 was tested by replacing $\gamma \log(P_i)$ (or simply $\log(P_i)$ if $\gamma$ was not significantly different from 1) with $\delta(A_i)$ in equation (1), where $\delta$ maps the $ith$ haul to the corresponding AS.

The final model was validated using residual deviance as a measure of goodness of fit (Madsen & Thyregod 2010). In addition, the assumption of linearity between the predictors and log-intensity was tested by replacing the linear terms with splines (replacing GLM with GAM) both with and without log-transformation of the predictors.

**Results**

**Bycatch model**

The model results are listed in Table 3. Model III had a lower AIC than models I and II, indicating that including target fish species ($S_i$) did not improve the model fit, and the same was true for net length ($NL_i$) (model IV versus III). When comparing model IV and V, $\beta$ was not significantly different from 1, which implies that the number of porpoises caught was directly proportional to the soak time ($ST_i$). When reducing from model V to model VI, $\gamma$ was not significantly different from 1, which means that the number of bycaught porpoises was proportional to their densities. Model VII and VIII, containing only either soak time or porpoise densities, both resulted in higher AIC’s compared to model VI. The alternative model VI A where porpoise density was replaced with a free parameter for each combination of area and season also provided a higher AIC compared to model VI. The AIC calculations therefore reveal that the best model in terms AIC was model VI.

![Figure 4. Plot of predicted bycatches from model VI against observed bycatches in the 5 different areas (A1, A2, B, C1, C2) and seasons. Season 1 = winter, 2=spring, 3=summer, 4=autumn.](image)
Table 3. Formulas, AIC and number of parameters of the eight different models.

<table>
<thead>
<tr>
<th>Model</th>
<th>Formula</th>
<th>AIC</th>
<th>No. parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>log(E(N)) = log(α(s)) + β(s) log(ST) + φ(s) log(NL) + γ log(P)</td>
<td>230.7</td>
<td>10</td>
</tr>
<tr>
<td>II</td>
<td>log(E(N)) = log(α(s)) + β log(ST) + φ log(NL) + γ log(P)</td>
<td>225.2</td>
<td>6</td>
</tr>
<tr>
<td>III</td>
<td>log(E(N)) = log(α) + β log(ST) + φ log(NL) + γ log(P)</td>
<td>222.2</td>
<td>4</td>
</tr>
<tr>
<td>IV</td>
<td>log(E(N)) = log(α) + β log(ST) + γ log(P)</td>
<td>221.2</td>
<td>3</td>
</tr>
<tr>
<td>V</td>
<td>log(E(N)) = log(α) + log(ST) + γ log(P)</td>
<td>219.2</td>
<td>2</td>
</tr>
<tr>
<td>VI</td>
<td>log(E(N)) = log(α) + log(ST) + γ log(P)</td>
<td><strong>218.7</strong></td>
<td><strong>1</strong></td>
</tr>
<tr>
<td>VI A</td>
<td>log(E(N)) = log(α) + log(ST) + δ(A)</td>
<td>235.7</td>
<td>19</td>
</tr>
<tr>
<td>VII</td>
<td>log(E(N)) = log(α) + log(ST)</td>
<td>225.1</td>
<td>1</td>
</tr>
<tr>
<td>VIII</td>
<td>log(E(N)) = log(α) + log(P)</td>
<td>228.7</td>
<td>1</td>
</tr>
</tbody>
</table>

The GAM equivalents of the models revealed no evidence against the assumption of linearity (model VI had lower AIC than all the GAMs). Model VI can, therefore, be written as:

\[ E(N) = \alpha STP \]

The goodness of fit test had a p value close to 1, which means that the Poisson distribution assumptions in the final model could not be rejected. The AIC difference of 6.4 between model VI and model VII revealed strong evidence against the null hypothesis of constant true underlying porpoise abundance. We can therefore conclude that the observed porpoise density was indeed useful for predicting bycatches and hypothesis 2, i.e. “Porpoise bycatch is best explained by a combination of fishing effort and observed porpoise densities (P) from independent satellite tracking data”, was therefore accepted.

The predicted number of bycatches from model VI is plotted against the total number of observed bycatches within each area and season in Figure 4.

Discussion

In this study, we have investigated fishing effort and densities as factors to predict observed porpoise bycatch in relation to area and season. Our best fitting model showed that a simple two-stage procedure using porpoise densities and fishing effort in terms of soak time could predict bycatch rate, since a clear correlation between this and the products of porpoise densities and soak time was identified. In addition, the results of the model revealed that there were large differences in the bycatch predictions in terms of area and season. Our results, nevertheless, indicate in which area and season porpoise bycatch risks are highest. Our final model can be used as a tool to identify the areas of porpoise bycatch risk and thereby support the achievement of conservation objectives formulated for the Natura 2000 sites. The model may, further, more be used as a tool since it will be possible to discover changes in potential bycatch by area and season and monitor if it changes over time due to either shifts in fishing grounds and effort, or changes in porpoise distribution. The modeled bycatch maps can therefore be used to facilitate a targeted, risk based, approach to fisheries management in relation to the Habitats Directive and protected areas designated for harbour porpoises. They also support development of sampling plans for bycatch monitoring and can assist managers in the development of bycatch mitigation strategies.

although the largest value was again identified for area A1 followed by B, C1, C2 and A2. In the autumn, the bycatch was high in area A1 followed by C2, B, A2 and C1.
Figure 5. Map of predicted harbour porpoise bycatch in five areas and four seasons. The unit of the bycatch legend is number of bycaught porpoises per 1000 hauls.

Figure 6. Bycatch of porpoises in relation to area and season. The number of bycatches is given per haul. Season 1 = winter, 2=spring, 3=summer, 4=autumn.
that are spatially explicit. The direct dependence of bycatch on both porpoise density and fishing effort thus highlights the importance of obtaining good density data in areas of high fishing effort and the documentation of this (and preferably direct bycatch statistics) for areas known to have high densities of porpoises.

Our model rests on a number of assumptions, however. The first is that satellite tagged porpoises are representative of the general distribution of individuals in the area. This depends on whether or not there are large differences in movements and preferred areas between individual porpoises and whether or not, if so, a sufficient number of porpoises have been tagged. This is difficult to examine, but analysis showed that the spatial patterns were stable over time (Appendix I). Further, the use of satellite tracking data of 66 porpoises to identify areas of high density were confirmed by comparison with independently derived densities obtained from acoustic surveys (Sveegaard et al. 2011b). This indicates that the satellite data were indeed representative for the general harbour porpoise distribution in the southeastern Skagerrak and Kattegat areas.

Porpoise density could, however, be biased if tagged individuals were different from the natural population in relation to either sex or age. Earlier studies showed no differences in home range size between males and females, but immature harbour porpoises had larger home ranges than mature individuals (Sveegaard et al. 2011a). Since the data set used in this study contained a mixture of both juvenile and adult males and females, we do not believe that any important bias is present due to demographic differences between tagged and natural populations.

The second assumption is that the fishing effort estimations truly represent the fishing effort of the four gillnet vessels. Fleet length was calculated as the distance between the start and end fishing positions meaning that unless nets were set in a straight line, this was underestimated. Due to the high resolution of GPS data (every 10 sec) it was possible when analyzing the data in the EMI programme to verify straight lines of the GPS tracks from fleet sets/hauls, indicating that most were indeed set in straight lines. Short net lengths were, however, identified in the data set (19 m, Table 2), which indicates that some inaccuracies were present, since most net panels are ~50m and a net length of only 19m is unlikely. We nonetheless believe that these are due to variation in determining the positions of the start and end of the net fleet and are unlikely to have biased our results. A systematic underestimation of the net fleet will influence the alpha constant, but since we are not interested in the value of this it does not influence our primary conclusions. Most important is that the fishing effort is calculated by the same method for all four vessels which will equal the bias for them and thereby standardise the results.

The third assumption is that recorded porpoise bycatches represented the true number of such events in the monitored fishing operations. As described by Kindt-Larsen et al. (2012), detections of bycatch on video footage can be influenced by video quality, positioning of the camera and viewer. Since the purpose of the Kindt-Larsen et al. (2012) study was, however, to detect porpoise bycatch, cameras were positioned for optimal detections, only trained staff were used and video recordings were never of a poor quality such that porpoise bycatch would not have been detectable. If, however, porpoise carcasses fall from the net before reaching the surface, they would not be registered. The bycatches registered on the video footage will therefore always be a minimum estimate. Since, however, good video quality was obtained from all vessels and the bycatches were almost evenly distributed between the vessels, there is no reason to believe that any particular, over-riding, bias should be present in the possible undetected bycatches.

The results of the model showed that bycatches were not distributed evenly but depended on porpoise density and fishing intensity in the area. It was, however, surprising that the net fleet length was not identified as a significant factor in the final model, since a logical thought would be - the longer the net, the higher the chance of catching a porpoise. Other researchers have shown that longer soak times have a positive correlation with bycatch (Palka et al. 2008; Orphanides 2009). The reason for the insignificance of fleet length in the full
model elaborated in this study could be due to the fact that one of the vessels carried out a wreck net fishery using short net strings to catch cod. The wreck net fishery has earlier exposed high bycatch rates (Vinther 1999) and short net lengths from this fishery could therefore influence the results in such a way that this factor would not emerge as significant factor overall. It could also be that differences in net lengths simply were too small to be detectable in the modeling. Target species was also rejected from the best fitting model. We believe that this is also due to the relative small data set since different bycatch rates have been identified in relation to target species in previous studies (Vinther 1999).

Bycatch was observed in all three monitored fisheries in this study. This corresponds well with earlier records from the North Sea, where porpoise bycatches were observed for cod, plaice and hake fisheries (Vinther 1999). Only one porpoise was bycaught during the 65 hauls for the hake fishery. Other programmes collecting porpoise bycatch data in the hake gillnet fisheries have identified relatively high rates (Trengenza et al. 1997, Larsen et al. 2013) and the results obtained herein of bycatches in the hake fishery should, therefore, be interpreted with caution due to our low coverage.

Only data from four REM monitored vessels were used, but these vessels represented 22% of the gillnet fleet in the area. VMS locations from the Danish gillnet fleet show that vessels >15m length overall (loa) were also active in areas B and C. Not a single VMS point was, however, recorded in area A. The most likely reason is that B and C are better fishing gillnet grounds, and area A serves as an important fishing ground for the trawl fishery and which may contribute to further risk of losing gillnets (Sørensen & Kindt-Larsen in prep). Vessels <15m loa would, however, constrained to using area A and take the risk of losing gear, since they would not have the possibility of fishing far from land. In 2010, vessels <15m loa did not carry VMS and their positioning data were therefore not recorded. Areas B and C are, however, visited frequently by the whole fleet and special awareness of potential bycatch should be emphasized for them.

The simple correlation identified by our model is logical, but - to our knowledge - this study is the first to demonstrate this. Our study is unique in the sense that we had the possibility of verifying predicted bycatches with actual, observed, harbour porpoise bycatches. The simple model of a two-factor product to detect risk was proposed initially in the Lotka-Volterra model of predator-prey relationships (Lotka 1910). This model states that a prey item can only be caught by a predator if there is an area and time overlap between the two. Transferring this into porpoise bycatch, we state that a bycatch incident can only occur if fisheries and porpoises overlap in space and time. Others authors have used fishing effort and species density data in similar methods to reveal areas of bycatch risk (Goldsworthy et al. 2007, Herr et al. 2009, Hamer et al. 2013). In South Australian shelf waters, overlays between distributions of demersal gillnet effort and Australian sea lions (Neophoca cinerea) and New Zealand fur seals (Arctocephalus forsteri) were made to identify areas of possible interactions (Goldsworthy et al. 2007, Hamer et al. 2013). Herr et al. (2009) mapped the spatial and temporal overlap between porpoises and fisheries in the German Bight. These authors could not, however, correlate their predicted high risk areas with observed bycatch rates due to lack of monitoring of the latter in the fisheries.

The need to identify high-risk areas in other waters, especially in relation to Natura 2000 sites, and other protection measures for porpoises is clear. If the present type of study is to be repeated in other areas, however, where no porpoise tagging data are available, discovering how many tagged porpoises are needed to describe the underlying population density would be needed since it will lower the possible cost of describing actual densities. Alternatively, porpoise densities could be assessed by other methods e.g. repeated acoustic or visual surveys with high spatial coverages (SAMBAH 2015, Hammond et al. 2013). In some cases, these types of density data might even be preferential since they pictures the total density and are not influenced by e.g. tagging position or a small number of individuals tagged. Surveys, however, only represent the density at that specific time, thereby eliminating the possibility of exploring
seasonal variations.

**Conclusion**
High resolution information on fishing effort, porpoise densities and bycatches have allowed a fine scale analysis of such data and identified and verified a correlation. The correlation has resulted in a method to predict potential areas of bycatch risk when spatial data on fishing effort and porpoise densities are available. The model predictions can function as a starting point for investigations of harbour porpoise bycatches and should be of considerable influence with respect to fisheries management and bycatch mitigation in general, and in relation to the design and implementation of effective conservation measures for protected areas in particular.

**Acknowledgements**
The authors thank the four fishers for access to REM data and for strong collaboration. Additionally, we thank Archipelago Marine Research Ltd for technical support with the REM system and data analysis. We would also like to thank everyone who assisted with the porpoise tagging especially the pound net fishermen, without whom no tagging would have been possible. The tagging was carried out under permission from the Danish Forest and Nature Agency (SN 343/SN-0008) and the Animal Welfare Division (Ministry of Justice, 1995-101-62). Some of the satellite tagged porpoises were tagged as part of a joint project between the Danish Institute for Fisheries Research, the Fjord and Belt Centre, Aarhus University (AU) and University of Southern Denmark in the years 1998 to 2002, and others were tagged as part of a co-operation between AU and U. Siebert at the University of Kiel, Research and Technology Centre (FTZ) in 2003 to 2009. We finally thank the Danish Ministry for Food, Agriculture and Fisheries, the European Fisheries Fund, MESMA (EU-FP7 project on monitoring and evaluation of spatially managed marine areas) and MYFISH (EU-FP7 project on monitoring and evaluation of spatially managed marine areas) for funding the project.

**References**


bycatch in two Australian fisheries. Biol. Conserv. 139, 269-285


Appendix 1

A list of the tagging sites, sex and age ratio, length, weight and year the porpoises were satellite-tagged is provided in Table 1. Porpoises 27, 25 and 14 were tagged in the Skagerrak, Inner Danish waters and the Kattegat, respectively. Skagen and Fjellerup were the only tagging sites used in the Skagerrak and Kattegat Sea, respectively, while several tagging sites were used in inner Danish waters with Korsør as the main one. The sex ratio was 38% females and 62% males. In relation to age distribution: 32% were estimated to be adults, 60% were juveniles and age was not estimated for 8% of the individuals. The mean length and weight of adults and juveniles were 145cm and 45kg and 118cm and 31kg, respectively.

Table 1. Information on tagging site, area, sex, age, length (cm), weight (kg) and year of tagging of the porpoises used within the satellite analysis.

<table>
<thead>
<tr>
<th>Number</th>
<th>Tagging site</th>
<th>Area</th>
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<th>Age</th>
<th>Length</th>
<th>Weight</th>
<th>Year of tagging</th>
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Autocorrelation in the satellite data

One concern about the analysis of the satellite data has been whether the spatial patterns were stable over time, allowing for the comparison of satellite data from one period with bycatch data from a different period. This concern is addressed below.
As the satellite data falls into two natural groups of approximately the same number of positions: from 1996-2003 and from 2006-2012, it is possible to ask whether the patterns seen in the two periods are identical?

The same analysis performed for the main manuscript was likewise undertaken with data separated into the two periods and the four seasons. Maps are shown in Figure 1 and 2. Spatial resolution was reduced to 4x4 km to, in turn, reduce computation time and allow for the calculation of variograms.

![Figure 1. Spatial patterns of satellite tagged porpoise positions, 1997-2003.](image-url)
Figure 2. Spatial patterns of satellite tagged porpoise positions, 2006-2012.

To compare the maps, variograms were computed. The variogram presents the spatial variation in 2-dimensional data and is useful to qualitatively address the question of whether cells in a grid are more similar to other cells nearby than to more distant ones. If this is the case, the variance will increase gradually with distance and finally level out. Variograms were computed for all four seasons and both periods (8 variograms in total) and 4 additional (“between-groups”) variograms were computed. The “between-groups” variograms represents the variance between all grid cells of the first (1997-2003) dataset and all grid cells in the subsequent dataset (2006-2012).
It is evident that the overall patterns seen in the data from the two periods are closely similar, when compared from period to period, and even when compared across seasons within periods.
PAPER III
Harbour porpoise (*Phocoena phocoena*) area use and habituation behavior in the presence of acoustic alarms.
Kindt-Larsen L, Berg CW, Northridge S, Larsen F.
Manuscript, submitted to Fisheries Research
Harbour porpoise (*Phocoena phocoena*) area use and habituation behaviour in the presence of pingers

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Abstract

The use of acoustic alarms (pingers) has been mandated in several gillnet fisheries around the world to help reduce the incidental catch of porpoises and other small cetaceans. Even though pingers have shown to reduce the bycatch of harbour porpoises there are still questions to be answered in relation to effective range, habituation and displacement. In the present study, the vocalisation behaviour of porpoises was recorded in response to two different pingers with different acoustic properties at three different locations in Denmark and the UK. The AQUAmark100 produces broadband complex high frequency signals; whereas the AQUAmark 300 pinger produces tonal 10 KHz pulses. The UK experiment included one AQUAmark100 pinger running in cycles of 23 hours on and off. The pinger was placed at the centre of a triangular array of 14 acoustic click detectors (C-PODs) spaced at 0, 200, 400, 800, 1600, 2400, and 3600m distances from the pinger. In Denmark, two experiments were conducted. One had a 23-hour period on-off AQUAmark100 pinger placed in an array of five C-PODs at 0, 200, 400, 800, 1600m. The second experiment used an AQUAmark300 pinger in a shorter array with two C-PODs at 0 and 300m distances only. The results showed that in the UK the AQUAmark100 significantly reduced the number of porpoise clicks at 0 and 200 m distances, whereas in Denmark a significant reduction in clicks was found at 0, 200 and 400m distances from the pinger. In none of the studies of the AQUAmark100 did the vocalisation behaviour reveal any signs of habituation. The studies of the AQUAmark300 revealed only a significant reduction in the number of clicks at 0m distance. At this station, however, habituation effects were indicated by an increase in clicks over time.

Key words: Harbour porpoise, pingers, habituation, Natura2000

1 Introduction

Incidental bycatch in gillnet fisheries is considered to be one of biggest threats to harbour porpoises (*Phocoena phocoena*) (Gaskin 1984, Jefferson Curry 1994, Reves et al. 2013). Bycatch monitoring schemes have documented relatively large takes of harbour porpoises within several gillnet fisheries (Tregenza et al. 1997, Vinther 1999, Read 2006, Kindt-Larsen et al. 2012). In order to reduce the bycatch of harbour porpoises, the use acoustic alarms (pingers) has been made mandatory on gillnets in certain designated areas and fisheries in the EU since the adoption of Council Regulation 812/2004, and in the northeastern USA under the Harbour Porpoise Take Reduction Plans (New England and Mid-Atlantic waters). A similar approach has been adopted in California by the Pacific Offshore Cetaceans Take Reduction Plan to minimise bycatch of short-beaked common dolphins (*Delphinus delphis*) and other marine mammal species (FR 1997, 1998, EU 2004). In EU waters, porpoises are further protected in a network of protected areas identified under the Habitats and Bird Directive Natura2000 (EC 1979, 1992). Natura2000 is not, however, a system of strict nature reserves where all human activities, such as fisheries, are excluded (EP 2010). As in the above-mentioned regulations/plans, pingers have been identified as one method to protect porpoises within the Natura2000 areas. Pingers have proven to be an effective tool to reduce the bycatch of harbor porpoises (Kraus et al. 1997, Gönener & Bilgin 2009, Dawson et al. 2013, Larsen & Eigaard 2014). Two main pinger types have been developed. One having a constant frequency (10kHz) with multiple harmonics and pulses repeated every 4 s (Dukane Netmark100, AQUAmark300) whereas the other uses higher frequencies and randomized signals (Fishtek, AQUAmark100, STM DDD, Save Wave dolphin saver) and may emit signals at randomized
intervals (AQUAmark100). Even though pingers have proven to reduce the bycatch of porpoises, several disadvantages, such as high costs, handling problems, noise pollution, habitat exclusion and habituation have raised some concerns (IWC 2000, Gearin et al. 2000, Cox et al. 2001). Habituation is defined as “a decrease in response to a stimulus after repeated presentations” (Bouton 2007) and is one of the most serious concerns, when using traditional pingers in commercial gillnet fisheries, since habituation might lead to increasing bycatch rates in pingered nets over time. Porpoises have been found to approach pingers at shorter distances over time (Cox et al. 2001, Carlström et al. 2009), which could lead, potentially, to increased bycatches. Despite these concerns, studies in commercial fisheries where pingers are in use have not found any evidence of habituation leading to an increase in bycatch rates over time (Palka et al. 2008, Carretta & Barlow 2011). Pingers have only been used to a limited extent in gillnet fisheries within the EU (ICES 2012) and long-term effects have not, therefore, been recorded in EU waters. If, however, pingers are introduced as part of management plans within Natura2000 sites, it is likely that they will be used more frequently, increasing the risk of either habituation or habitat exclusion. Fine scale knowledge on how pingers affect the presence of porpoises is needed therefore.

Porpoises are difficult to observe since they spend most of their time below the sea surface. Passive acoustic monitoring (PAM) takes advantage of the fact that porpoises echolocate almost continuously (Møhl & Andersen 1973, Akamatsu et al. 2007) and PAM has therefore been used to determine either porpoise presence or absence in numerous studies (Carlstöm et al. 2009, Kyhn et al. 2012, Dähne et al. 2013). Our study investigates changes in porpoise echolocation patterns in the presence and absence of two different pinger types over time periods of several weeks using PAM. Two questions were addressed: firstly, at what distance is porpoise echolocation activity affected by the presence of pingers and secondly, do porpoises habituate to such signals?

2 Materials and methods
Three experiments were conducted in coastal waters at three different locations: 1) Jammerland Bay, Great Belt, Denmark; 2) St. Andrews Bay, North Sea, Scotland and 3) Gilleleje Flak, Kattegat, Denmark (Fig.1). We recorded porpoise echolocation activity using C-PODs, porpoise click detectors, version 2 (Chelonia Ltd.). The C-PODs comprise a hydrophone, an analogue processor and a digital timing/logging system, which scans for and logs high frequency narrow band acoustic signals centered around 130kHz, which it classifies as echolocation clicks from porpoises under a set of assumptions. A detailed description of the C-POD can be found at www.chelonia.co.uk.

2.1 Jammerland Bay
The experiment was conducted between 22 March and 13 June 2010 (Table 1). An array of 5 C-PODs was set parallel to the coastline (Fig.1, 1) at approximately 8.5 m depth and 1.5m above the sea bed. A single modified AQUAmark100 pinger (Aquatec Group Ltd. www.netpinger.net) was attached above the first C-POD in the array. The next four C-PODs were deployed at distances of 200, 400, 800 and 1600m from the pinger. The AQUAmark100 pinger emitted eight different signals, in random order, two at a constant frequency and six with frequency sweeps (20-40 kHz). The mean source level and duration was 145dB re 1µPa@1m (RMS) and 200-300ms, respectively. The pinger was activated by an internal clock in cycles of 23 hours on and off. The 23 hour cycle was chosen to reduce any effect of diurnal variation in porpoise echolocation activity.

2.2 St. Andrews Bay, Scotland
The UK experiment was conducted in St. Andrews Bay between 20 September and 7 December 2010. In the UK a different array setup was used (Fig.1, 2) and was built on experiences and preliminary results obtained during the processing of the data from Jammerland Bay, DK. The preliminary results from Jammerland Bay indicated a pinger effect outwards for 1600 m (which later turned out to be incorrect, see Results). To ensure, therefore, that the UK array contained a station where the pinger had no effect, this array was extended to contain stations at longer distances (2400 m and 3000 m). Another concern about the DK setup was that the array only recorded porpoises in one direction from the pinger (northern direction, Fig.1, 1). If, for example, the porpoises only visited the pinger area from either a southern or eastern direction, the northern stations would be biased, since all the animals would only encounter the 0m station before they would be scared away by the pinger.
Figure 1: Map of experimental setup in (1) Jammerland Bay, Denmark (2) St Andrews Bay, Scotland and (3) Gilleleje Flak, Denmark. The triangles indicate the positions of the C-PODs and their distance to the pinger.

Table 1: Overview of trial experiments

<table>
<thead>
<tr>
<th>Trial 1 – DK</th>
<th>Start</th>
<th>End</th>
<th>Pinger</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control 1.1</td>
<td>24 March 2010</td>
<td>28 April 2010</td>
<td>No pinger</td>
<td>AQUAmark100</td>
</tr>
<tr>
<td>Experiment 1.1</td>
<td>28 April 2010</td>
<td>13 July 2010</td>
<td>No pinger</td>
<td>On/off cycles 23 hours</td>
</tr>
<tr>
<td>Control 1.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not collected</td>
</tr>
<tr>
<td>Control 2.1</td>
<td>20 September 2010</td>
<td>5 October 2010</td>
<td>No pinger</td>
<td>AQUAmark100</td>
</tr>
<tr>
<td>Experiment 2.1</td>
<td>5 October 2010</td>
<td>30 October 2010</td>
<td>On/off cycles 23 hours</td>
<td></td>
</tr>
<tr>
<td>Control 2.2</td>
<td>30 October 2010</td>
<td>4 November 2010 (6PODs)</td>
<td>No pinger</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 December 2010 (4 PODs)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Trial 3 – DK</td>
<td>3 October 2013</td>
<td>5 March 2014</td>
<td>On/off cycles 23 hours</td>
<td>AQUAmark300</td>
</tr>
</tbody>
</table>

The UK study was thus established as a triangle array to detect porpoises from three directions. A total of 14 C-PODs were deployed in the array (Fig. 1, 2) at 10-15m depth and placed 1.5m above the sea bed. An AQUAmark100 pinger was deployed in the centre of the array together with two C-PODs. The other 12 PODs were deployed at distances of 200, 400, 800, 1600, 2400, and 3000 m, with two at each distance.

The Jammerland and St. Andrews Bay trials were both initiated with a control period measuring the porpoises’ presence before introduction of the AQUAmark100 pinger (Table 1).

2.3 Gilleleje Flak, Denmark

This trial was conducted from 3 October 2013 to 5 March 2014. Once again, the study design was
adjusted. The final results from the trials in both St Andrews and Jammerland Bay did not reveal any signs of habituation (see results), which have been identified in earlier trials (Cox et al. 2001, Carlström et al. 2009). In order, therefore, to compare the results obtained with the earlier studies, a simple setup was made using the same type of pinger as those. Two C-PODs were deployed at 8m depth, placed 1.5m above the sea floor with 300m spacing. At station 1 a single modified AQUAmark300 pinger was attached to the C-POD. The modified AQUAmark300 emitted 10kHz signals lasting 300ms at 4 second intervals. The source level was 132dB re 1µPa@1m (RMS). The pinger was run in cycles of 23 hours on and off during the whole trial.

2.4 Porpoise activity classification
The echolocation clicks recorded on the C-PODs were classified as being of porpoise origin by use of the C-POD software CPOD (V2.035 Chelonia Ltd.) that filters the data for porpoise clicks automatically by use of a detection algorithm. Click trains were classified into quality classes Hi (High-probability cetacean trains) and Mo (Moderate-probability cetacean trains). Only trains containing more than 5 clicks and within the frequencies spectrum 125-145kHz were used as indicators of porpoise activity. The number of echolocation clicks per hour was then exported to a spreadsheet for more detailed analysis. The hour when the pinger was changing on/off was eliminated from the data set in order to remove recordings of any porpoises that had been exposed both to pinger sounds and silence periods.

2.5 Statistical analysis
The C-POD output data contained many zeros in periods when the pinger was on (Fig.2). We believe, however, that these are all true zeros since the recordings had been conducted in areas with high densities of porpoises (Sveegaard et al. 2011) and high numbers of porpoise clicks were detected when the pingers were off. When analyzing the data, therefore, we considered a zero inflated negative binomial model (Martin et al. 2005) as well as an ordinary negative binomial model. Preliminary analyses suggested that the zero inflated model was more appropriate when these were compared using AIC (Akaike 1974). The zero inflated model allowed for even more zeros than the negative binomial. Ignoring zero inflation can cause errors in parameter estimates and bias standard errors (Zuur et al. 2009). The regressors of the binomial and negative binomial part of the model were chosen to be identical, and the logit link and log link were used as link functions for the binomial and negative binomial parts of the model, respectively.

The full model included the following terms:
\[ Y = \text{zeroinfl}(\beta_0 + \beta_1 \times \text{pinger} + \beta_2 \times \text{time} + \beta_3 \times \text{clock} + \beta_4 \times \text{click}) \]

where the response variable Y is defined as the number of clicks per hour. The covariate pinger indicated whether the pinger was on or off, time was a continuous variable from the beginning to the end of the trial and clock was a categorical effect from 1-24 representing the time of day. The covariate click was defined as the logarithm of the number of clicks in the previous hour plus 1, and was included to model autocorrelation in the observed time-series of clicks. The log-transformation was chosen since the AIC value for this covariate had the lowest AIC compared to when the variable was un-logged. Test for model reduction was performed using AIC.

The full model could, however, only be used on the Danish data since the Scottish data had fewer logged clicks. The UK data was therefore tested in a reduced model

\[ Y = \text{zeroinfl}(\beta_0 + \beta_1 \times \text{pinger} + \beta_2 \times \text{time} + \beta_3 \times \text{click}) \]

All analyses were made in the R 3.0.1 statistical package (R Core Team 2013) using the packages pscl (Zeileis et al. 2008).

3 Results
The trial in Jammerland Bay was initiated with a control period of 36 days. Unfortunately, the C-POD on 0m stopped after 3 days of recording and as a consequence no data were collected from this station in the control period. During the pinger on/off period, 77 days of recording were collected resulting in 80 cycles of on/off periods. The trial conducted in St Andrews Bay had a total of three data collection periods: “Control before“, “pinger cycle” and “control after”, which consisted of 16, 25 and 5-49 days, respectively. The reason for the differences in last control period was due to adverse weather conditions, which postponed the collection of some of the PODs. The trial from Gilleleje resulted in a total of 167 days of recording, corresponding to 182 pinger cycles of “on” and “off” periods of the AQUAmark300. Raw data on
Figure 2: Box and whiskers plot of the raw click data according to the distance (m) of the C-PODs within the 3 trials and divided by pinger setting (on/off). Trial 1 refers to Jammerland Bay, Trial 2 to St Andrews Bay and Trial 3 refers to Gilleleje Flak.

Table 2. The different covariates included in the models since all stations were run separately. Under each covariate (Ping, Time, Clock and Click) the distances where they were included in the model are indicated.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Ping</th>
<th>Time</th>
<th>Clock</th>
<th>Click</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0, 200, 400</td>
<td>0, 400, 800, 1600</td>
<td>0</td>
<td>0, 200, 400, 800, 1600</td>
</tr>
<tr>
<td>2A</td>
<td>0, 200</td>
<td>0, 200, 400, 1600</td>
<td>0</td>
<td>0, 200, 200, 400</td>
</tr>
<tr>
<td>2B</td>
<td>0, 200</td>
<td>0, 200, 400, 1600</td>
<td>0</td>
<td>0, 200, 3000</td>
</tr>
<tr>
<td>2C</td>
<td>0</td>
<td>0, 800, 2400, 3000</td>
<td>0</td>
<td>0, 300</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0, 300</td>
<td>0</td>
<td>0, 300</td>
</tr>
</tbody>
</table>

the number of porpoise clicks detected at the different distances are plotted in Figure 2 below.

3.1 Effective range
Depending on the station, different covariates were included in the model (Table 2). The table shows that the covariates time and ping were especially important since they were included by the AIC criteria in 16 and 9 out of 18 stations, respectively. The covariates clock and click were included in 1 and 7 out of 18 stations. In Jammerland Bay, the results of the model showed that the number of clicks was significantly less in “pinger on” compared to “pinger off” periods at 0, 200 and 400 m distance from the AQUAmark100 pinger. No changes were identified in the number of clicks between on and off periods at 800 and 1600m distance to the pinger (Fig. 3). In St Andrews Bay, the model revealed a significant difference in the number of porpoise clicks per hour between pinger state at both stations 0 m from the AQUAmark100pinger (Stations 1 & 2) and at 200 m from the pinger (stations A200, B200). No effect of the pinger was identified from all other stations (Fig. 4). The results from Gilleleje showed a significant pinger effect at 0 m distance from the pinger, whereas no effect of the AQUAmark300 pinger could be detected at 300m (Fig. 5).
Figure 3: Expected number of porpoise clicks per hour at the five different distances in relation to on (circles) and off (triangle) pinger periods recorded in Jammerland Bay, Denmark. Predictions were calculated using the final model and the lines indicate 95% confidence intervals.

Figure 4: Expected number of porpoise clicks per hour at the different distances in array A, B and C in relation to “on” (circles) and “off” periods (triangle) recorded in St Andrews Bay, UK. Predictions were calculated using the final model and the lines indicate 95% confidence intervals.

Figure 5: Predicted number of porpoise clicks per hour at the two distances in relation to “on” (circles) and “off” periods (triangles) recorded near Gilleleje, Denmark. Predictions were calculated using the final model and the lines indicate 95% confidence intervals.
3.2 Habituation
All three trials were analysed in relation to habituation, defined by a significant increase in porpoise clicks per hour over time. In Jammerland Bay and St Andrews Bay, both testing the AQUAmark100 pinger, a reduction in clicks was identified over time at the station where the pinger had an effect and, likewise, at the stations were it had no effect, indicating no signs of habituation. Figure 6 shows the estimates from both Jammerland Bay and St Andrews Bay at stations where the pinger had an effect on the number of clicks (0m) and where it had no effect (800m).

The results from Gilleleje, testing the AQUAmark300, showed a significant increase in the number of clicks over time at 0m from the pinger, whereas a decrease in clicks was identified for the station where the pinger had no effect, which could indicate a habituation effect (Fig 6).

4 Discussion
The three trials demonstrated that the presence of a single pinger significantly reduces the number of porpoise clicks per hour. The distance at which a significant effect of pingers can be detected did, however, differ according to area and pinger type.

The AQUAmark100 pinger had a significant impact 400m outwards from it in the Danish study while the UK study only showed an effect outwards to 200m. The reasons for this may be several. One possibility is that insufficient data were collected during the UK trial, which was conducted over a shorter time period (25 days) compared to the Danish trial (77 days) resulting in fewer on-off cycles. The shorter time period reduces the power to detect low-level differences between on and off periods, which should be expected at longer distances from the sound source. It is therefore possible that a significant effect would have been found at 400m in the UK if the experimental period had been longer. A second possibility for the above discrepancy is that it may be due to differences in the ambient noise levels between the Danish and UK study areas. If an area has a high background noise level, it could lower the signal to noise ratio significantly (Urick 1983), making it more difficult for the porpoises to detect pinger signals. High sediment (sand) noise was detected at several of the UK stations, caused by large sand migrations due to high tidal movements (5m) at the time. The discrepancy could, thirdly, be caused by differences in seafloor morphology and water depths at the two study areas since the pinger sound field is highly dependent on this. The Danish trial was conducted in shallow waters, which can lead to multi-path sound propagation (Shapiro et al. 2009) whereas the UK trial was conducted in deeper waters with longer distances to reflecting boundaries, that is, the sea floor and surface. All the above factors may influence the obtained results and differences in the effective pinger radius are thus expected to vary between different locations.

When comparing the AQUAmark100 pinger with the AQUAmark300, they both had a significant effect on the number of clicks recorded. The pinger impact distance was between 200-400m for the AQUAmark100 while a significant effect could be detected at 0m distance from the pinger for the AQUAmark300 but not at 300 m. Again, there may be several reasons for this difference. The most obvious reason for such differences between the two is the pinger signals. The signals differ considerably according to frequency, source level and inter-signal interval, which will affect the distance at which it will be audible for the porpoises. Further, the difference could also be caused by differences in background noise levels, seafloor morphology and water depths. Both Danish trials were conducted in areas with high ship traffic noise but no sand movements were detected at either of the stations nor during both trials which were conducted on sandy bottoms at similar water depths. We therefore believe that the difference in the results obtained was most likely due to differences between the two types of pinger signals.

When analysing and evaluating the results from these pinger trials, there are several considerations that need to be taken into account. Firstly, detecting sounds from porpoises by a PAM device such as a C-POD does not in itself provide information on the absolute density of animals because the detection distance is not known and may vary depending on circumstances. As with visual observations, acoustic detections will decrease as the distance from the observation point increases and more and more animals remain undetected (Kyhn et al. 2012). This means that even though the C-PODs have been placed at different distances from the pinger, the C-POD does not only record porpoise clicks at that specific distance. C-PODs can theoretically record clicks at a distance of up to 500m, although trials measuring detection range of T-PODs have revealed much smaller effective detection radii (22-104m) for that POD type (Kyhn et al. 2012). Similar studies have
Figure 6: Results on habituation effects in relation to the 3 different study areas. Part 1 and 2 shows the number of clicks in relation the AQUAmark100 pinger and time at 0m (where the pinger had an effect) and on 800m (where the pinger had no effect) in Jammerland Bay and St Andrews Bay respectively. Part 3 shows the number of clicks in relation to the AQUAmark300 0m distance and 300m. Time is given in days and lines indicate 95% CIs.
not, to our knowledge, been published on C-PODs, although Mikkelsen et al. (2013) used an array of C-POD’s close to a porpoise trapped in a pound net and found the effective detection radius was more likely to be 100m for such instruments under those circumstances. In relation to our results, this would mean that the recorded clicks may have originated from an area of approximately 31,400m² but with a centre at the relevant distance. We cannot therefore tell the exact distance from where the recorded porpoise was positioned in relation to the pinger. One way of obtaining better information on the position of the porpoises would be by using a theodolite, a method that has been used in other studies (Koschinski & Culik 1997, Carlström et al. 2009). Notwithstanding, the porpoises would still have the possibility of swimming closer to the pinger, without being registered, since it is only possible using a theodolite to track surfacing porpoises and not their underwater paths.

Secondly, porpoises in captivity have been observed to echo-locate less in the presence of pinger sounds (Teilmann et al. 2006). This indicates that a porpoise could be present in the on-pinger periods without being recorded on the PODs. Kastelein et al. (2000), however, showed that porpoises swam to the farthest end of the pool when exposed to pingers and Culik et al. (2001) determined that porpoises tracked with a theodolite were absent from areas in the vicinity of a pinger. We therefore believe that even though porpoises reduce their echolocation in the presence of pinger sounds, they will not remain in close proximity to a pinger and our porpoise registrations during pinger-on periods can, therefore, be trusted.

Studies investigating pinger spacing of AQUAmark100 have documented that they can be spaced within 585m and still have a significant bycatch reduction effect (Larsen et al. 2013). The results obtained from Jammerland Bay using the AQUAmark100 corresponded well with these results since the impact distance of 400m would allow pingers to be spaced with longer intervals than the 200m recommended by the manufacturer. The UK trial did, however, indicate that the effective range of a pinger may vary according to area morphology, water depth and/or background noise level. Studies examining increased pinger spacing of 10 kHz pingers such as the AQUAmark300 have not been conducted. Murray et al. (2000), however, showed that when Dukane NetMark 1000 pingers were set at 200m spacing they reduced the bycatch of porpoises significantly. In situations where a pinger had been nonfunctional, however, thereby doubling the distance between them, the bycatch rate of porpoises was increased. This indicates that the AQUAmark300 has a shorter effective range compared to the AQUAmark100, which was also indicated in our trials.

One shortcoming of our experiments was that only one pinger was used at a time. The sound field from several pingers might produce a different reaction by porpoises in the surrounding water. This could be the reason why Carlström et al. (2009) showed that a Dukane NetMark 1000 pinger affected porpoise click rates at a distance of 500m. The differences could, however, also be due to the other factors (as described above) such as depth, bottom type and background noise levels.

4.1 Habituation

Ideally, habituation should be investigated by using repeated observations of known individuals (Richardson 1995). From C-POD recordings it is, however, not possible to identify individual porpoise clicks. Potential habituation effects may therefore be difficult to detect if the recorded porpoises have not been exposed repeatedly to the pinger’s sound. Porpoises in Denmark have been tagged with satellite tags and data from the Jammerland area have shown that, among 37 such animals, half moved through the area whereas the other half stayed for an average of 29 days (Teilmann et al. 2008). It is therefore likely that the C-POD recordings in Jammerland Bay contain data from porpoises that had been exposed to the pinger several times during the experiment, but also that data in all areas will always be obtained from a mixture of porpoises with different levels of pinger-sound exposure. Due to the many replicates of on and off cycles, however, habituation effects will most likely be detected.

A comparison between the results of the AQUAmark100 and AQUAmark300 experiments showed a difference in habituation to the two pinger types. The AQUAmark300 experiment resulted in an apparent habituation effect over time even at the sound source, whereas no such effect was obtained in studies of the AQUAmark100. Other studies have similarly reported habituation effects in relation to 10kHz pingers. Carlström et al. (2009) investigated porpoises’ acoustic, spatial, and temporal responses to Dukane NetMark 1000 pingers. They identified an increased echolocation rate over time as evidence of habituation. Likewise, Cox et al. (2001) discovered a habituation
effect when studying porpoise echolocation in relation to a Dukane NetMark1000. The most obvious reason for the different behavioural response observed between the two pinger types is, thus, that porpoises react differently to simple tonal signals compared with more complex signals with more energy at higher frequencies. As described earlier, the Dukane NetMark1000 pinger emitted the same 10kHz signal every 4 sec. In contrast, the AQUAmark100 emitted 8 different signals centred around 20-40 kHz in a random order. The signals and play order of the AQUAmark100 were designed to try to avoid habituation, and this aim seems to have been achieved according to this study. These results therefore indicate that porpoises may habituate more easily to a constant signal compared to a mixture of different signals such as the AQUAmark100. Since only one experiment was carried out with the AQUAmark300 pinger, the risk of observing a spurious habituation effect is substantial, and we therefore recommend that further experiments should be carried out.

4.2 Habitat exclusion
As with concerns over habituation, habitat exclusion has been a cause for concern since pingers have been shown to affect porpoise distribution patterns (Culik et al. 2001, Carlström et al. 2009), which was also indicated in the results of our study. Habitat exclusion is, however, inevitable when using traditional pingers since their function is to keep the porpoises away from the net. Calculating the exact exclusion zone is therefore difficult. In relation to our results, the AQUAmark100 showed differences in its effective range depending on area, and habituation effects were identified in relation to the AQUAmark300. Both results make it hard to determine the exact exclusion zone since it always will be a result of variable factors, for example, background noise and level of habituation over time. One important factor to report upon in relation to our results, however, is that even though the porpoise clicks may be reduced considerably in the vicinity of a pinger when it is “on” does not mean the porpoises are not there meaning, in turn, that pingers do not totally or necessarily exclude porpoises from their vicinity. Indeed, some low level of bycatch is usually reported upon even when nets are fully equipped with pingers (Kraus et al. 1997, Larsen et al. 2013). In wider areas, where pingers (10 kHz) have been used frequently, pingers have not shown any effects on the presence of porpoise within the area (Carretta & Barlow 2011). The question about habitat exclusion, however, remains a concern if pingers are used at high densities in areas of preferred porpoise habitat (Dawson et al. 2013).

4.3 Pinger use in Natura2000 areas
A number of the Natura2000 areas in Denmark have been selected based on high densities of satellite tagged porpoises (Sveegaard et al. 2011). At this stage, no management plans exist for the Natura2000 areas, although an obvious idea would be a requirement for fishermen to use pingers on gillnets to minimize bycatch. The effect of pinger use in these areas is not straightforward and has been the subject of some discussion (ICES 2014). The net benefit of pinger use will depend on the size of the area, its importance for porpoises, the level of fishing effort and effort distribution in the area. It is likely that the net benefit will need to be assessed on a case-by-case basis. It is possible that larger Natura2000 areas could encompass both porpoises and gillnet fisheries required to use pingers at the same time provided the fishery only occupied certain parts of it. Pinger use in small Natura2000 areas could, however, reduce the number porpoises in the area that had been initially established for their conservation. Clearly, some balance is required, though high levels of by-catch should generally be considered a less desirable outcome than some degree of displacement.

The results obtained from these trials are important in relation to pinger use in Natura2000 sites, since the experiments identify several different impact radii at different sites, but also differences in habituation in relation to pinger type. Both of these aspects need to be considered before management plans are drawn up to include pingers as a conservation measure in Natura2000 sites.

5 Acknowledgements
We thank our colleague Alexander Coram at SMRU, Scottish fishers and Jeppe Dalgaard Balle from Aarhus University for assistance with the deployment and collection of C-Pods. We thank Chelonia Ltd. for technical support with the C-PODs and data analysis. Finally, we would like to thank the Danish Ministry for Food, Agriculture and Fisheries and the European Fisheries Fund and DEFRA for funding the project.
6 References


PAPER IV

Uncovering governance mechanisms surrounding harbour porpoise conservation in the Danish Skagerrak Sea.

Sørensen T.K, Kindt-Larsen L & Jones, P.

Manuscript, ready for submission as a part of a special issue of European Policy.

(This paper was written as part of a Special Issue devoted to Marine Policy. The issue contains 13 papers each representing a different case study from the MESMA (Monitoring and Evaluation of Spatially Managed marine Areas) Project. The papers describe governance issues such as conflict analysis, degrees of integration, participation, transparency and accountability, equity and justice and uncertainty. The paper thus follows a defined structure for all papers submitted to the special issue to follow. A synthesis paper uniting all case studies is in progress. The submission of Paper IV, therefore, has to wait for the completion of this.)
Uncovering governance mechanisms surrounding harbour porpoise conservation in the Danish Skagerrak Sea

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Abstract

The harbour porpoise (*Phocoena phocoena*) is the focus of a range of conservation efforts and policies, including the Habitats Directive, aimed at reducing the bycatch of non-target species in gillnet fisheries. This paper describes the governance process and analyses the governance mechanisms and conflicts surrounding ongoing fisheries management planning with a focus on two Natura 2000 sites in the Danish part of the Skagerrak Sea designated to protect harbour porpoises. Responsibility for developing fisheries management for Natura 2000 sites is solely the remit of the fisheries agency, including mechanisms related to stakeholder involvement. This approach fuels the efficiency of the decision making process, while full transparency and/or co-decision becomes less of a given within a ministry for an economic sector compared with the environment ministry. In relation to porpoises, conflicts are driven mainly by the economy and the varying perceptions of the bycatch issue, with great differences between government, NGO’s and fishermen. Interviews with fishermen and fishing effort data reveal intra-sectoral conflicts pertaining to the incompatibility of active trawling and passive gillnetting in the areas. The paper questions the overall approach to managing the harbour porpoise bycatch issue in light of Natura 2000 and discusses the role of science and its high level of influence in this planning process.

Keywords: marine mammals, marine spatial planning, marine protected areas, fisheries impacts, stakeholder involvement, governance

1. Introduction

The harbour porpoise (*Phocoena phocoena*) is a small toothed whale that is widespread throughout the northern hemisphere [1]. The main direct threat to harbour porpoise populations in northern European waters is their entanglement and drowning in bottom-set gillnets [2]. However, porpoises may also be negatively impacted by high noise levels [3] and overfishing of prey species. The only known method to avoid bycatch of harbour porpoises, apart from reducing the overall fishing effort, is to attach acoustic deterrents (*pingers*) to the nets, i.e. scaring the animals away from nets [4]. In Denmark, estimates of total harbour porpoise bycatch have only been made in the North Sea, where high levels of bycatch were observed in the bottom-set gillnet fisheries for turbot, cod, hake and plaice [5]. As a result of the overall threat of gillnets to porpoise, a number of conservation efforts and policies are targeted towards reducing the bycatch of the species either through technological solutions (e.g. acoustic deterrents) or through the establishment of marine protected areas (MPAs) [6,7].

The European Union’s Habitats Directive [7] is the overarching basis upon which a large number of protected areas, known as special areas of conservation (SACs) have been nationally designated in the land and sea areas of EU Member States, to protect a set of habitats and species listed in the annexes of the directive. Together with special protection areas (SPAs) under the Birds Directive [8], these sites constitute the so-called Natura 2000 network of protected sites. The aim of the Habitats Directive is to achieve a *favourable conservation status* for the listed habitats and species. The harbour porpoise is listed in both Annex II, as a priority species whose conservation requires the designation of special areas of SACs, and Annex IV, as a species in need of particularly strict protection throughout its natural range. This means that the obligation
Figure 1. Natura 2000 sites in waters surrounding northern Denmark, including case study areas Skagens Gren & Skagerrak (A) and Store Rev (B).

to protect the harbour porpoise applies to marine areas within as well as outside SACs. Harbour porpoises are also the focal species of a number of agreements rooted in fisheries policy. The European Common Fisheries Policy (CFP) aims, among other things, to ensure sustainable exploitation of living aquatic resources [9]. In light of the wider species conservation targets of the Habitats Directive, the EU addresses porpoise bycatch directly through Council Regulation 812/2004 [6], which lays down measures concerning incidental catches of cetaceans in fisheries, including the implementation of monitoring systems to register the incidental catches of these species. Member States must also take action and conduct research to ensure that incidental catches do not have a significant impact on the species concerned and the marine ecosystem. The Regulation aims at mitigating incidental catches of cetaceans by introducing technical measures concerning gillnets (incl. mandatory use of pingers) and by creating a monitoring framework on board fishing vessels to obtain information on bycatches of cetaceans in ‘at risk’ fisheries. In addition to the CFP, the agreement on the conservation of small cetaceans of the Baltic and North Seas (ASCOBANS) aims to restore and/or maintain harbour porpoise populations at 80% of their carrying capacity [10] and to reduce bycatch to levels not exceeding 1.7% of the population [11].

This study focuses on Skagens Gren & Skagerrak and Store Rev, two SACs designated under the Habitats Directive to protect harbour porpoises in the Danish part of the Skagerrak Sea, a sea area shared by Norway, Denmark and Sweden (see Fig 1). Skagens Gren & Skagerrak (approx. 2,690 km²) is designated to protect harbour porpoises and sandbanks, while the neighbouring site Store Rev (approx. 109 km²) is designated to protect harbour porpoises as well as reefs and submarine structures made by leaking gases [12]. The focus of the current study is solely on harbour porpoises.

Originally designated in 1998, the Skagens Gren & Skagerrak site included only terrestrial habitats. In 2003 the site was expanded to include adjacent coastal waters (albeit no marine habitats and species) and in 2010 the site was finally expanded to also encompass additional offshore areas including harbour porpoise habitats. As a result of the 2010 expansion the SAC became subject to both national fisheries regulations (out to 12 nm) and international regulation under the CFP. Store Rev was
designated in 2010. The two Danish SACs were designated by the Danish Ministry of the Environment on the basis of porpoise density data derived from satellite tracking of captured and tagged individuals [13], with site boundaries drawn to encompass those areas with the highest observed densities of harbour porpoises. There is no obligation under the Habitats Directive to develop formal management plans for these two sites until 2015 (5 years after designation).

Although the two SACs are nationally designated by Denmark, EU Member States do not have exclusive fishing rights within their Exclusive Economic Zones and much of the Skagerrak is fished by vessels from several other member states in accordance with the CFP. Several major Danish ports are located in the vicinity of the Skagerrak, including the fishing ports of Skagen and Hirtshals. There are many fishing communities in this region, which is considered to be one where employment opportunities are otherwise sparse.

The governance issues, conflicts and impacts surrounding the two MPAs were analysed by the authors on the basis of policy research, face-to-face interviews with 20 local fishers from Skagen and Hirtshals, satellite data from vessel monitoring systems (VMS) of fishing vessels larger than 12 m, and results of experimental video monitoring, where cameras were installed on smaller vessels fishing in the sites, allowing hitherto inaccessible detection of harbour porpoise bycatch incidents [14]. DTU Aqua scientists played no role in the selection of the two sites, but do support the implementation process by delivering scientific data for stakeholder meetings and data requests from the involved ministries. The current paper therefore draws on personal experiences from the authors, but also contains stakeholder views based on interviews and information from available literature.

2. Case study process and governance

The Danish Ministry of the Environment has the overall national responsibility for the implementation of the Habitats Directive. This responsibility is placed within the Ministry’s Nature Agency that designates sites, develops and publishes overarching management plans and conservation objectives for each site, carries out public hearings, etc. However, the Ministry of the Environment has legally delegated sectoral management responsibilities to various other ministries (e.g. the Ministry of Transport, Energy etc.). As a result the Ministry of Food, Agriculture and Fisheries of Denmark and its AgriFish Agency have been given the official responsibility to ensure that fisheries and aquaculture in Danish seas are not a hindrance to the achievement of favourable conservation status for listed species and designated habitats. If it is deemed necessary, the AgriFish Agency must carry out measures to protect species and habitats from any threats originating from fishing activity. This legal obligation is written into Danish fisheries legislation and any issues pertaining to fishing in relation to the Habitats Directive are therefore centred around the AgriFish Agency.

Although it is only the AgriFish Agency that has a mandate to make decisions regarding management of fisheries in and around SACs, there are a number of organisations that are involved in the Skagens Gren & Skagerrak and Store Rev initiatives and other SACs designated under the Habitats Directive:

- the Danish Ministry of the Environment’s Nature Agency;
- the fishing sector, including the Danish Fishermen’s Association, Danish Recreational fishing associations, the Danish Amateur Fishing Association, Danish Sport Fisher Association, the Danish Fishermen’s Producers' Organization and the Danish Pelagic Producers' Organization;
- environmental NGOs such as WWF, Greenpeace, Living Seas, the Danish Society for Nature Conservation, Danish Ornithological Society and Oceana;
- to a degree also universities such as DTU Aqua and Aarhus University, who have provided documentation, expert knowledge, etc.

The process through which the fisheries authorities are addressing the fisheries management challenge is a combination of different approaches ranging from top-down to bottom-up approaches (see Fig 2). The process has been top-down in the sense that it is coordinated by the Danish AgriFish Agency and ultimately it is the Danish AgriFish Agency who
Figure 2. Diagram of the fisheries management planning process for Natura 2000 SACs in Denmark. While the Danish Ministry of the Environment’s Nature Agency has the responsibility for designation of sites and development of e.g. conservation objectives, the Ministry of Fisheries and its AgriFish Agency are responsible for developing fisheries management plans to ensure that the fishing sector is not an obstacle or threat to the achievement of favourable conservation status for the habitats and species.

has the sole decision making power, particularly focused on fulfilling legal obligations under the Habitats Directive. However, in order to foster an open and effective dialogue between stakeholders the Danish AgriFish Agency has invited fisheries organizations, environmental organizations and other relevant institutions to join the a group called the dialogue forum. The Terms of Reference of the forum [15] state that it provides the opportunity for a technical dialogue between authorities, fisheries organisations, green NGOs and relevant scientific institutions about fisheries and protection of marine Natura 2000 sites with the intention of including these organisations in the fisheries related issues surrounding Natura 2000. In addition, the forum can also be drawn on if more knowledge is needed in order to develop the informed management of sites.

The underlying philosophy behind these dialogues is that stakeholders will benefit from each other’s knowledge and experience through a series of meetings, each addressing a range of relevant topics which are mainly identified by the Danish AgriFish Agency. During each meeting the group discusses selected areas, issues or species, thereby directing the meetings towards specific and detailed discussions on these pre-defined topics. The meetings are informal in nature but points of view are noted and meeting minutes are subsequently emailed to participants. In preparation for these meetings, the Danish AgriFish Agency relies on scientific background documents provided by independent research institutions such as DTU Aqua, Aarhus University, etc.

3. Conflict analysis

The Danish AgriFish Agency is not obliged to develop management plans for the two SACs before the end of 2015. However, it is apparent in trade press, interviews with local fishers and
stakeholder processes such as the dialogue forum that there are a number of emerging conflicts that the Habitats Directive requires to be addressed in order to protect harbour porpoise populations.

The most obvious conflict in the *Skagerrak* and *Store Rev* case study is the one that exists between those that wish to fish with gillnets (e.g. fishers, fishers’ associations) and those who wish to protect the harbour porpoises (e.g. NGOs). For instance, in a report published by a coalition of the main environmental NGOs in Denmark [16] it is clearly stated that the NGOs envision gillnet fishing to be banned within SACs designated for harbour porpoises. In the same document, NGOs also underline the importance of applying acoustic deterrents on all gillnets to address harbour porpoise bycatches on a general level. One potential indirect impact of ecological importance that has not emerged as a conflict is the risk that fisheries may potentially deplete prey species of importance to porpoises, thereby limiting the success of the population.

Conflicts are driven mainly by two factors: the economy and the varying perceptions of the bycatch issue. Local gillnet fishers are directly dependent on fishing in the areas to sustain their livelihoods and are therefore set on defending their right to fish, while the overall economic success of NGOs depends on victories to recruit members and/or receive donations, so is less directly linked with these specific sites. A different and more complex driver of conflict is the fact that the perception of the harbour porpoise bycatch issue varies greatly between fishers, government and the NGOs. As became apparent in interviews, fishers often do not view the occasional bycatch incidents that they have observed as being problematic. However, when considering the sum of all such individual incidents, bycatch frequencies may exceed levels that are acceptable to society, international agreements, policy obligations etc., i.e. an issue that must be dealt with by the Danish AgriFish Agency. Furthermore, national governments are driven by policy obligations and conservation objectives such as favourable conservation status or keeping bycatch levels below 1.7 % of the population as prescribed by the ASCOBANS Agreement [11]. Meanwhile, NGOs may also focus on the emotional aspects relating to the fact that the harbour porpoise is a ‘charismatic’ species, making the NGO’s less likely to accept harbour porpoise bycatch at all. Such a variation in the perception of the issue fuels conflicts that are difficult to resolve.

There is, however, also an intra-sectoral conflict that became apparent both in interviews with fishers and when analysing the distribution of fishing effort in and around the SACs (see Fig 3). Fishing grounds for especially small scale gillnet fishers are not only limited by depth, distance from shore and the presence of target species, but also by the presence of towed gear fishing activity. Due to the risk of losing or damaging fishing gear, the employment of both passive gears such as gillnets and towed gears such as bottom trawls are incompatible within a given area. The *Store Rev* site contains complex reef structures that exclude the possibility of
employing bottom trawl gear in this area. As a result, there is a very high gillnet effort concentrated in the area. This clear division in distribution of fishing effort among passive and towed gears is not observed in the Skagerrak site where trawl fishing is more or less ubiquitous, static fisheries not being feasible due to the depth and distance from shore. The consequence of e.g. banning the use of gillnets in the Store Rev site would therefore be substantial, since gillnetters would have very few untrawled sites to which they could relocate their fishing effort. This point has also been made by interviewed fishers who utilise the Store Rev site (Area B), i.e. they have no other fishing grounds to move to if restrictions are imposed on gillnetting in harbour porpoise SACs.

4. The degree of integration

The sectoral approach to the legal transposition of the Habitats Directive in Denmark, combined with centralized structure of management of Danish fisheries, together eliminate the formal requirement for practical co-management between fisheries and environmental authorities and between local and central government bodies within the Ministry of Fisheries. One advantage of this approach is the elimination of doubt or contest regarding authority, while a disadvantage may be that a government ministry representing an economic sector may run the risk of compromising the achievement of conservation objectives in meeting the equally important aim of ensuring the economic viability of the fishing industry, which has an effective and persistent lobby. Another disadvantage may be the lack of local presence when developing fisheries management measures for SACs. Although several fishers’ associations are represented on the AgriFish Agency’s dialogue forum, the absence of local government bodies that can interact directly with (especially small scale) fisheries stakeholders that might be directly affected by management decisions may fuel the idea that the management approach is purely top-down and that local concerns are not taken account of. This has also been expressed by local fishers interviewed within this project. Prior to our own interviews, the majority of the interviewees had not been approached directly by the AgriFish Agency. In addition, most interviewees had received most news and updates regarding fisheries management in SACs in their region from their industry association representatives and not from the government itself through localized staff, targeted websites etc. Finally, while cross-sector integration (or a lack thereof) is not currently an issue in relation to the two study sites, a single sector approach may potentially be a general obstacle for development of a more holistic, integrated approach to management of maritime activities in and around protected areas. In addition, a lack of cross-sector integration calls for an even larger emphasis to be placed on assessing cumulative impacts of all sectoral activities on protected species and habitats [17,18].

5. Participation, transparency and accountability

There is a long tradition of public hearings in Danish governmental processes and this is also the case regarding the implementation of the Habitats Directive. Public hearings have been held in connection with specific site designations, publication of draft overarching management plans for SACs, etc. In these hearings, the wider public as well as interest organisations formally express their views on a specific issue or plan to the Ministry of Environment. In addition, both the NGOs and the fishers express their general views through campaigns and lobbying through e.g. social media, trade press or through official channels of communication with the AgriFish Agency. It is extremely difficult to determine the degree to which a stakeholder or an organisation’s point of view is accommodated in such processes.

In relation to the development of fisheries management plans for SACs, the AgriFish Agency’s stakeholder dialogue forum is the most central mechanism through which stakeholders and the AgriFish Agency exchange concrete information and points of view, and gain a common understanding of fundamental scientific aspects regarding management options, e.g. the impacts of fishing gears on specific habitats, the frequency with which harbour porpoises or sea birds are bycaught, etc. The forum has proven effective in coralling issues that have had the potential to become controversial, i.e. using scientific advice to establish some kind of common starting point from where to proceed. In some cases, however, fisheries stakeholders have expressed scepticism towards the scientific advice upon which fisheries management aspects are to be based. Environmental NGO’s have also used the
meetings to express disagreement on the national interpretation of the Habitats Directive.

The AgriFish Agency often commissions scientific advice from DTU Aqua and Aarhus University. In the face of conflicting viewpoints amongst stakeholders, such scientific advice is usually used by the AgriFish Agency as a foundation for the development of management plans. For instance, in relation to harbour porpoises, there is a need for action both regarding the specific SACs designated for harbour porpoises and for mitigating impacts of gillnet fishing on harbour porpoises throughout their natural range. As a result, the AgriFish Agency has established a porpoise expert group that can assist in the development of an overarching action plan for mitigating the effects of fishing on harbour porpoises. In addition, the AgriFish Agency has funded a project that investigates the potential consequences of deploying pingers within a Natura 2000 site. Analyses have revealed that bycatch incidents are both found in and outside the SAC boundaries and as such, too much emphasis may currently be placed specifically on the SACs. Taking into account that gillnet fishing represents the largest known threat to the species, it can be argued that by further developing solutions to mitigate bycatch of porpoises both within and outside SACs, objectives for the SACs would also likely be met, though this does call the role of such site specific designations for the protection of cetaceans into question.

The dialogue forum must not be mistaken for an attempt to reach consensus or achieve co-decision on management issues. There are no stated guarantees that viewpoints expressed will be taken into account and once the meetings are over, the decision making process continues behind the closed doors of the AgriFish Agency until management decisions are proposed and consulted upon. The AgriFish Agency is therefore not held accountable as such in relation to stakeholders. However, they are in general held accountable for their actions in the sense that there have been incidents where, for example, the Danish Society for Nature Conservation, filed a formal complaint to the European Commission over the AgriFish Agency’s decision to allow mussel dredging in coastal SACs. However, the EC ultimately decided against initiating a court case.

The AgriFish Agency has in recent years become increasingly efficient and proactive in relation to development of fisheries management in accordance with conservation targets stated in the Habitats Directive. This is likely due to a combination of two factors: time is becoming shorter in relation to meeting the 2015 deadline for fisheries management plans and a new government came to power in 2011, among other things due to a stated strong environmental profile. This new proactive approach to development of fisheries management plans requires more effective leadership than an approach based on dealing with problems individually as they arise.

6. Equity and justice

The authors interviewed 20 local fishers as part of the MESMA project. Among these, several have clearly stated that a closure of the two SACs to gillnetting would mean a loss of fishing opportunities. Many gillnet vessels are small and do not travel over large distances to set their nets. In addition, most areas in the region are frequently trawled by either pelagic or bottom trawlers, making it risky or ultimately impossible to employ gillnets. Interviewees fishing in the Store Rev site (Area B) have also stated that it is not possible to find alternative fishing grounds with the same potential due to exceptionally high abundances of their target fish species in the area. It is therefore apparent that gillnet fishers within the SACs would be the main losers if a gillnet closure is implemented as envisioned by environmental NGOs. Even if acoustic deterrents are chosen over a closure of the fishery, such devices represent a high financial cost to fishers. The main winners would, if such a closure indeed improves the conservation status of the harbour porpoise, be the porpoises themselves and those who support their protection.

7. Uncertainty

There are several levels of uncertainty involved in the Skagens Gren & Skagerrak and Store Rev case study MPAs. Some of this uncertainty relates to the scientific basis of management measures, including the overall approach of using MPAs to protect harbour porpoises. The harbour porpoise population residing in the Skagerrak is a part of the greater North Sea population and can therefore not be considered in isolation in relation to conservation efforts
and management of impacts. Uncertainty is also something that most involved stakeholders face in such processes, i.e. relating to future fishing opportunities, the effects of management measures on their livelihoods, etc.

The Danish AgriFish Agency’s dialogue forum was established in part to ensure that information regarding the implementation of the Habitats Directive is effectively disseminated to all affected stakeholders and to allow for these stakeholders to respond. As such, the local fishers’ association of the Skagerrak area has been effective in disseminating updates on the progression of management measures to its members. On a similar note, the dialogue forum keeps environmental NGOs informed on a regular basis, preventing a situation where public statements on social media, etc. are based on guesswork or opinions. Nonetheless, interviews with local fishers revealed that rumours do flourish around the fishing ports about the future consequences that the two SACs might bring about. Ultimately, there is no one outside the AgriFish Agency who can influence the final decisions made and the uncertainty will likely continue until such a decision is made public.

Scientific advice is central to the process of developing management measures for the case study SACs. In light of scientific uncertainty the precautionary approach is prescribed by many environmental policies and agreements, particularly the Treaty on the Functioning of the European Union, which includes wider a wider obligation for precautionary approaches across all EU sectoral policies [Qiu and Jones 2013]. Most decision makers (especially those representing an economic sector), however, prefer to base any decisions on ‘facts’ and scientific evidence rather than the precautionary approach and the AgriFish Agency is no exception. The Agency therefore regularly commissions scientific advice to inform the decision making process. Even though it can take a considerable time for management actions to be implemented, partly due to efforts to improve this knowledge base, there does not seem to be a tendency to deliberately postpone action on the basis of this lack of knowledge, and this case arguably represents a reasonably balanced application of the precautionary principle.

There is, however, also substantial uncertainty surrounding the negative consequences that eventual management measures put in place within SACs, such as a total gillnet closure or mandatory use of acoustic deterrents, might have such as e.g. animals leaving the SAC area due to excessive noise from acoustic deterrents or gillnet fishers being displaced to other areas where impacts on harbour porpoises may be equally high or even higher. In both cases it is of great importance that management measures are chosen wisely, that they are adaptive to any changes in distribution of animals within the case study area or the knowledge base, and that they are based on the best available science.

8. Discussion & conclusions

While the delegation to the Danish Ministry of Fisheries of full responsibility for development of fisheries management measures to protect harbour porpoises has some clear benefits, it also has its weaknesses in relation to stakeholder involvement and transparency. One overarching benefit is that inter-ministerial conflicts or power struggles that might otherwise muddle this specific aspect of the overall Natura 2000 implementation process are almost non-existent, which enhances the effectiveness of the decision making process and allows the staff involved in developing sector specific management to work efficiently without having to coordinate every step with e.g. the Ministry of the Environment or other ministries. However, locating the arena for stakeholder discussions within the AgriFish Agency also means moving them from the comparatively neutral ground of environmental policy into the domain of a ministry that represents an important economic sector. The AgriFish Agency’s Natura 2000 stakeholder dialogue forum has been successful in fostering dialogue and creating a common understanding of the scientific foundation upon which management must be built. However, while the dialogue forum may give participants the impression of transparency and involvement, the actual involvement of stakeholders can be steered by the agency through the selection of discussion topics/themes and, more importantly, the degree to which the viewpoints of stakeholders are ultimately taken account of in final proposals and decisions for fisheries management measures.

The harbour porpoise conservation challenge is currently being addressed in Denmark through a
two-tiered approach: one that utilizes marine protected areas (Natura 2000 SACs) to protect areas with highest porpoise densities and another that addresses wider protection in general through technical measures such as pingers. There are several inter-related risks involved in the use of MPAs to protect harbour porpoises. If protected sites with the highest porpoise densities do not correspond completely with the areas where rates of bycatch in gillnets are highest, which is feasible given uncertainty, then fishing effort from protected sites might be displaced from SACs to non-protected sites, thereby increasing the threat of bycatch in non-protected areas correspondingly. The underlying data utilised in site selection must be as certain as feasible and updated regularly, otherwise MPAs may give the illusion of protection while the majority of harbour porpoises in reality inhabit other, non-protected areas to which gillnet fishing and associate bycatch could be displaced. Finally, it is recognised fact that harbour porpoises are highly mobile and that individuals are known to move over very large distances in varying patterns, adding the challenge of variability to uncertainty [13].

It can be argued that, to fulfil overarching obligations relating in particular to impacts of fishing on harbour porpoises, it would suffice to pursue solutions to mitigate bycatch of porpoises wherever the animals occur (as prescribed by Annex IV of the Habitats Directive), as objectives for the SACs would therefore also likely be met, perhaps rendering MPAs more central as a mechanism to protect harbour porpoises from impacts other than fishing, such as e.g. overfishing of prey species, underwater noise.

MESMA interviews with local fishers as well as VMS data from fishing vessels have revealed that there is a sharp division of fishing grounds among those fishers that use passive gears (e.g. gillnets) and active gears (e.g. trawls) (Fig 3). It is highly likely that this division is based on gillnetters avoiding areas where trawling takes place and trawlers avoiding areas where bottom trawls may get snagged or damaged on the seabed. As a result gillnet fishers often would have no viable alternative fishing grounds to which they can reallocate their effort if gillnetting is prohibited within SACs, fuelling intra-sectoral conflicts between these fleet segments. Such conflicts could potentially be resolved through allocating new areas for passive gears outside of the SACs, through wider marine spatial planning processes, but this approach has so far not yet been pursued or proposed.

As the current study on the development of fisheries management measures has been conducted mid-process we must ultimately wait until the end of 2015 in order to determine whether or not the Danish AgriFish Agency is successful in developing measures that effectively address the harbour porpoise bycatch issue within Natura 2000 SACs and beyond. It is clear, however, that addressing inter-sectoral conflicts between fishing and conservation and intra-sectoral conflicts between static and towed gears will require a more integrated approach, involving both narrower measures in MPAs and wider marine spatial planning approaches that are themselves both integrated and adaptive.

Acknowledgements

This research was funded by the European Commission’s Monitoring and Evaluation of Spatially Managed Areas (MESMA) project under the 7th Framework Programme. We are grateful to the fishers who were willing to let us interview them, Peter J.S. Jones and his team at UCL for excellent guidance throughout the MESMA project and Finn Larsen of DTU Aqua for constructive feedback.
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