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Contribution to the Theme Section 'Techniques for reducing bycatch of marine mammals in gillnets'

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 to15 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

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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

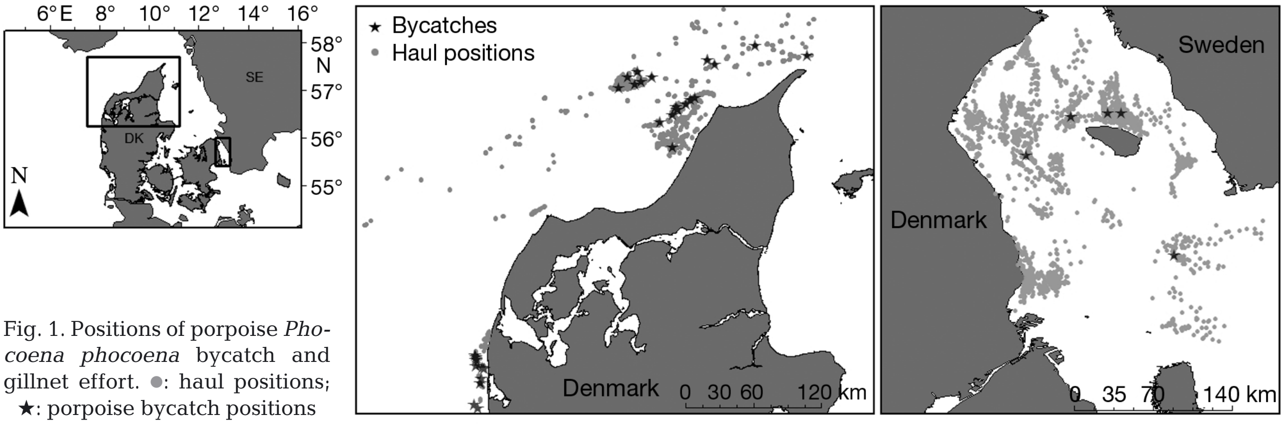

Fig. 1. Positions of porpoise *Phocoena phocoena* bycatch and gillnet effort. ●: haul positions; ★: porpoise bycatch positions

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 × 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 bycatches 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 × 11 × 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.

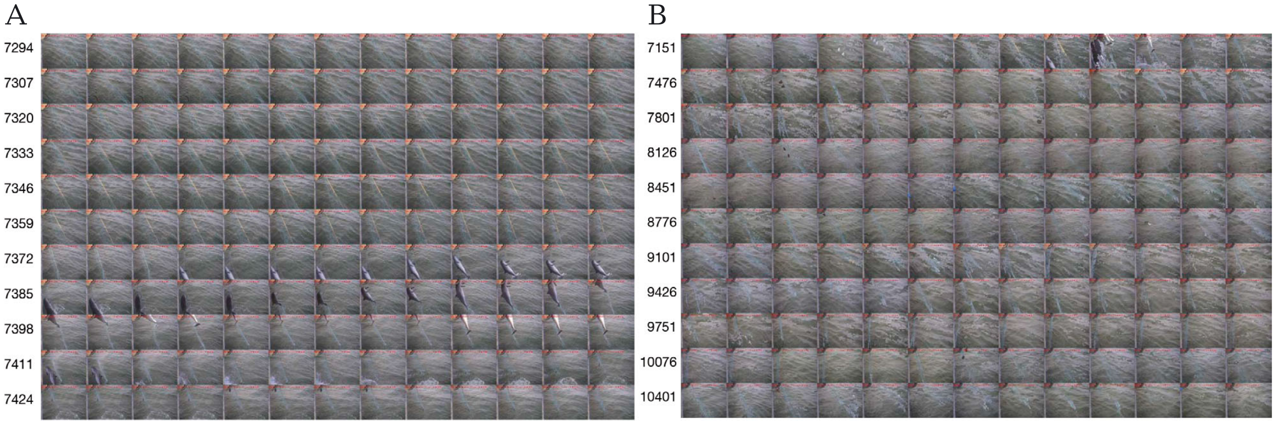

Fig. 2. (A) Image montage of Method A (143 frames). The frames show a porpoise *Phocoena phocoena* from bycatch in Rows 7 to 9. (B) Image montage of Method B (2145 frames, 15 frames are overlaid in 1 frame). Shows the same porpoise from bycatch as in Method A in Row 1

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-

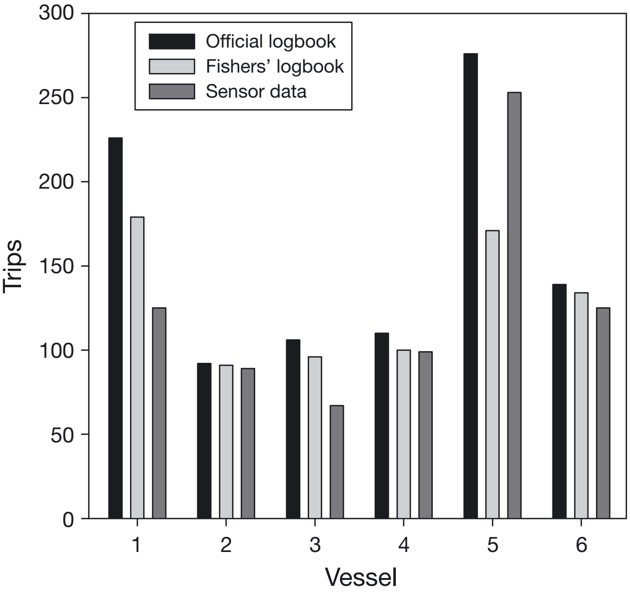

Fig. 3. Number of fishing trips recorded in official logbooks, fishers' supplementary logbooks and by the sensor system

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

Vessel	Hours at sea Official logbooks	 Sensor data	Coverage (%)
1	1373	833	61
2	1270	1215	96
3	2060	1613	78
4	1574	1358	86
5	1872	1812	97
6	1906	1806	95
Total/mean	8149	6831	86

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 €.

Table 2. Number of bycaught porpoises *Phocoena phocoena* registered by logbook and video, or logbook only and showing whether the porpoises were seen or not seen by the fishers. Vessel 3 fished mainly over shipwrecks and stone reefs, whereas the other 5 vessels fished mainly over sand, stone and gravel

Vessel	Logbook & video	Logbook only	Video only Seen	Video only Not seen	Total
1	1	1	0	0	2
2	1	0	3	1	5
3	0	0	1	0	1
4	6	0	2	0	8
5	3	2	0	0	5
6	11	0	1	6	18
Total	22	3	7	7	39

Table 3. Overall costs for 811 d of observation IN 2011

Item	Cost (€)
6 remote electronic monitoring systems (incl. installation)	61 200
Video and sensor analyses (913 student hours)	14 600
Technical support and maintenance	4300
Total running costs	18 900
Total costs of the trial	80 100

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 porpoises 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 often 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.
- Pinger 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.

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