Estimated bycatch of harbour porpoise *Phocoena phocoena* in two coastal gillnet fisheries in Norway

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ABSTRACT

Based on catch and bycatch data from 2006-2008 from a monitored segment of the fleet of coastal gillnetters targeting anglerfish and cod, we used general additive models (GAMs) to model bycatch rates, where number of harbour porpoises entered as the response variable, and catch by the fisheries was entered as offset. Landings statistics of target species landed by the same gear and vessel types, were used to extrapolate to entire fisheries. The two best models predicted the total number of harbour porpoise bycatch to 20,719 and 20,989 porpoises, with CVs 36.05% and 27.33%, respectively. Thus, the models predict annual bycatches of 6,900 harbour porpoises in the anglerfish and cod fisheries.

KEYWORDS: HARBOUR PORPOISE, BYCATCH, GENERAL ADDITIVE MODELS, GILLNET FISHERIES, NORWEGIAN COASTAL WATERS

INTRODUCTION

Throughout their range, harbour porpoises *Phocoena phocoena* are notoriously vulnerable to incidental catches in gillnets (Read *et al.* 2006; Vinther 1999; IWC 1992, 1996; ICES 2008, 2009, 2010, 2011a). ASCOBANS has advised that bycatches should not exceed 1.7% of the best population estimate. In USA a different approach is used to set limits for bycatches (the Potential Biological Removal approach, Wade 1998). Mitigation measures to reduce bycatches are in place in USA (Rossman 2010). EU has recommended some mitigating measures in EU waters (Regulation 812/2004), but according to ICES (2011b) these measures are not well implemented.

Essential information to assess the sustainability of bycatches is the population structure and abundance of the bycaught species. The population structure of porpoises in Norway is not well documented. Gaskin (1984) assumed two populations in Norwegian waters divided by the deep waters of Vestfjorden. Bjørge and Øien (1995) found a hiatus in the offshore distribution of porpoises off central Norway and suggested two population components, one southern associated with the shelf waters of the North Sea and a northern component associated with the Barents Sea. Based on mtDNA from 45 porpoises from the North Sea and 38 porpoises from the Barents Sea, Tolley *et al.* (1999) concluded that porpoises along the entire Norwegian coast belonged to the same population unit. In a review paper, Andersen (2003) supported the conclusion of Tolley *et al.* (1999), but indicated further that results from wider studies of both mtDNA and nuclear DNA point to the existence of genetically differentiated Norwegian population separated from porpoises in the rest of Scandinavian and European waters. Seasonal movements and the relations between coastal and offshore porpoises are not known.

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The Abundance of porpoises in the wider North Sea area has been estimated at 341,366 (CV 0.14) in 1995 (Hammond *et al*. 2002), and 334,948 (CV 0.16) in 2005 (SCANS II 2008). Bjørge and Øien (1995) gave an estimate of 11,000 (CV 0.44) porpoises in the wider and offshore Barents Sea area. This estimate was based on the assumption that all porpoises on the track line were seen (g(0)=1), and is clearly an underestimate of true abundance. The abundance of porpoises in the complex coastal and fjord waters of Norway is not known.

Norwegian fisheries are extensive and fish products are Norway's second largest export article. Most of the demersal catches are taken with bottom trawl and most of the pelagic catches are taken with purse seine. Onboard observer programmes revealed that these gear types are associated with relatively low risk of entanglement of marine mammals (Bjørge *et al*. 2006).

The focus has therefore been on the small vessels (total length less than 15m) using gillnets in the coastal zone. In a pilot study in 2005, a number of coastal fishermen were interviewed to identify gear types associated with high incidental mortality of marine mammals. They identified three fisheries: the bottom-sett gillnets for anglerfish *Lophius piscatorius,* cod *Gadus morhua* and lumpsucker *Cyclopterus lumpus*. Harbour porpoise *Phocoena phocoena*, harbour *Phoca vitulina* and grey *Halichoerus grypus* seals were mentioned as the most frequently bycaught mammals. The fishery for lumpsucker has little fishing effort, a short season and restricted distribution. We therefore decided to focus on the fisheries for anglerfish and cod.

This is an attempt to model the bycatches in a monitored segment of the coastal gillnetter fleet and to extrapolate to entire gillnet fisheries for anglerfish and cod.

MATERIAL AND METHODS

Assembly of data

The coastal gillnet fisheries are carried out by small vessels less than 15 m total length. These vessels are usually not suitable for carrying an extra person as observer when at sea for multiple days. The Norwegian landing statistics for target species fish are good, and also effort statistics are good for the larger fishing vessels. However, for the fleet of small coastal vessels, there was a demand for improved statistics on the relationship between effort and catch of target species, sex, age and size distribution for target species and all non-target species of fish. Therefore, the Institute of Marine Research (IMR) contracted two fishing vessels in each of nine coastal statistical areas (Fig. 1) to provide detailed information on effort, catch of target and all non-target species, including marine mammals and birds. The contracted fleet is named Coastal Reference Fleet (CRF). Each CRF vessel has a contact person at IMR. These contact persons visit the vessels regularly and stay onboard on day trips at sea. Any discrepancies in statistics between days with and without IMR staff onboard may lead to termination of the contract.

Catch data from the monitored segment of the fleet, CRF

The CRF was contracted to target anglerfish and cod using the same gillnet type as the rest of the commercial coastal fleet (bottom-set gillnets with half mesh of 180 mm for anglerfish and bottom-set gillnets with half mesh of 75-105 mm for cod). The catches of anglerfish and cod taken by the CRF are shown in Tables 1 and 2. The reported incidental catches of harbour porpoise are shown in Table 3 and the approximate locations of the bycaught porpoises are shown in Fig. 1.

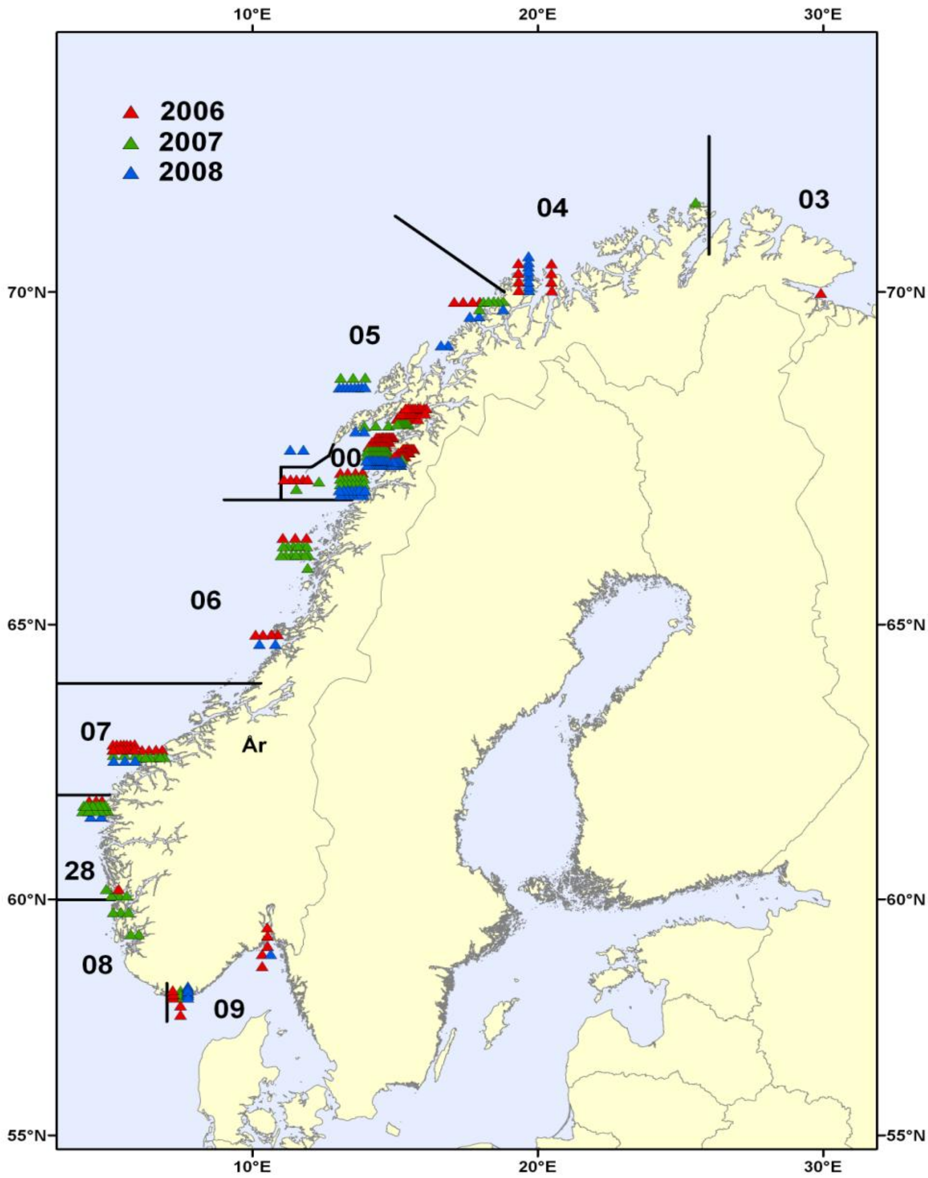

Fig. 1. Nine domestic Norwegian coastal fishery statistics areas and the distribution of porpoises caught on gillnets set for anglerfish or cod by the monitored segment of the fleet (CRF) in 2006, 2007 and 2008 (see Table 3 for numbers).

Table 1

Catches of anglerfish (kg) in 2006, 2007, 2008 taken on anglerfish nets by the monitored segment of fleet (CRF), by area listed from North to South.

Area	2006	2007	2008	Total
03	0	0	0	0
04	0	0	0	0
05	16 402	22 152	39 615	78 169
00	23 983	34 471	28 387	86 841
06	7 080	0	1 265	8 345
07	63 322	64 978	35 828	164 128
28	6 020	17 401	4 870	28 291
08	646	2 825	59	3 530
09	5 279	2 187	4 795	122 261
Total	**122 732**	**144 014**	**114 819**	**381 565**

Table 2

Catches of cod (kg) in 2006, 2007, 2008 taken on cod nets and unspecified nets by the monitored segment of fleet (CRF), by area listed from North to South.

Area	2006	2007	2008	Total
03	20 651	1 885	15 486	38 022
04	371 076	185 101	234 634	790 811
05	283 979	297 079	293 684	874 742
00	121 989	74 821	67 227	264 037
06	82 666	59 954	91 619	234 239
07	44 559	35 186	37 697	117 442
28	1 465	563	40	2 068
08	2 462	1 771	1 846	6 079
09	12 862	8 595	5 515	26 972
Total	**941 7 09**	**664 955**	**747748**	**2 354 412**

Table 3

Incidental catches of harbour porpoise by the monitored segment of the coastal gillnetting fleet (CRF).

Area	2006	2007	2008	Total
03	1	0	0	1
04	8	1	7	17
05	4	1	16	28
00	97	54	50	204
06	7	2	2	22
07	18	5	28	56
28	4	7	4	29
08	0	5	0	5
09	10	1	4	20
Total	**149**	**76**	**107**	**332**

Landings statistics from the entire fleet

Landings statistics are provided by the Directorate of Fisheries. These statistics are based on fish landed in harbours. The statistics are not specified by gillnet type and include therefore fish taken on all types of gillnet.

The main season for the anglerfish fishery is primarily in late summer and autumn. Landings of anglerfish taken on gillnets by the entire fleet of commercial vessels less than 15 m total length are shown in Fig. 2.

The fishing effort with gillnets for cod is large, in particular during the spawning season for cod in February-April in areas 00, 04 and 05 (Fig. 2). Nets of similar mesh size are used for multispecies fisheries for Gadoids along the entire Norwegian coast throughout the year, but with smaller effort. Landings of cod taken with cod nets by vessels less than 15 m total length are large in February to April and are relatively small during July to October.

Analytical approach

The catches by CRF generally followed the same seasonal and geographical patterns as the commercial fisheries (Fig. 2). However, the patterns deviated in some months and areas due to low catches by CRF (e.g., area 6 by the anglerfish fisheries). The low sampling effort in some months and areas increased the variability in observed bycatch rate by month and area (Fig. 2). For instance, the low angler fish catch by CRF in area 06 resulted in no bycatches in this area, despite high bycatch numbers in the neighbouring areas 00 and 07 (Fig. 2). To provide a robust bycatch estimate we aimed at avoiding strong influences of a few incidents on the predicted bycatch numbers. We therefore decided to perform the analyses at a coarser spatial and temporal scale than by month and statistical area. To model the geographic patterns, we combined neighbouring areas into a factor variable with four levels (hereafter referred to as *areas.comb*); level 1 consisted of areas 03, 04 and 05; level 2 of area 00; level 3 of areas 06 and 07; and finally, level 4 of areas 28, 08, and 09. Area 00 had elevated bycatch numbers in both fisheries relative to all other areas (Fig. 2). Therefore, only area 00 was included in *areas.comb* level 2.

We also tested a smoothed function of area, by simply using the relative position of each area along the coast (numbered from 1 to 9) as a continuous variable. In that way, the estimated bycatch rate in one area would borrow support from bycatch rates in neighbouring areas. However, this approach would also smooth bycatch rate between neighbouring areas with potentially very different catch rates, such as areas 05 and 00. To model effects of season, we chose to use half year (January – June, July – December) as a factor variable. There was a pronounced seasonal change in both fisheries, and the bycatch rates (i.e., harbour porpoise catches relative to fish catches) appeared to be higher in the second half than in the first half for both fisheries (Fig. 2).

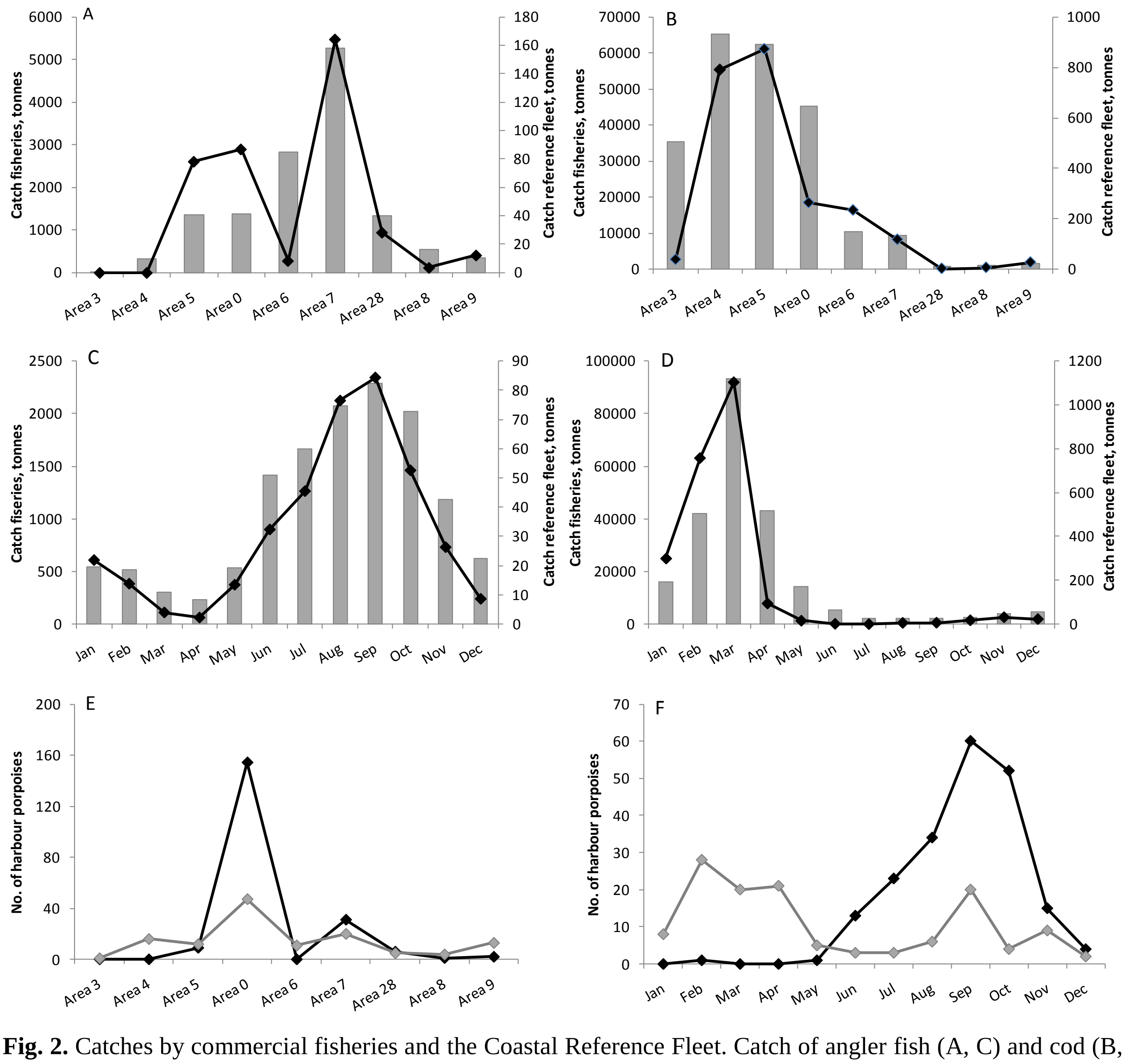

Fig. 2. Catches by commercial fisheries and the Coastal Reference Fleet. Catch of angler fish (A, C) and cod (B, D) by area and month. Catch of harbour porpoises by angler fish fisheries (black) and cod fisheries (grey) by area (E) and month (F).

The analytical approach was similar to the approach presented by Orphanides (2009). We used general additive models (GAMs) to model bycatch rates, where number of harbour porpoises entered as the response variable, and catch by the fisheries was entered as offset. We combined the data for both fisheries in the statistical analyses, and included type of fisheries (anglerfish or cod) as a factor variable. We did not attempt to include time x space interactions due to the low effort in several time x space combinations. However, we found the sampling sufficient to include the interactions time x fisheries and space x fisheries, in addition to main effects of fishery, time and space. Thus, the models combining the two fisheries included the following terms:

1. No. of harbor porpoises ~ offset(log.catch) + fishery + season + area + fishery * season + fishery * area

where season was included as half year, and area was included as areas with 4 levels, or as a smooth function of areas, s(area). For each approach all possible models nested within the models in equation 1, and the best models were selected based on Akaikes information criterion, adjusted for small samples, AICc. The model fit was further assessed by plotting predicted versus observed values and dispersion. Year was included as a random factor in initial analyses. However, a substantial increase in over-dispersion (Dispersion factors > 300) in these mixed models relative to models without year demonstrated a poor capability to estimate any random year effects. We therefore chose to use models without accounting for year effects.

We used the best model in the *predict.gam* function to predict the total number of bycaught harbour porpoises in the anglerfish and cod fisheries based on the catches by the commercial fisheries. However, in the CRF data, 9.85 % of the anglerfish were caught in cod nets, while < 1% of cod were caught in the angler fish nets. According to Fig. 3, there were no geographic or temporal patterns in the relative size of catches between net types. The catches from the commercial fisheries were not separated by net types. Thus, to reflect the anglerfish fisheries effort, we adjusted for catches of angler fish in cod nets by multiplying the total angler fish catches with 0.9. No such adjustment was required for the cod catches.

CV for the predicted numbers was obtained through bootstrapping as in Orphanides (2009). Three years of data, summed by fishery, month and area, yielded N=648 observations. In the bootstrapping procedure, we therefore randomly selected N=648 observations with replacement. We replicated this selection a 1000 times, and for each replicated set of selected observations we ran the best models and predicted the total number of bycatch. CVs were calculated in the resulting distribution of the predicted values.

All analyses were performed in R 2.10.1 (ref R team) with the mgcv library (Wood 2006).

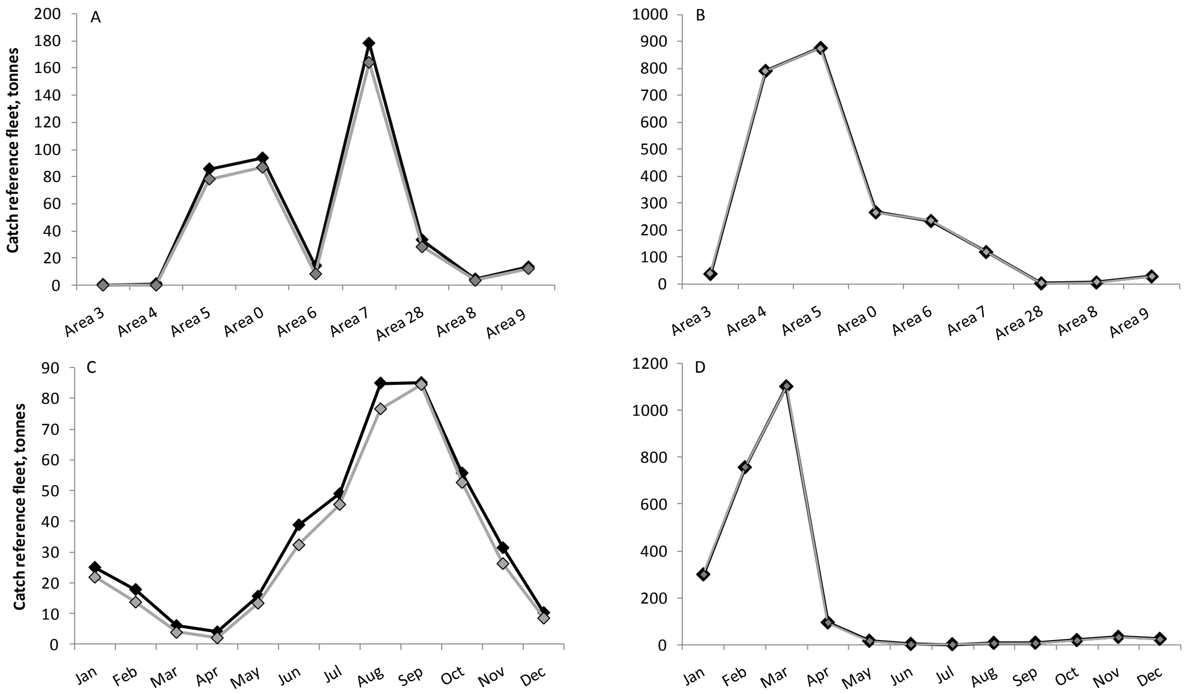

Fig. 3. Catch by reference fleet of anglerfish and cod, in anglerfish fisheries and cod fisheries, respectively. A and C: anglerfish catch in anglerfish nets (grey) and total catch (black), by area and month. B and D: cod catch in cod nets (grey) and total catch (black, almost completely overlapping).

RESULTS

The statistics for the different models are given in Table 4. The best model in terms of AICc was model 1.10, which included area as a factor variable with 4 levels, and the interaction fishery x areas and fishery x season. The model accounted for 53% of the deviance, and therefore that half of the variation in the observed bycatch rates could be explained by the predictor variables used. The scale parameter of 1.35 indicated that the Poisson approximation was relatively good. In accordance with the proportion of variance explained, the plot of observed versus fitted values from model 1.10 demonstrated that the model was able to produce the major trends, although with considerable variability between predicted and observed values (Fig. 4). The correlation coefficient between fitted and observed values was 0.70. The second best model was the corresponding model with the geographic patterns modelled as a nonlinear, continuous variable. This model accounted for 52% of the variation, with a scale parameter of 1.35.

Fig. 5 shows the total harbour porpoise bycatch by area and month, as predicted using the two best models (mod1.10 and mod2.10). Both models predict highest bycatch numbers in Area 00 and in spring. For the period 2006 – 2008, the total predicted number of harbour porpoise bycatch was 20,719 and 20,989 porpoises based on mod1.10 and mod2.10, respectively, with CVs 36.05% and 27.33%, respectively. Thus, the models predict annual bycatches of 6,900 harbour porpoises in the anglerfish and cod fisheries.

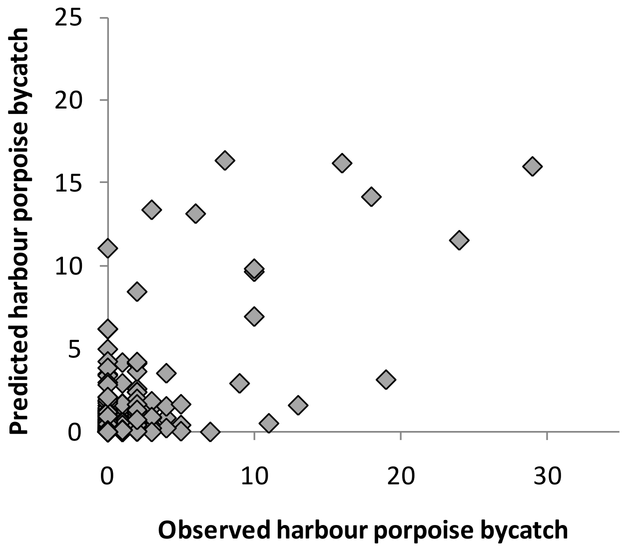

Fig. 4. Observed versus predicted bycatch numbers. Predicted values are from the best model (model 1.10).

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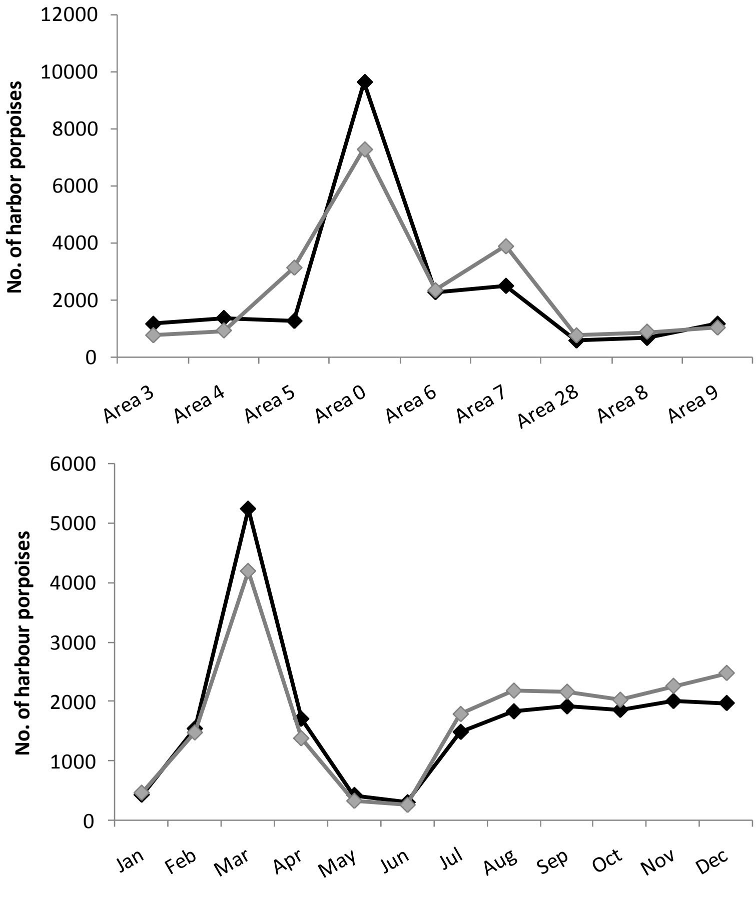

Fig. 5. Predicted harbour porpoise bycatches for the period 2006 – 2008 from two best models (model 1.10 in black, model 2.10 in grey) by area and month.

Table 4
Models tested for combined fisheries. Model in bold have the lowest AICc values.

	Model	DF	Dev expl.	Scale	AICc
Models with combined areas (4 levels) and season					
Mod1.1	offset(log catch) + factor(fishery)	2	0.22	2.17	1654.76
Mod1.2	offset(log catch) + factor(comb.areas)	4	0.31	1.92	1492.51
Mod1.3	offset(log catch) + factor(season)	2	0.3	1.95	1509.36
Mod1.4	offset(log catch) + factor(fishery) + factor(season)	3	0.31	1.94	1502.13
Mod1.5	offset(log catch) + factor(fishery) + factor(comb.areas)	5	0.42	1.63	1306.88
Mod1.6	offset(log catch) + factor(season) + factor(comb.areas)	5	0.49	1.41	1165.72
Mod1.7	offset(log catch) + factor(fishery) + factor(season) + factor(comb.areas)	6	0.49	1.42	1167.62
Mod1.8	offset(log catch) + factor(fishery) + factor(season) + factor(comb.areas) + factor(fishery):factor(season)	7	0.5	1.4	1158.09
Mod1.9	offset(log catch) + factor(fishery) + factor(season) + factor(comb.areas) + factor(fishery):factor(comb.areas)	9	0.52	1.35	1129.73
Mod1.10	**offset(log catch) + factor(fishery) + factor(season) + factor(comb.areas) + factor(fishery):factor(comb.areas) + factor(fishery):factor(season)**	**10**	**0.53**	**1.33**	**1117.54**
Models with s(areas) and season					
Mod2.1	offset(log catch) + factor(fishery)	2	0.22	2.17	1654.76
Mod2.2	offset(log catch) + s(areas)	7.0	0.28	2.02	1554.6
Mod2.3	offset(log catch) + factor(season)	2	0.3	1.95	1509.36
Mod2.4	offset(log catch) + factor(fishery) + factor(season)	3	0.31	1.94	1502.13
Mod2.5	offset(log catch) + factor(fishery) + s(areas)	7.9	0.39	1.71	1355.14
Mod2.6	offset(log catch) + factor(season) + s(areas)	7.8	0.47	1.49	1214.75
Mod2.7	offset(log catch) + factor(fishery) + factor(season) + s(areas)	8.8	0.47	1.49	1216.74
Mod2.8	offset(log catch) + factor(fishery) + factor(season) + s(areas) + factor(fishery):factor(season)	9.7	0.48	1.47	1202.7
Mod2.9	offset(log catch) + factor(fishery) + factor(season) + s(areas) + factor(fishery):s(areas)	14. 4	0.51	1.38	1151.93
Mod2.10	**offset(log catch) + factor(fishery) + factor(season) + s(areas) + factor(fishery):s(areas) + factor(fishery):factor(season)**	**15.14**	**0.52**	**1.35**	**1135.17**

DISCUSSION

Independent observer onboard is the recommended method to obtain bycatch statistics. The large number of small vessels less than 15 meter total length operating in the Norwegian coastal waters has been a challenge for monitoring marine mammal bycatch. There are about 7,000 of these small commercial vessels and most of them have limited possibility to carry an extra person when at sea for multiple days. The vessels contracted by IMR to report detailed information on effort, catch and bycatch are providing data that can be used to estimate bycatch rate (incidental catch per kg target species). In combination with landings statistics of the target species the bycatch rate can be extrapolated to bycatch estimates in entire fisheries.

This method for monitoring marine mammal bycatches is not ideal. A combination of contracted vessels and observers onboard other vessels (vessels that can carry an extra person), will improve the method. An automated video monitoring system during hauling of nets can be an alternative to onboard observers for providing independent information. Such systems are currently tested in Sweden and Denmark (Tilander and Lunneryd 2010; Kindt-Larsen and Dalskov 2010).

Small sample size (little fishing effort by CRF) in areas and periods where the commercial fleet has large effort, has the potential to introduce biases in the extrapolated bycatch. This can be compensated by increasing the number of vessels in the CRF.

The gillnet fishery for cod has a very large effort during the spring spawning season for cod. The same type of gillnets are used by some fishers for other species of gadoids during the rest of the year, but with significantly less effort. These fisheries are included in the current estimate. However, there are other gillnet fisheries not covered by this estimate. The small scale fishery for lumpsucker is deploying gillnets in shallow, nearshore waters and is likely to catch porpoises. There is also a small scale gillnet fishery for mackerel *Scomber scombrus* in the North Sea. Leisure fishers are also allowed to use gillnets in Norway. Therefore, the total incidental catches of harbour porpoise are likely to be larger than 6,900 per year.

According to the criteria advised by ASCOBANS, a population in excess of 400,000 is required to sustain an annual bycatch of 6,900 harbour porpoises. Both for conservation and animal welfare reasons this incidental take should be reduced. There are several methods to mitigate marine mammal bycatches including time area closures, modification of gillnets and acoustic alarm devises (pingers) (Proelss et al 2010; NMFS 1998; Trippel et al 1999; Gönener and Bilgin 2009). Pingers have proven efficient in several experiments. However, Palka *et al.* (2008) reported that the promising results of a pinger experiment that led to 92% reduction of harbour porpoise bycatches in 1994, had not transferred to the operational commercial fishery.

There are currently no porpoise bycatch mitigation measures in place in Norway. There is therefore a potential to reduce the incidental takes by implementing such measures. In collaboration with the fishers we will seek to find solutions that significantly reduce the incidental takes without a concomitant reduction in the catch of the target species.

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