Bycatches of harbour porpoises (*Phocoena phocoena* L.) in Danish set-net fisheries

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ABSTRACT

Data on bycatch of harbour porpoise (*Phocoena phocoena* L.) in the commercial Danish set-net fisheries were sampled from 5,591km nets in the period 1992 to 1998 using independent observers. A total bycatch of 325 harbour porpoises was reported. Cluster analysis was used to stratify the sampled fishing trips and official catch statistics into a number of different métiers defined by the target species for the trips. Extrapolation of the observed bycatch rate to total fish landings of the Danish set-net fleet gave an average annual bycatch of 6,785 (CV 0.12) for the North Sea fisheries in the period 1994-1998. Sampling was not sufficient to estimate total bycatch for other areas. Bycatch was observed in Kattegat but not in the Baltic Sea.

Generalised Linear Models were used to identify significant factors for bycatch in the North Sea. The bycatch rate, given as number per length of nets × soak time, was significantly lower in fisheries for flatfish compared to roundfish fisheries. The highest bycatch rate was in the cod fishery over wrecks and no bycatch was observed in the sole fishery. Significant seasonal variation of bycatch was identified with the highest bycatch rate in the first and third quarter of the year. Bycatch rates had not changed in the observed period and there was no significant difference in bycatch rates between sub-areas.

KEYWORDS: HARBOUR PORPOISE; INCIDENTAL CATCHES; EUROPE; GILLNETS; FISHERIES; STATISTICS

INTRODUCTION

Growing concern about the status of the harbour porpoise in the North Sea and adjacent waters (e.g. Bjørge *et al.*, 1994; Donovan and Bjørge, 1995) led to the establishment of the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS)) under the United Nation's Bonn Convention. At the first ASCOBANS meeting in 1994, the reduction of bycatch of small cetaceans was given high priority (Anon., 1994). Harbour porpoise bycatches mainly occur in set-nets (see e.g. IWC, 1996). The Danish set-net fisheries are the largest in the central and southern North Sea and thus have the potential for a high total bycatch.

In this paper, the term set-net is used to denote gillnets, tangle nets and trammel nets. Nets used are bottom set-nets and are anchored and operated on the seabed. In the North Sea area, the dominant species in the Danish set-net fisheries are cod (*Gadus morhua*), plaice (*Pleuronectes platessa*), sole (*Solea solea*), turbot (*Scophthalmus rhombus*) and hake (*Merluccius merluccius*); lumpfish (*Cyclopterus lumpus*) and common dab (*Limanda limanda*) are important species in Kattegat. In addition to the set-net fisheries, salmon (*Salmo salar*) is an important species fished in the Baltic Sea and caught using surface drift nets. Most often, individual species are targeted by species-specific gear types and only one species is targeted on a trip (Vinther, 1995). However, small vessels, mainly in the inner Danish waters (Skagerrak, Kattegat and western and eastern Baltic Sea) operate multispecies (trammel) set-nets, which often result in a mixed species landing. The Danish set-net fisheries had average annual landings of 45,500 tonnes fish in the period 1994-1998 (Fig. 1).

Several authors have considered the question of harbour porpoise bycatches in the eastern North Atlantic area (e.g. Andersen, 1982; Clausen and Andersen, 1988; Christensen, 1991; Clausen and Kinze, 1993; Kinze, 1994; Lowry and Teilmann, 1994). Based on interviews and voluntary reporting in 1980-1981, Clausen and Andersen (1988) estimated a considerable bycatch, particularly in the North Sea cod fishery over wrecks.

The importance of using independent observers to collect bycatch information has been recognised (e.g. Donovan, 1994; IWC, 1994) and in 1992, the Danish Institute for Fisheries Research (DIFRES) established a large-scale sampling programme for the set-net fisheries, using independent observers on board commercial fishing vessels. The North Sea sole fishery was sampled to quantify effort, fish landings and discards for use in fish stock assessment and similar sampling for fisheries data was continued in the cod and turbot fisheries in 1993. This programme revealed a substantial bycatch of harbour porpoise (Vinther, 1996). Bycatches of marine mammals were routinely recorded on all succeeding surveys. Sampling in the North Sea area has continued up to 1999 whilst the inner Danish waters have been sampled from 1995 and onwards.

This paper presents estimates of the total Danish bycatch of harbour porpoise based on the various sampling schemes during the period 1992-1998. Significant factors with respect to bycatches, such as season, fishery and area, are identified from statistical models.

MATERIALS AND METHODS

At sea sampling

Most of the data were obtained from surveys whose main objective was the sampling of fisheries data for stock assessment. Data were collected on fishing activity (fishing location, depth, bottom type, gear specifications and date and time for shooting and hauling of nets), fish catches (species, numbers, weight and length of both landings and discards) and harbour porpoise bycatch (minimum catch number and, where possible, length, sex and other measurements). Table 1 gives an overview of sampling schemes.

The basic sampling unit was nets fishing on the same location. A unit might comprise as little as 150m of nets in cases where fishing was carried out over shipwrecks or stone reefs. For other fishing grounds, a string of nets might often exceed one kilometre.

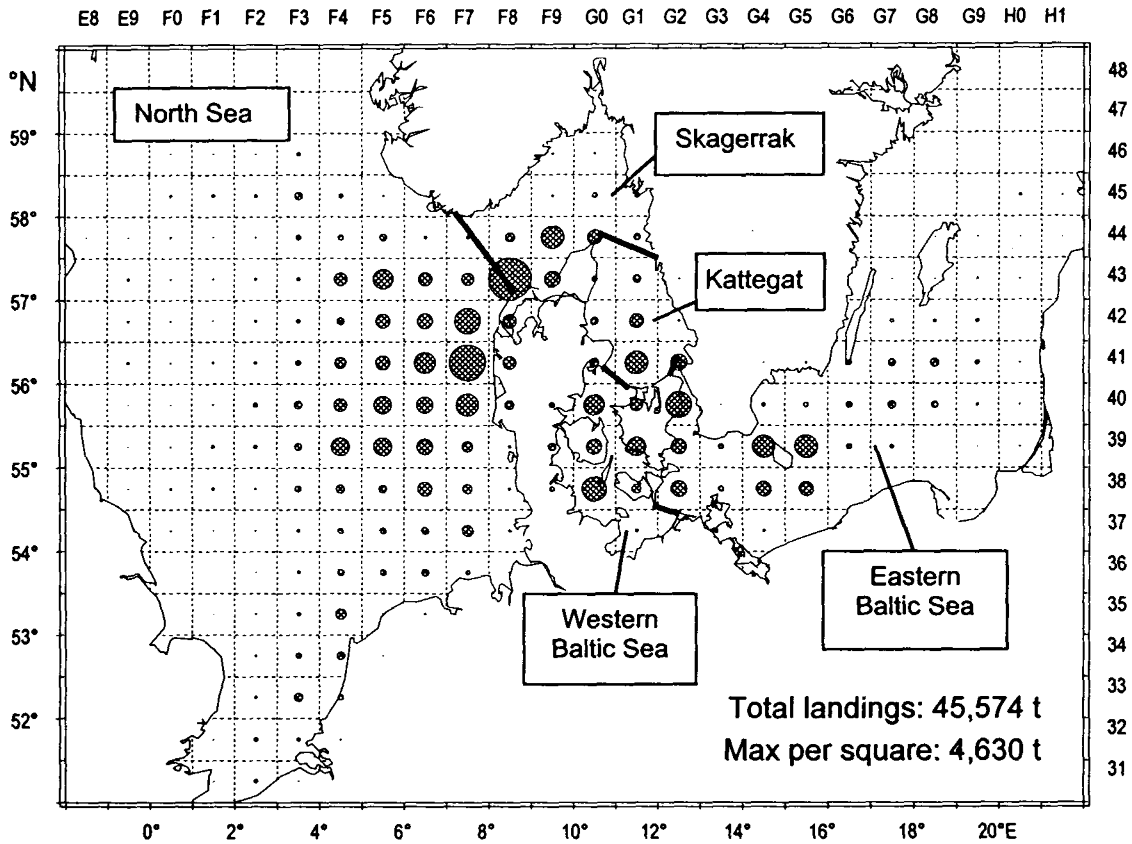

Fig. 1. Average annual Danish set-net landings, 1994-1998. Landings weight by ICES rectangle are given by the area of the dots.

In the beginning of the sampling period, vessels were organised by direct contact with skippers and no compensation was paid for having an observer onboard. Later, a more formal collaboration between the Fishermen's Association and DIFRES was established. Vessels for sampling were then selected from a list provided by the Fishermen's Association and the skippers were paid 400DKK (around £40) per day at sea monitored by an observer. It has always been voluntary for the skippers to participate.

Analysis of bycatch rates

Generalised linear models (GLMs) and Generalised additive models (GAMs) were used to identify significant factors for bycatch. GAMs are a complement to GLMs and use a nonparametric technique for fitting a regression function in a flexible data defined manner (see, e.g. Chambers and Hastie, 1992).

The number of harbour porpoises in a sampling unit was modelled assuming a Poisson probability response and log link function. The significance of a model term was assessed by an F test of the difference in model deviance for models with and without the term. For overdispersed Poisson models, the dispersion parameter was assumed to be given by the Pearson's chi-square statistics divided by the degrees of freedom. Statistics such as standard errors of type III means for each model term were adjusted appropriately.

A robust Poisson regression (Heiberger and Becker, 1992) and GLMs with negative binomial distribution and log link were used as an alternative where Poisson models fitted extremely badly, due to very patchy distribution of the bycatch. The parameter θ, used in the variance estimator ($var(Y) = \mu + \mu^2/\theta$) for the negative binomial distribution, was found by maximum likelihood estimation (software from Venables and Ripley, 1994).

Data from the North Sea only were analysed because of the limited sampling and bycatch in other areas. The fisheries have distinct seasons and catch areas that made the sampling and dataset for analysis highly unbalanced. In addition the length of nets in a sampling unit and the soak time are not fishery independent. Model complexity has thus been kept to a minimum and models analyse only the effect of target species, year, season, depth, fish catches and area. Data were too sparse to analyse by individual year and instead the models tested for differences between the two periods, 1992-1995 and 1996-1998. Two area definitions were tried in the models: a north-south sub-area (borderline at 55°5'N) and one where the northern area was divided further into an eastern and western part at 5°E. Area definitions were based on the overall spatial variation in

Table 1

Overview of sampling schemes on the Danish set-net fisheries.

Period	Target species	Area	Main purpose
1992	Sole	North Sea	Fisheries data collection
1993	Cod	North Sea	Experimental fishery: 'Cod quota in numbers'
1993-1994	Cod and turbot	North Sea	Fisheries data collection
1994-1995	Salmon	Eastern Baltic Sea	Stomach sampling
1997	Cod	North Sea	Experimental fishery: 'Effect of acoustic alarms'
1995-1998	Cod, flatfish and lumpfish	Skagerrak, Kattegat and the Baltic Sea	Fisheries data collection
1995-1998	Cod, plaice, turbot, hake and sole	North Sea	Fisheries data collection

bycatch, but the unbalanced data limited the use of a large number of areas. For numerical model terms, linear and quadratic regression and scatterplot smoothers were tested. The sole fishery had no observations of bycatch and was not included in the analysis. Sampling in the hake fishery comprised two trips only and these data were also excluded from the analysis.

The length of net of each initial sampling unit varies from 150m up to more than 20km, with the shortest length in the cod-wreck fishery and the longest in the turbot fisheries. This difference is mainly due to different fishing practice but in a few cases, samples included nets from one day's fishing and not as intended, data from an unbroken string of nets. To balance the length of nets in each sampling unit, and to reduce variance of bycatch rate; data from consecutive sampling stations for a trip were aggregated up to a length of 5km net, which is the mean of the total length of net used on a trip in the cod-wreck fishery. For trips covering more fisheries or areas, this aggregation was made for each combination. Effort expressed as length of nets or length of nets × soak time (km×h) was used as an offset variable; that is, a regression variable with a constant coefficient of one for each observation. The use of an offset variable ensures a one-to-one relationship between effort and bycatch, which seems the most reasonable, considering the aggregation of individual samples.

The North Sea cod and turbot fisheries have been sampled most intensively, and in thus separate models were also developed to analyse the data for these two fisheries using both the individual and aggregated samples as input.

Fisheries statistics

Fisheries statistics used for extrapolation of the observed bycatch are compiled by the Danish Directorate of Fisheries and are based on sales notes from the first-hand sales, together with the logbook information for the fishing trips. Information on all Danish commercial fishing vessels is available from a vessel register administrated by the Danish Directorate of Fisheries.

Logbook sheets

The logbook sheet is a formula to be completed by the skipper during the fishing trip. It holds information on vessel, fishing gear, fishing area (ICES statistical rectangle) and estimated catches of the landed fish. Fishermen with a vessel with overall length less than 10m are exempted from submitting a logbook when landing in a Danish port, provided they submit a declaration giving the fishing area.

Sales note

The information stored in the sales note database includes species, quantity and price in addition to vessel identification, date and place of landings. Information on fishing area is supplied by linking the sales note with the logbook from the fishing trip during which the fish were caught.

Vessel register

The vessel register includes information on vessel size, engine power and vessel category (e.g. trawler, purse seiner, netter). The categories recorded include a number of multi-purpose vessels such as trawler/netter or seiner/netter, such that the default gear cannot be predicted from the vessel information. From 1992, all commercial vessels with an overall length of 6m or more were included and from 1995, all commercial fishing vessels were included in the vessel register.

Datasets used

The databases contain confidential data and DIFRES does not have direct data access. A merge and extract of the three main official data sources was therefore used to obtain the following information for each fishing trip:

(a) coded vessel identity and vessel characteristics (from the vessel register);
(b) gear information (from logbook);
(c) date of the landing (from sales notes and logbook);
(d) landed weight and value by species and ICES rectangle (quantity from sales notes and spatial information from logbooks).

Set-net landings were defined as landings from vessels where set-nets were used according to the logbooks. Landings from small vessels without logbook information were assumed to be taken by set-net if the vessel category was 'set-net vessels' or 'small boats'. DIFRES does not have access to the database that includes fishing area for the small vessels and catch area for this vessel group was defined by the location of the landings harbour. Landings by species from small vessels were distributed on ICES rectangles proportionally to landings from the larger vessels.

The official fisheries statistics used for extrapolation do not include data from the recreational fishery for which fishing with up to 135m nets is permitted. The extent of the recreational fishery is limited in the North Sea area, but is more common in inner Danish waters.

Cluster analysis was used to classify trips with logbooks into fisheries (métiers) defined by target species. Each trip in the period 1994-1998 was classified into groups with homogeneous species compositions based on the relative landings value of the 13 most common species. Relative value and not weight was used as input, to reflect the fact that fishermen try to optimise the economic outcome of a trip and not necessarily the quantity landed. Data from the trips with observers, where target species and gear were known, were also included in the cluster analysis to evaluate the efficiency of the classification.

More than 65,000 fishing trips are performed per year and such a large dataset prevented the use of hierarchical cluster analysis. Instead, a disjoint cluster analysis based on Euclidean distances was performed for each sea area separately, using the SAS procedure 'fastclust' (Anon., 1989). The analysis was carried out in two steps to prevent outliers from distorting the results. The first step produces a number of 'seeds' which are used in the second step to form the initial clusters. Outliers were detected in the second step by setting a maximum Euclidean distance between cluster means and observation for inclusion of an observation.

Estimation of total fleet bycatch

Two methods were applied to extrapolate the observed bycatch rates to total fleet level. The first method uses the parameter estimates from the GLM/GAM analyses of bycatch per unit effort to predict bycatch for the total fleet. In the calculation of the total fleet's effort it was assumed that target species landings per unit effort for the sampled vessels and the total fleet were equal for a given fishery and season, such that total fleet effort can be derived from the official total fleet landings.

The second method used is an extrapolation of the observed bycatch per landed weight of target species to the total fleet's target species landings. Variance of both fish catches and bycatch numbers and a possible co-variance contribute to the variance of the bycatch rate and the bootstrap method (Efron and Tibshirani, 1993) was used as a simple way to provide estimates of the confidence interval for the mean bycatch rate for each individual stratum. One thousand samples of coherent target species landings weight and bycatch number, each of the same size as the observed data, were drawn by Monte Carlo sampling with replacement from the observed data. For each sample, the mean bycatch rate was calculated as the sum of bycatch numbers divided by the sum of landings weight. The 95% confidence interval of the mean is given from the bias-corrected and accelerated method (Bca; Efron and Tibshirani, 1993).

Both methods require implicitly that the observed fish catch per unit effort (CPUE) is constant in the observed period and a GLM analysis was used to test significance of the sampling year for CPUE. The analysis was carried out separately for each fishery using the observed CPUE per trip in a model that included the terms year, quarter and area.

RESULTS

At sea sampling and bycatch

In the period 1992-1998, observers have been on board 331 fishing trips monitoring the catch and bycatch from 5,591km nets. Sampling was most intense in the North Sea cod and turbot fisheries, where on average 4.0% and 8.7% of one year's landings were monitored. For other areas and fisheries, the sampling level has been much lower, typically less than 0.5% of one year's total landings. Detailed information on bycatch and sampling activity together with landings statistics for the Danish fleet are given in Table 2.

Table 2

Mean annual landings and effort for the total Danish set-net fleet in 1994-1998 and total sampling activity and by-catch numbers for 1992-1998.

	Total fleet				Survey			
Area and Fishery	Season, quarter of the year	Target species landings (tonnes)	Total landings (tonnes)	No. trips	No. sampling stations	Target species landings (tonnes)	Length of nets (km)	No. harbour porpoise
North Sea								
Cod	1	3,446	3,819	16	229	64.7	307	36
	2	2,063	2,353	12	173	42.8	160	4
	3	2,560	2,931	55	638	186.3	1,076	83
	4	2,747	3,006	25	357	140.4	791	17
Hake	2-3	289	548	2	32	3.1	122	4
Plaice	1	1,846	2,218	4	38	43.2	316	21
	2	1,520	2,064	6	27	7.7	135	0
	3-4	689	844	1	1	0.1	1	0
Sole	2	528	926	12	37	3.8	322	0
	3	303	398	2	8	1.5	259	0
Turbot	2	281	480	12	109	24.3	936	78
	3	71	124	5	41	6.2	301	77
Other	1-4	-	572	-	-	-	-	-
Small vessels	1-4	-	2,500	-	-	-	-	-
Total			22,784	152	1,706	524.3	4,726	320
Skagerrak								
Cod	1-4	3,109	3,604	-	-	-	-	-
Hake	1-4	90	202	2	16	0.4	8	0
Plaice	1-4	993	1,300	-	-	-	-	-
Sole	1-4	25	88	-	-	-	-	-
Other	1-4	-	196	-	-	-	-	-
Small vessels	1-4	-	1,032	-	-	-	-	-
Total			6,421	2	16	0.4	8	0
Kattegat								
Cod	1-4	269	317	11	11	1.0	19	0
Mixed species	1-4	829	829	55	58	6.4	173	1
Lumpfish	1-2	201	216	10	13	2.8	40	4
Small vessels	1-4	-	1,627	-	-	-	-	-
Total			2,989	76	82	10.2	232	5
Western Baltic Sea								
Cod	1-4	1,983	2,231	33	56	6.1	109	0
Mixed species	1-4	556	556	15	29	1.6	38	0
Lumpfish	1-2	79	90	3	3	0.5	7	0
Small vessels	1-4	-	2,330	-	-	-	-	-
Total			5,206	51	88	8.2	154	0
The Sound and eastern Baltic Sea								
Cod	1-4	5,202	5,381	45	86	15.9	212	0
Herring	1-4	437	442	-	-	-	-	-
Other	1-4	258	258	-	-	-	-	-
Salmon	1-4	252	266	5	13	-	260	0
Small vessels		-	1,897	-	-	-	-	-
Total			8,245	50	99		472	0

Fig. 2 shows the spatial distribution (by ICES rectangles) of sampling sites and bycatch rates and Fig. 3 gives the distribution of sampling sites and total feet landings by fishery.

The mean vessel size is bigger in the North Sea than in the inner Danish waters and the size of the monitored vessels follows that pattern. Small vessels do not provide the same favourable working conditions for the observer as the bigger

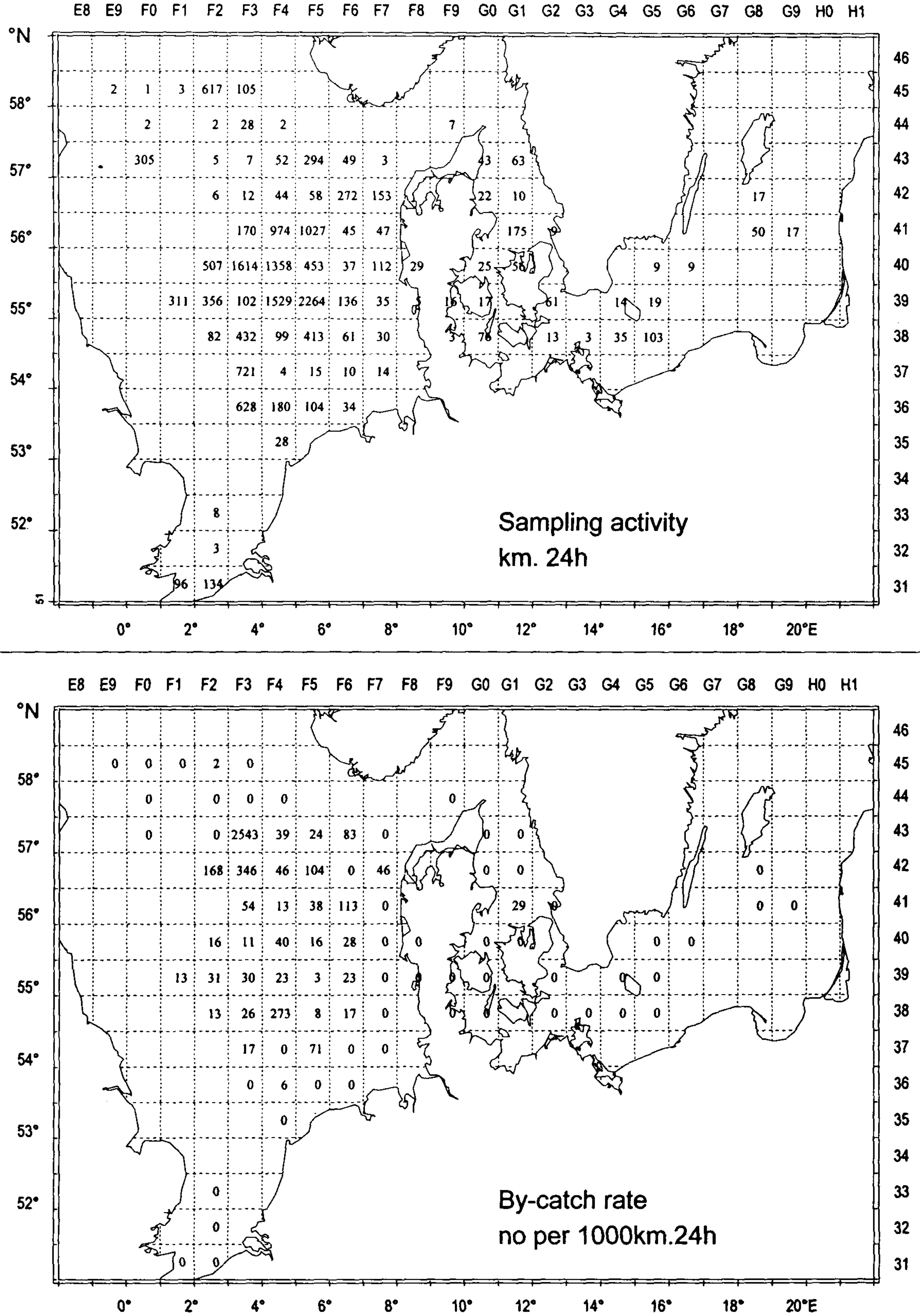

Fig. 2. Sampling activity given as km net × soaktime and observed bycatch in the Danish set-net fisheries, 1992-1998.

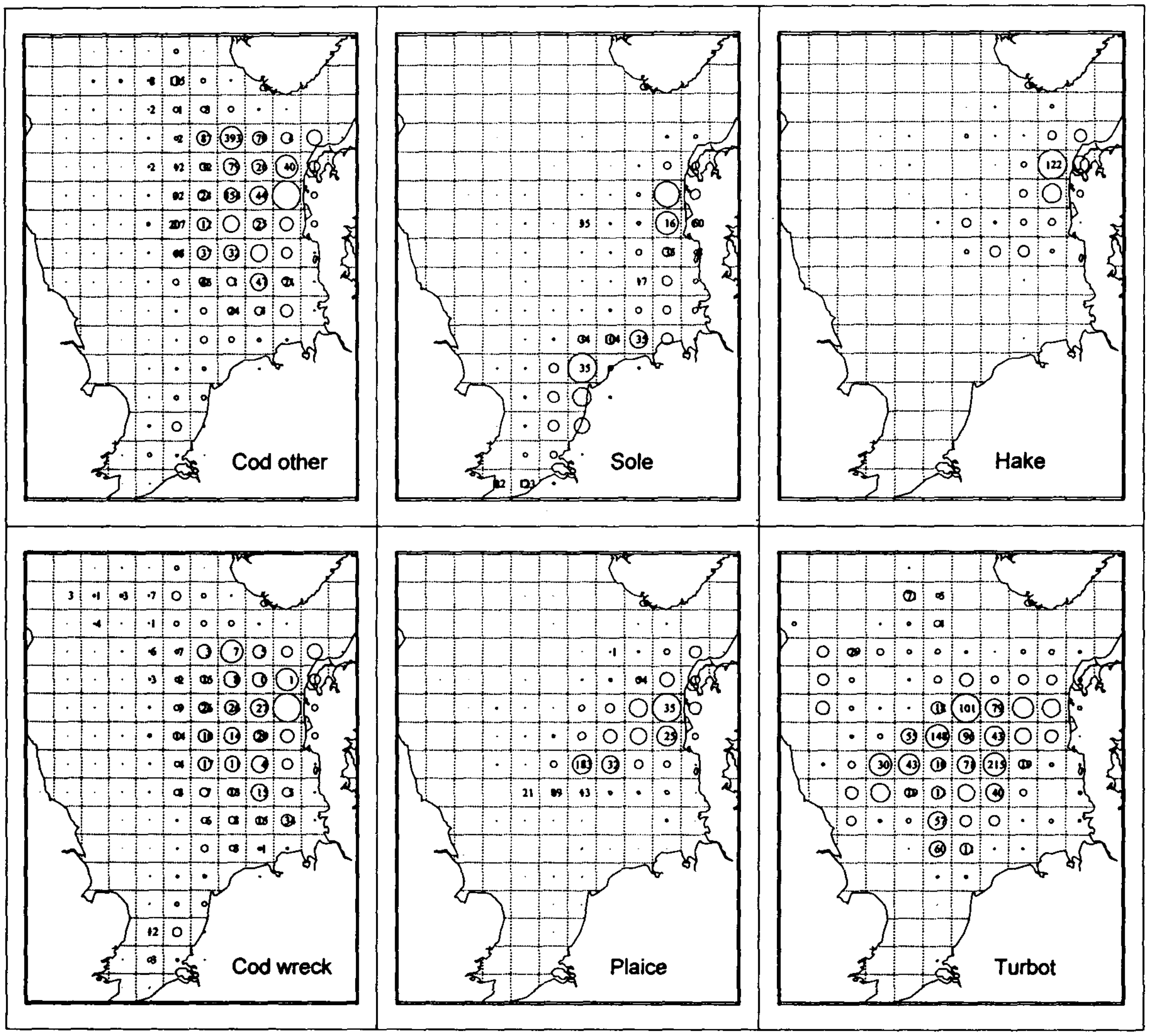

Fig. 3. Sampling activity given as km net (text) and total fleet landings weight of target species (area of the dots) for the North Sea set-net fisheries.

ones, and too few small vessels, fishing in the coastal waters of the North Sea, have been sampled. Both coastal and open sea areas have been sampled proportionally to the total fleet's catches in the inner Danish waters.

The gear used and the mean observed soak time during the survey agree with normal fishing practice in the particular area (Table 3). The mean mesh size observed in the North Sea plaice fishery (161mm) is, however, somewhat larger than the average mesh size in the fleet which is around 140mm.

There were 325 harbour porpoises reported in the sampling programme, mainly in the North Sea turbot and cod fisheries, where most of the sampling took place (Table 2). In Kattegat, three trips in March and April 1997 had a total bycatch of five porpoises of which four were taken in the lumpfish fishery. No porpoises were caught in the Baltic Sea. All harbour porpoises, except one, were dead on hauling. One *Lagenorhyncus* spp. was taken in the North Sea but no other marine mammals were caught.

The sampled North Sea cod and turbot fisheries had total bycatches of 140 and 155, respectively. For the cod fishery, 63% of the trips had no bycatch; 14% had one porpoise; 18% had 2-5 porpoises and 5% had a bycatch greater than 6 porpoises. The highest bycatch number on a trip in the cod fishery was 27 porpoises. Another trip had the highest bycatch rate of 13 porpoises in 0.6km nets fishing over a wreck. For the turbot fishery, 4 out of 17 trips had no bycatch. Seven trips had less than 10 porpoises per trip and five trips had a bycatch of 10-15 porpoises. The skipper prohibited the observer recording accurately the very high bycatch on one trip where 50 animals were caught.

Fisheries statistics

In most cases, the cluster analysis classified the sampled trips into fisheries in a similar way to that predicted by the skipper before the trip and as recorded by the observer on board. For the North Sea and the eastern Baltic Sea area, the classifications were identical, but for western Baltic Sea and Kattegat misclassification occurred, mainly in the mixed species fisheries from small vessels. On a few trips in the North Sea, two different species were targeted using species specific gears and catch and bycatch information was obtained separately from each part of the trip. Table 2 gives the landings statistics for each of the fisheries defined by the cluster analysis. Landings of target species comprise in most cases more than 80-90% of the total landings. The cluster analysis gave six clusters as the best estimate for both the western Baltic Sea and Kattegat. Two clusters only (cod and lumpfish) were considered as single species fisheries and the rest were combined into one 'mixed species fishery' group.

Table 3

Values of the gear characteristics observed on surveys.

	Mesh size (mm)		Net depth	Soak time (hours)	
Area and fishery	Mean	CV%	(meshes)	Mean	CV %
North Sea					
Cod	170	8	24.5-30.5	18	53
Hake	126	8	30.5-40.5	18	42
Plaice	161	28	9.5-14.5	82	106
Sole	105	10	11.5-14.5	18	102
Turbot	267	8	6.5-7.5	244	102
Kattegat					
Cod	125	25	-	17	55
Mixed species	107	37	11.5-20.5	25	106
Lumpfish	256	4	8.5-10.5	77	90
Western Baltic					
Cod	124	25	20.5-22.5	26	48
Mixed species	135	10	10.5-25.5	24	10
Lumpfish	270	0	6.5-10.5	1557	66
Eastern Baltic					
Cod	131	16	22.5-30.5	25	55
Salmon	160	-	40.5-45.5	10	-

Table 4

Overview of GAM (Poisson distribution and log link) analyses.

Model 1
Fisheries: cod-wreck, cod-other, plaice and turbot
Aggregation of data: Up to 5km nets
Model: bycatch = s(day,6) + fishery
Offset: net length Dispersion parameter = 2.48
Null deviance 991 on 560 df
Residual deviance 753 on 551 df
Test of single term deletion from full model (type III test):

Term	Df	Deviance	F value	Prob (F)
-fishery	-3	-60	7.2	< 0.0001
-s(day,6)	-6	-184	12.4	< 0.0001

Model 2
Fisheries: cod-wreck, cod-other, plaice and turbot.
Aggregation of data: Up to 5km nets
Model: bycatch = s(day,6) + fishery
Offset: net length * soak time Dispersion parameter = 2.08
Null deviance 1077 on 560 df
Residual deviance 691 on 551 df
Test of single term deletion from full model (type III test):

Term	Df	Deviance	F value	Prob (F)
-fishery	-3	-122	17.7	< 0.0001
-s(day,6)	-6	-246	19.7	< 0.0001

Model 3
Fisheries: turbot. Aggregation of data: None
Model: bycatch = quarter +depth +s(soaktime,4)
Offset: net length Dispersion parameter = 1.55
Null deviance 306 on 136 df
Residual deviance 189 on 130 df
Test of single term deletion from full model (type III test):

Term	Df	Deviance	F value	Prob (F)
-quarter	-1	-36.7	23.5	< 0.0001
-depth	-1	-9.3	6.0	0.0158
-s(soaktime)	-3.9	-47.1	7.8	< 0.0001

Landings from small vessels without logbooks comprise more than one third of total landings in Kattegat and the western Baltic Sea. The species compositions of landings from small vessels in the North Sea area indicate that a considerable part of the landings come from the surrounding brackish water inlets, such that the small vessel's landings from the North Sea proper are less than 5-8% of the total.

Lumpfish are mainly fished in the spring for their roe and are in some cases recorded by sex using different names in the sales note database. DIFRES's extract of the databases mistakenly has only the male lumpfish recorded as lumpfish and the more plentiful landings of the females are lumped into a group of 'other species'. Data extraction has been very time consuming due to the Directorate of Fisheries' obsolete IT equipment, and re-extraction of data was not done. According to the official landings statistics (Anon., 1997) based on vessel category, the average Kattegat lumpfish landings from gillnet vessels is a factor of two higher than given in Table 2.

Two different fishing practices are used in North Sea cod fishery. Nets can either be set in larger quantity over smooth bottom (sand, gravel, stone etc.) where the concentration of fish most often is low, or over small spots, mainly shipwrecks, with a high concentration of large cod. Modern navigation equipment makes it possible for the fishermen to place short strings of nets over or very close to a wreck. The exact landings from each of the fishing practices are not known, but about half of the cod set-net landings in the North Sea are estimated to come from the wreck fishery (Støttrup and Stockholm, 1997). Fishing over wrecks is less important in inner Danish waters.

For all fishing areas, the total effort (days absent from harbour) and landings from set-nets has decreased in the most recent years, although some local fisheries have increased. The weight of total landings from set-net fisheries in the North Sea varies by 16% in the period 1994-1998, but for the individual fisheries the changes are much larger. The North Sea sole, hake and turbot landings have decreased to about one third of the landings in 1994 and plaice landings are reduced to less than a half. The cod fishery has, however, increased landings by 45% since 1994.

Analysis of bycatch rates in the cod, plaice and turbot fisheries

The GLM analysis of bycatch in the North Sea fisheries shows that season and fishery are significant model terms, but area, fish catches, depth and year effects are not significant. Season effect was modelled both as a continuous (day of the year) variable using a scatterplot smoother (Table 4, model 1) and as a quarter of the year factor. Both season terms are significant but the model with a continuous time variable fitted significantly better. The scatterplot smoother can be thought of as a running average where the degree of freedom used for smoothing defines how wide a window is used in the smoothing process. With a degree of freedom of six, the season effect curve is reasonably smooth. An increase in the degree of freedom increases the model deviance significantly, but creates unlikely local deviations in the estimated season effect.

The turbot fishery has a significantly higher bycatch rate compared to the other fisheries, when effort is given as length of net (Fig. 4a; Table 4, model 1). For the model with effort given as km×h (Table 4, model 2), the bycatch rate is significantly higher in the fisheries for roundfish than those for flatfish (Fig. 4c). Season effect is similar for the two models and the highest bycatch rate is estimated in the first and third quarter of the year (Fig. 4b), with the most narrow confidence limits for the third quarter estimate. When soak time is included in the effort term, the peak in season effect in the beginning of the year decreases as a result of the relatively longer soak time used in the colder water in that period.

Although the model with soak time included in the effort term has a slightly better fit, both models exhibit a very skewed residual distribution; the high dispersion parameter (Table 4) found in both models pointed out that the variability in bycatch numbers is greater than expected from a Poisson variable. It is the high bycatch observations that cause problems and a robust Poisson regression, where the high bycatch 'outliers' are downweighted, gave an approximately 25% reduction of the estimated dispersion parameter. The significant parameters are identical for both types of the Poisson GAMs and the parameter estimates are also similar. The minor differences in parameter estimates for the two types of Poisson GAMs seem to be caused mainly by three trips in the first quarter where two trips in the cod fishery and one in the plaice had very high bycatches. Compared to the standard Poisson regression, the robust version gave a slightly higher parameter estimate for the plaice fishery and a little lower estimate of the first quarter effect.

Although it might be thought that the very patchy bycatches might be better handled by the negative binomial distribution, a GLM with that distribution did not really improve the overall model fit. Software for GAMs with a negative binomial response variable is not available and the comparison between the result of the Poisson GLM with a quarter of a year factor as time variable and the result from a similar negative binomial regression showed almost identical parameter estimates.

The models that included all fisheries (Fig. 4a) does not show a significantly different bycatch rate for the cod-wreck and the cod-other fisheries, and separate models for the cod fisheries alone confirm this result. Soak time and season are the only significant model terms when length of net is used as an offset and effort variable. Bycatch rate is highest in the third quarter and increases with increasing soak time. This result is consistent for analysis on both individual sampling units and on aggregated data. The models fitted poorly with very skewed distribution of deviance residuals and a large dispersion parameter, especially for the most aggregated data. Two trips with very high bycatch have a large influence on the estimated dispersion parameter and some influence on the estimated season effect.

Although the two kinds of cod fisheries use the same kind of gear, the fishing practice differs considerably. The cod-wreck fishery uses 1-3 strings of nets over or close to a wreck, with a mean total net length of 0.4km. Individual strings fish often with a space of only a few meters. The other type of cod fishery uses a much longer string of nets with a mean length of 4km. Soak time in both fisheries is related to the water temperature, but soak time is relatively shorter in the wreck fishery. To overcome this correlation in the 'independent' model terms, separate models for the two fisheries were tried.

In the cod-wreck fishery, 34 out of 35 porpoises were caught in August-October and all porpoises were caught north of 55°5'N. A chi-square test for independence of absence/presence of bycatch in a sample showed a significant association between bycatch and area or season.

The seasonal distribution of bycatches is more regular for the cod-other fisheries but Poisson GLMs fitted badly and the significance of the model parameters depends on the inclusion of data from one high bycatch trip. Moreover, the significant parameters differ between the standard Poisson and the robust regression. The only consistent significant parameter was the catch rate of cod. CPUE for cod was modelled as a factor, higher or lower CPUE than median of catch per km×h; the low CPUE group has the highest bycatch rate.

Observations north of 57° N were excluded from the turbot fishery analysis as these observations make a remote group themselves (Fig. 3) and the unbalanced sampling did not permit an analysis of area/depth effect. The final model for the turbot fisheries includes the significant terms depth, soak time and quarter of the year (Table 4, model 3; Fig. 5), where depth is the less significant term. Depth modelled as a second order polynomial fitted equally as well as the linear relation. The bycatch rate was highest in the third quarter, decreased with depth and increased with soak time up to a level of 12 days.

Total fleet bycatch

The bootstrap estimates of mean bycatch number per landed weight of target species are given in Table 5. The distributions of the replicated variance are in most cases symmetric and close to the normal distribution. Data from the first quarter cod fishery do however produce multimodal distributions.

The two estimates of the stratified mean annual bycatch in the North Sea cod fishery are not significantly different (Table 5). The highest estimate of bycatch and CV are obtained when the stratification is done by each quarter independently of fishing practice. The analyses indicated that season effect is different for the two cod fisheries. If this result is used in the stratification, the lowest CV is obtained and the mean bycatch rate is 272 (CV 20%) porpoises per 1,000 tonnes landed cod or 2,942 porpoises per year for the total fleet (Table 6).

Table 5

Bootstrapping estimates of by-catch numbers per 1,000 tonnes landed target species. The stratified mean is weighted by mean landings of target species.

Fishery	Quarter and fishing method	Mean	95% BCa CI	CV %
Cod all	1	558	150-2,079	67
	2	95	22-306	62
	3	447	299-754	22
	4	123	75-05	26
	Stratified	333		37
Cod	1, 2 and 4, wreck	34	9-89	49
	3, wreck	508	198-1,289	46
	1 and 3, other	573	375-1,140	29
	2 and 4, other	177	104-307	27
	Stratified	272		20
Turbot	2	3,229	2,264-4,611	18
	3	12,409	7,508-20,607	27
	Stratified	5,080		16
	2 and 3	5,082	3,846-7,340	17
Hake	3	1,332	310-4,139	59
Plaice	1, 2 and 3	412	248-648	24

Table 6

Estimated mean annual by-catch number of harbour porpoise in the Danish North Sea set-net fisheries, 1994-1998. Sampling level is given a percentage of annual target species landings in the fleet.

	GAM prediction	Bootstrap estimate		
Fishery	Bycatch	Bycatch	CV	Sampling level (%)
Cod	3,530	2,942	0.20	4.0
Hake	-	385	0.59	1.1
Plaice	1,478	1,670	0.24	1.3
Sole	-	0	-	0.6
Turbot	1,748	1,788	0.16	8.7
All	-	6,785	0.12	3.1

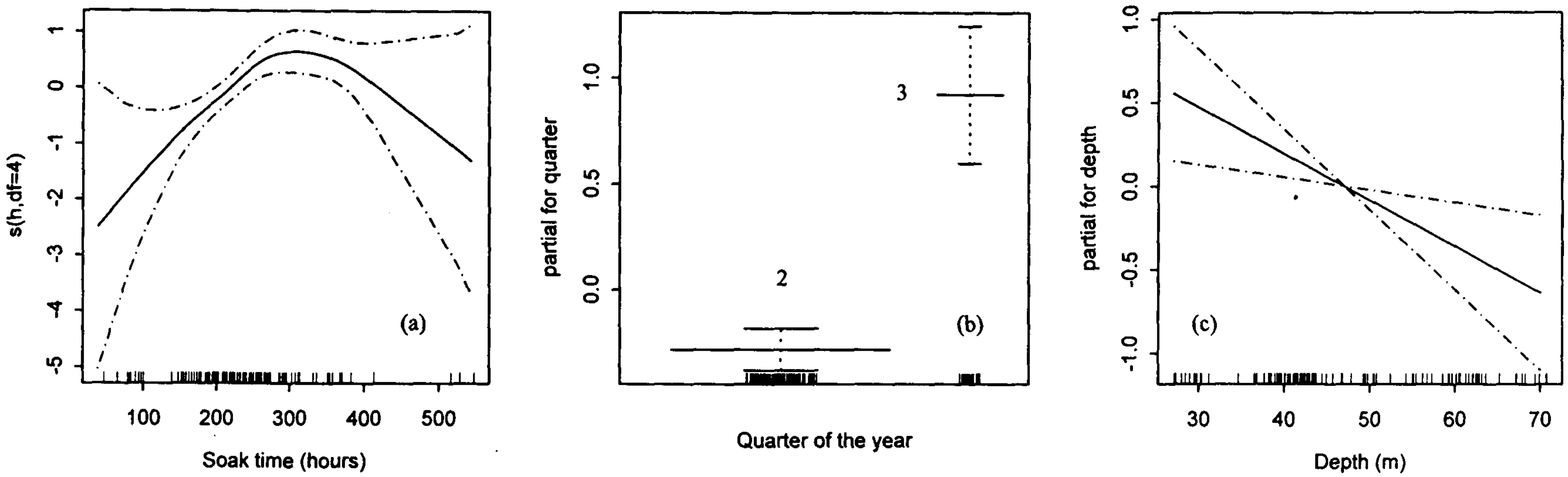

Fig. 4. Partial fits for GAMs of bycatch rates per length of nets with respect to (a) fishery and (b) season. Plot (c) gives effect of fishery in a similar model where effort is given as length of nets × soak time. The dashed curves are upper and lower pointwise twice-standard-error bands. s(day, df = 6) indicates a smooth function of a calendar day counter with 6 degrees of freedom. The y-axis gives log values and is scaled to zero. Rugplot on the x-axis indicates location and number of observations.

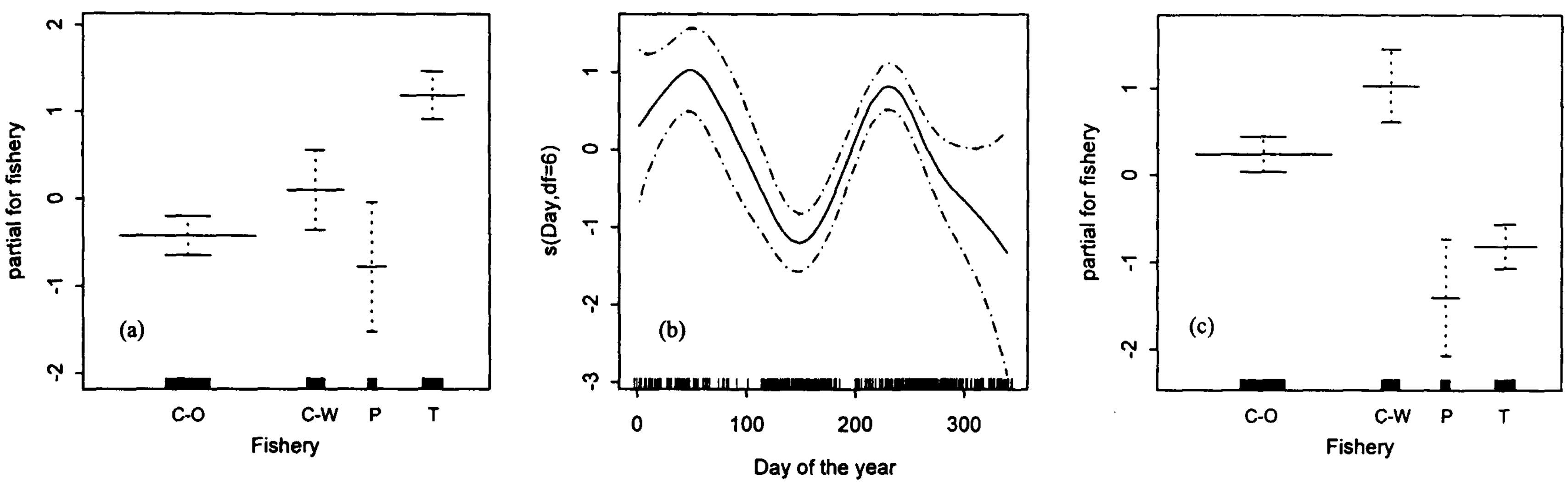

Fig.5. Partial fits for GAM of bycatch number per length of nets in the turbot fishery with respect to (a) soak time, (b) season and (c) depth.

Mean and variance of bycatch rate are independent of stratification method for the North Sea turbot fishery (Table 5) and the mean bycatch rate is set to 5,080 porpoises (CV 16%) per 1,000 tonnes landed turbot equivalent to 1,788 porpoises per year for the fleet.

The monitored landings for the rest of the North Sea fisheries are around 1% of the total annual fleet landings and the estimated bycatch rates and CV are considered to be preliminary. However, ignoring that, the average annual bycatch for total North Sea set-net fleet is estimated as 6,785 (CV 12%) porpoises of which 25% come from the insufficiently sampled plaice fishery (Table 6). The spatial distribution of bycatches estimated from average landings by ICES rectangles and the bycatch rates are shown for a whole year in Fig. 6. Estimated effort and bycatch is highest along the west coast of Jutland, close to the most important set-net harbours.

The total bycatch estimate based on the GAM analysis (Table 4, model 2) is similar to the bootstrap estimates. Effort per fishery and calendar day counter used in the prediction was derived from fleet landings of the target species and the observed CPUE. The seasonal stratification used in the calculation of CPUE is as given in Table 2. The predicted bycatch in the cod fisheries is 20% higher than the bootstrap estimate, while the GAM prediction is lower for the plaice and turbot fisheries (Table 6). Variance of the estimated bycatch is not available for the GAM prediction such that a significance test between the two sets of estimates can be made.

Sampling level outside the North Sea has been too limited to give estimates of total bycatch. No bycatch was observed in the Skagerrak, but the absence of bycatch from this area seems to be mere chance as only 8km nets were sampled.

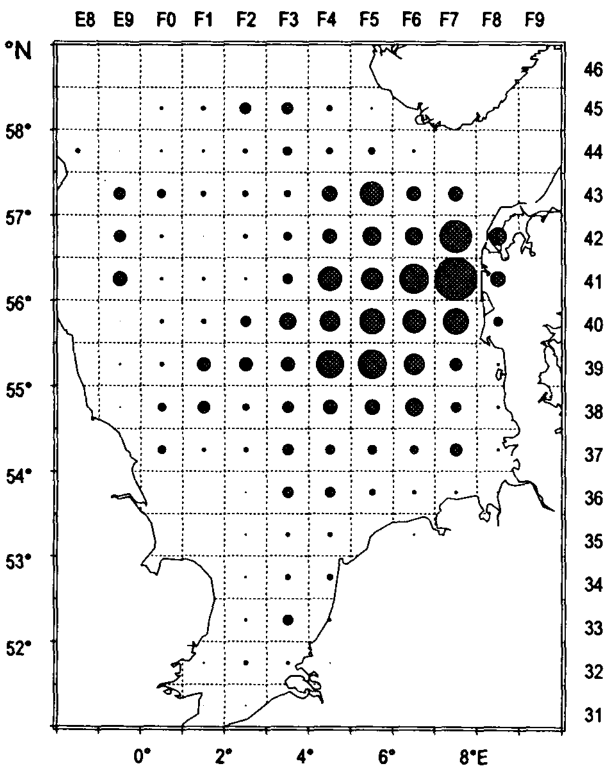

Fig. 6. Spatial distribution of estimated bycatch of harbour porpoise by the Danish North Sea set-net fisheries 1994-1998. Area of the dots is equivalent to bycatch number.

The very low density of harbour porpoise in the eastern Baltic Sea (Berggren, 1995; Hammond *et al.*, 1995) has been monitored with only 211km bottom set-net and 260km drift net, and therefore absence of bycatch is only indicative.

In Kattegat, five porpoises were caught of which four were taken in 40km nets fishing for lumpfish. Net type in the lumpfish fishery is similar to the North Sea turbot fishery and a relatively long soak time is used in both fisheries; the bycatch rate unfortunately seems to be similar as well.

DISCUSSION

Bias in sampling and presented estimates

Data sampling for bycatch estimation has mainly taken place as part of surveys for collection of fisheries data and experimental fisheries (Table 1). The objective of the experimental fishery survey 'Cod quota in number' in 1993 was to investigate the effect of a vessel cod quota set by number of fish rather than weight. During the survey, some fishermen fished more northerly and in deeper water than normal and had in some cases a lower CPUE. Total landings in a quota period were however larger due to higher effort and a larger mean size of the cod. The relatively higher effort might have caused an overestimation of bycatch per landed fish weight used in the extrapolation. Observations used from the other experimental fishery 'the effect of acoustic alarms' include data from nets fitted without alarms or dummy alarms and these data should not cause bias.

The way sampling is organised might also bias the result. In the beginning of the period, vessels for sampling were organised by direct contact with the skippers. The publication in spring 1994 of estimated bycatch numbers for the period 1992-1993 (Vinther, 1996) put the bycatch problem in focus and after some discussion within the fishing industry, data sampling was continued. Vessels are now organised through the Fishermen's Association and the skippers are paid 400DKK per day for having an observer onboard. This system has worked well since the Fishermen's Association managed to convince their members to participate. The amount of money paid to the skipper for having an observer onboard is too little to compensate for them changing to different fishing practice with lower bycatches in the case of the larger North Sea vessels normally sampled; no change in type or fishing practice of the sampled vessels has been observed. The observed fishing practice seems therefore not to be biased. However, observers might have been excluded from fishing trips with a very high expected bycatch. In the inner Danish waters, the compensation paid might have resulted in relatively higher sampling from many small vessels with a modest effort in the beginning of the sampling period.

Sampling from smaller vessels in the coastal area of the North Sea has been too limited, especially for the cod and plaice fisheries with relatively large coastal catches. The fishing practice is similar for small and large vessels, but bycatch rates might be different for the coastal and open sea area and this might lead to bias in the total bycatch estimate.

The plaice fishery has been sampled insufficiently and a relatively large mesh size was used during part of the survey. Plaice are normally fished with 120-140mm mesh size but can also be fished with larger meshes (170mm) in fisheries where plaice are targeted together with other species. The larger meshed fishery is over represented in the sampling compared to the total fleet. This might have underestimated the CPUE of plaice and thereby overestimated the total effort and bycatch in plaice fishery. Moreover, a relatively higher bycatch rate was observed in the larger meshed plaice fishery and if mesh size affects bycatch rate, the total bycatch in the plaice fishery is probably overestimated.

The extent of the hake fishery varies much between years due to fluctuation in local hake abundance and this fishery has been very poorly sampled. Anecdotal evidence suggest that bycatches can be very high in the fishery when nets with depth of up to 9m are operated mainly in the third quarter. The observed bycatch rate in the 130km nets was however lower than rates observed in the cod fisheries and thus the total bycatch in the hake fishery might be underestimated.

The result of no bycatch in the sole fishery seems to be too optimistic. Sole can be fished using 'sole nets' with meshes of 96-105mm or nets with larger meshes used for sole and in addition for plaice or small cod. The 'sole nets' have a depth of 1-1.25m and fish only 4-8 hours in the evening twilight. The total effort is therefore relatively modest, although the total length of nets used is huge and a limited bycatch must be expected. When sole are fished in a mixed species fishery, a longer soak time is used and the bycatch rate might be similar to the bycatch rate observed in the plaice fishery. At present, the minimum legal mesh size is 110mm in the sole fishery and the scale of the short soak time fishing is expected to decrease. Parts of the fishing grounds for the fleet, as well as the sampling area, are in the most southern part of the North Sea. This area had relatively low density of porpoise in July 1994 according to the SCANS survey (Hammond *et al.*, 1995). The sole fishery takes place mainly in May and June and if the distribution of porpoise is relatively stable, a low bycatch is expected in that area.

Landings statistics used for extrapolation might be inaccurate due to misreported landings. Several skippers have received heavy sentences for fraud over their declared landings, especially at the beginning of the sampling period. The Total Allowable Catch (TAC) of North Sea cod and sole have been very restricted whereas landings of plaice in some years have been less than the TAC. There is no TAC on turbot. Although underestimated total landings seem to be the most likely result of fraud, misreported catch area or species name may complicate the situation; sole might for instance have been landed as the non TAC species, turbot.

The GLM analysis of CPUE showed that the assumption of a year independent CPUE holds for the cod, turbot and plaice fisheries, but that the sole fishery had significantly higher fish catch rates in 1992. However, as no bycatch was observed in the sole fishery, the year dependent CPUE does not bias the total bycatch estimation. The use of bycatch per landed weight of fish, as basis for the extrapolation to total fleet bycatch, seems however to give a reliable result for the other fisheries.

Given that most surveys included in this investigation have had sampling of fisheries data for stock assessment as the main purpose, it should be noted that the observers use most of their working time on the measurement of the fish catches. Although the observers are most often very close to the net-hauling devices and can watch the nets coming up, drop-out of porpoises from the nets, at or below the surface, might not be detected. There has not been a consistent recording of drop-outs over the entire sampling period, but the available data indicate a low (around 5%) value. However, in studies (e.g. Bravington and Bisack, 1996; Trippel *et al.*, 1996; Tregenza *et al.*, 1997) where bycatch estimation was the main objective, much higher drop-out percentages (18-33%) have been recorded. It is thus possible that the present estimates might be seriously negatively biased.

The GAM analysis of bycatch rates gave large residuals for the high bycatch observations and generally poor model fit, indicating that the assumptions of a Poisson or negative binomial distribution were not met and that the prediction is uncertain. However, the bootstrap method has no distributional assumptions and this method seems to be the best choice. Taking the different methods and stratification used into account, the two methods give a confirmatory consistent estimate of the total bycatch.

The bootstrap estimated mean annual bycatch of 6,785 harbour porpoises is reassuringly close to the 'guesstimate' of 7,000 animals based upon data from 1992-1993 only (Vinther, 1996). The GAM analysis showed that the bycatch rates were not significantly different for the two periods 1993-1995 and 1996-1998, but the total landings used for extrapolation have changed leading to different total bycatch. If the annual landings and the average bycatch rates are used in the extrapolation, the annual bycatch decreased from 8,061 porpoises in 1994 to 5,031 porpoises in 1998. This estimated large reduction in bycatch is due to the decrease in the turbot, hake and plaice landings.

Important factors for bycatch

For both the analysis made on all fisheries combined and the analysis made on the cod-other and turbot fisheries, there is no significant area effect. The chosen area definitions have been relatively large due to the unbalanced sampling, and local 'hot-spots' might have been overlooked. There is no direct relation between the SCANS survey's local abundance estimate for the summer 1994 period and the estimated seasonal or annual bycatch number taken by the Danish fleet. Along the west coast of Jutland (SCANS area L) the abundance is relatively high and the bycatch is also very high in this area. In the northern Wadden Sea area (SCANS area Y) almost no set-net fishing takes place and the area has a relatively high abundance of harbour porpoise. In deeper waters and more southerly (SCANS area H), bycatch is relatively modest and so is the porpoise abundance.

There is a significant difference in bycatch rate between fisheries, but the factor or combination of factors causing this is more difficult to identify. Bycatches per km×h are about three times higher in the roundfish fisheries compared to the flatfish fisheries and the depth of nets used in different fisheries might be part of the explanation. For the cod fishery, nets of about 4m depth are used and flatfish are taken in nets at a depth of 1-1.5m, probably lower when fishing. However, the nets are also different with respect to hanging ratio, mesh size, material and flotation and net height seems to be one of many factors of importance. These factors are in most cases correlated with target species, which makes it difficult to use commercial fisheries data in statistical models. Looking at mesh size as an example; absence of observed bycatches in the sole fishery might be an effect of the small mesh size, but it could equally well reflect the relatively short soak time or simply the less robust netting material used in sole nets. The separate analyses of the turbot and cod fisheries show, not surprisingly, that longer soak time gives higher bycatch. Depth effect was significant only in the model for the turbot fishery where bycatch decreases with increasing depth. Studies in neighbouring areas (Berggren, 1994; Tregenza *et al.*, 1997) cannot confirm a depth effect for the relatively modest depth range observed in the North Sea fisheries.

Both the models including all fisheries and the models for the individual fisheries showed a significant season effect with high bycatch in August-September. Lockyer (1995) reported calving in British waters between June and July, with a peak in June. Lockyer and Kinze (1999) reported a peak calving period in Danish waters in June/July. A steep drop in mean size of by caught porpoises in the summer months indicates calves in the bycatches. The delay between peak in calving and high bycatch in the third quarter of the year, might be the result of changed diving behaviour for the calves during the period, or a non-overlap of sampling and breeding areas. Sampling was mainly in the non-coastal areas whilst most of the calving might take place in coastal areas. Strandings observations on the North Sea coast of Germany confirm a high mortality in the summer months (Kock and Benke, 1996), but earlier Danish investigations (Clausen and Andersen, 1988; Clausen and Kinze, 1993) did not reveal a clear picture of seasonal variation of bycatch in the North Sea due to limited sampling. Lockyer and Kinze (1999) report an increase in the period June through October for strandings.

The relationship between fish catch and bycatch is not clear. The gear used in the two kinds of cod fisheries is the same and allows further investigation of other effects. Fishing substrates are by definition different in the fishery over wrecks and on smooth bottom, but fishing takes place in the same area and fishermen do in some cases fish over both substrates on a trip. The bycatch rate is higher and CPUE is three times higher in the wreck fishery compared to the smooth bottom fishery, indicating positive correlation between fish and porpoise catches. It seems unlikely that harbour porpoises feed on fish caught in the nets with a mean length of more than 70cm (Vinther, 1995), but the reason for the observed correlation might be a higher concentration of prey fish for both cod and porpoise over wrecks. The analysis of the cod-other fishery however showed significantly larger bycatches in nets with the smallest fish catch.

Bycatch reduction

The results of the statistical analysis including the cod, plaice and turbot fisheries showed that bycatch rates in the North Sea depend on fishery and season, but were not significantly different between areas. This suggests that bycatch reduction in the form of closed areas will have a limited effect, as there are no distinct areas with higher bycatch rates. Effort reallocation will furthermore cause increasing effort and bycatch in other neighbouring areas. Reduction in total bycatch number might however be obtained by moving effort from the high-risk seasons to other periods for the non-seasonal fisheries. The Danish fishery is TAC regulated with individual vessel quotas for a limited (e.g. two months) time period; an unused period quota cannot be utilised later on. This regulation, in combination with the fact that the capacity of the fleet is often higher than the quota, forces the fishermen to utilise any possible quota without taking the risk of high bycatches into consideration.

Acoustic deterrents are effective in the Danish cod fishery for at least a short-term reduction in bycatch (Larsen, 1999). The required density of alarms is still unclear, but the use of alarms in the turbot fishery, where one vessel can operate up to 100km of nets, would probably be impractical and require some kind of financial compensation. For the cod fisheries, and especially the cod-wreck fishery with relatively short nets used, the approach seems promising. The period for use of alarms might even be restricted to August-October when the high bycatch rates are observed. This will also reduce acoustic disturbance and minimise the possible risk of habituation.

There is a fundamental relationship between effort and bycatch, and reduction in total length of nets used is therefore the most obvious option for reducing bycatch. The total length of the nets operated by a vessel is mainly determined by the time used to take fish and debris out of the nets and to gut the catch (Vinther, 1995). Larger meshes catch larger fish, but smaller fish dominate the size distribution in the stock and the number of both landed and discarded fish in the net becomes, in general, higher when smaller meshes are used. However, total labour used per landed weight and value is most often lower for larger meshes. The North Sea cod, and partly the plaice and sole fisheries specialise in using relatively large meshes, which makes it possible to operate very long nets. A maximum allowable length of nets employed by a vessel will reduce total bycatch and might lead to a less extensive small-mesh fishery so that landing quantity can remain at the present level. However, an economical analysis is necessary to quantify the cost and benefits of such an approach. The present exploitation of primarily older fish is in line with the advice given by fisheries biologists and the consequences of a changed exploitation pattern must be clarified. However, it may be almost impossible to enforce such regulations, and a maximum allowable mesh size for each fishery might be more practical. Smaller mesh size will not in itself reduce bycatches, but will prevent extensive fishing practices and thus might reduce total effort and bycatch.

Very long nets, fishing for several days, with large mesh sizes are used in the turbot and lumpfish fishery. The density of fish in the net is low and the mesh size used prevents the catch of most other species. However, the high average weight and price of the fish compensate for the low density. The mesh size used for turbot or lumpfish is close to the optimum for catching these large fish and use of a smaller mesh size, to reduce indirectly the length of net in use, will produce more discards and reduce landings. An average soak time of 10 days is the case in the turbot fishery. Turbot and the important bycatch species, anglerfish, can normally survive this long period whereas other fish die within 24-48 hours and become unsuitable for human consumption. A maximum allowable soak time, e.g. five days, might be used as a management tool in the turbot fishery to reduce discards, effort and bycatch, but the financial consequences of this are unknown. The use of a 'parking disc' on each anchor buoy may allow the enforcement of soak time restrictions.

CONCLUSION

Over 5,000km of nets have been monitored in the Danish set-net fisheries. Despite this, the estimate of total bycatch remains uncertain, especially in the inner Danish waters. The available data are sufficient to confirm a substantial bycatch in the North Sea and further sampling in that area should be concentrated on the coastal fishery and the plaice fishery. However, all fisheries should also be monitored to determine possible trends in bycatch levels. The present surveys have identified high-risk seasons and clarified differences in bycatch rates between fisheries that will prove of use in the coming bycatch reduction process. Data have been collected over six years but greater effort in a shorter period would give a more balanced and better dataset for statistical analysis. The relatively high sampling level has been possible because bycatch recording was part of surveys designed mainly for sampling of fisheries data. However, the detailed fisheries data sampled have not contributed greatly to an understanding of the bycatch process and the multi-purpose sampling approach might have downwardly biased the bycatch estimates due to drop-outs of porpoises from the nets not being seen. Although dedicated bycatch surveys would probably give the most accurate estimates, DIFRES will continue the present multi-purpose methodology in the near future.

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