Updated estimates of harbour porpoise (*Phocoena phocoena*) bycatch in the Danish North Sea bottom-set gillnet fishery

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ABSTRACT

The bycatch of harbour porpoise in the Danish North Sea bottom-set gillnet fisheries between 1987-2001 is estimated using two methods involving extrapolation of observer data. When observed entanglements are extrapolated to fleet level based on target species landings, the annual bycatch was estimated to be in the range of 2,867-7,566 harbour porpoise with a mean of 5,817. When observations are extrapolated based on fishing effort, estimates are in the range of 3,887-7,366 porpoises with a mean of 5,591. Both methods estimate a significant reduction in bycatch in the most recent years due to a decrease in both effort and landings. However, the reduction is less pronounced with the effort based method.

KEYWORDS: HARBOUR PORPOISE; FISHERIES; GILLNETS; BYCATCH; NORTH SEA

INTRODUCTION

Bycatches in Danish fisheries have been monitored using observer programmes since 1992. High bycatches of harbour porpoises (*Phocoena phocoena*) in the North Sea bottom-set gillnet fisheries for turbot, cod, hake and plaice were documented by Vinther (1995; 1997; 1999), who estimated the average total annual bycatch in the period 1994-1998 at 6,785 porpoises (Vinther, 1999). The total bycatch was well above the level agreed by ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas) in 1997 as acceptable (ASCOBANS, 1997), and led to the formation of a Danish action plan to reduce bycatch of porpoises in the North Sea (Ministry of Environment and Energy, 1998). The action plan recommends the use of acoustic alarms (pingers) as a primary means of mitigation, and from 2000, use of pingers became mandatory in the Danish wreck fishery in the North Sea (ICES sub-area IV) in the months August-October.

Vinther (1999) extrapolated the observed bycatch number per landed weight of target species to the total fleets' landings of target species. This method assumes implicitly that the fish Catch Per Unit Effort (CPUE) is constant during the period. However, the stock sizes and fish quotas of the target species have changed considerably during the last ten years (ICES, 2003). Such changes may violate the assumption of constant CPUE and the bycatch estimates may be seriously biased. This paper explores the possibilities of taking changes in fish CPUE into account in extrapolating observed bycatch to the total fleet.

The total Danish North Sea porpoise bycatch for the period 1987-2001 is estimated using the 1992-1998 bycatch observations presented in Vinther (1999), and additional bycatch observations from the period since 1998. Two methods for extrapolation are used; the landings-based method used by Vinther (1999); and an effort-based method. The underlying assumptions for these methods as well as sampling strategies for the relevant fisheries are also discussed.

MATERIALS AND METHODS

Materials and methods used in this paper are in most cases similar to those presented by Vinther (1999) and therefore details are only provided for additional data and methods. The time series of observer data has been extended with data from additional fishing trips since 1998, including data from 10 trips in the cod fishery, 8 trips in the plaice fishery, 8 trips in the sole fishery and 1 trip in the turbot fishery. Statistics for the whole sampling period (1992-2001) are presented in Table 1. Although fish landings and harbour porpoise bycatch were monitored from more than 5,500km of net, the observer coverage has been rather low. The average sampling activity was highest in the turbot fishery where, on average, 1.1% of the annual landings were monitored. Lowest sampling coverage was in the plaice fishery with just 0.3% coverage. For safety and cost/benefit reasons, larger vessels were preferred for monitoring such that smaller vessels were under-sampled as presented for the cod fishery in Fig. 1. Mean bycatch numbers per landed target species weight, using the same stratification and method as in Vinther (1999), are presented in Table 2. Landings and effort statistics for the total Danish North Sea set-net fleet were separated into fisheries using cluster analysis on the species composition for each individual trip (see Vinther, 1999). For the hake fishery, it should be noted that data are available from only two trips, both in 1997; thus the estimated bycatch rate should be treated with caution. For the plaice fishery, it should be noted that all porpoise bycatch was in the first quarter of the year and that 17 of the 21 porpoises bycaught were taken on two trips in January-February 1998; thus the bycatch rate for this fishery should also be treated with some caution.

Observed bycatch in this study is recorded as numbers per km-hours of net fished. Such an effort measure is however not available for the total fleet and an indirect way of extrapolation of observed bycatch to total fleet level must be applied. In addition, data for several years have to be merged, as sampling within a year has been too limited for an

Table 1

Mean annual fleet landings (in tonnes) for the Danish North Sea set-net fleet given by fishery and period, and corresponding observer sampling activity and porpoise bycatch numbers.

	Total fleet (mean annual)			Observed fleet (summed for all years)					
Fishery and period	Quarter of the year	Target species landings (tonnes)	Total landings (tonnes)	No. of trips	No. of sampling units	Target species landings (tonnes)	Length of nets (km)	Mean observer coverage (%)	No. of harbour porpoise
Cod (1993-2000)	1	3,241	3,699	18	280	68.5	356	0.3	36
	2	1,965	2,263	14	215	49.4	243	0.3	5
	3	2,296	2,661	58	681	188.3	1,175	1.0	86
	4	2,266	2,571	28	393	144.1	887	0.8	22
Hake (1997)	2-3	90	212	2	32	3.1	122	3.4	4
Plaice (1994-2001)	1	1,607	1,943	9	61	61.6	498	0.5	21
	2	1,217	1,718	12	33	8.5	157	0.1	0
	3-4	479	607	3	3	0.2	7	0.0	0
Sole (1992-2000)	1-4	768	926	22	68	8.2	875	0.1	0
Turbot (1993-2000)	2	280	489	13	110	24.4	945	1.1	78
	3	67	124	5	41	6.2	301	1.2	77
Other (1993-2000)	1-4	-	94	-	-	-	-	-	-
Small vessels	1-4	-	2,500	-	-	-	-	-	-
Total	1-4	14,276	19,807	184	1,917	562.6	5,565		329

Table 2

Bootstrap estimates of porpoise bycatch (in numbers per 1,000 tonnes landed target species weight) by fishery and period, and corresponding mean target species CPUE (in kg per day at sea).

Quarter and fishing method	Bycatch (numbers per 1,000 tonnes)			CPUE
	Mean	95% CI	CV %	Mean
Cod (1993-2000)				
1, 2, 4, wreck	33	8-81	53	438
3, wreck	502	186-1,188	46	418
1, 3, other	577	364-1,112	29	449
2, 4, other	218	135-357	24	413
Stratified	281		20	
Turbot (1993-1999)				
2	3,211	2,233-4,590	18	
3	12,417	6,786-19,453	27	
Stratified	5,067		16	250
Hake (1997)				
3	1,332	310-4,139	59	234
Plaice (1994-2001)				
All	295	176-484	26	681
Sole (1992-2000)				
All	0			186

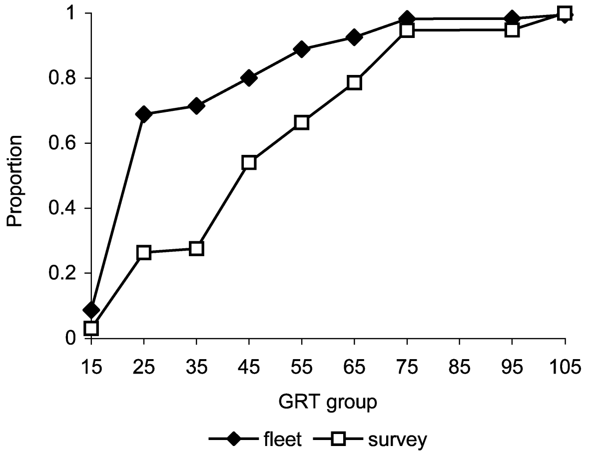

Fig. 1. Proportion of cod landings by vessel GRT group in the fleet and survey, 1993-2001.

estimate of total annual bycatch. Two methods for extrapolation are applied in this study: the 'landings' method; and the 'effort' method. The 'landings' method is the same applied in Vinther (1999) and assumes constant CPUE for the target species during the whole period, as effort is derived from the fleet's landings and the observed CPUE from the sampling period.

'Landings' method

$$total\quad bycatch_{year} = \frac{\sum_{y=Y1}^{Y2} obs\quad bycatch_y}{\sum_{y=Y1}^{Y2} obs\quad effort_y} * \frac{\sum_{y=Y1}^{Y2} obs\quad effort_y}{\sum_{y=Y1}^{Y2} obs\quad landings_y} * fleet\quad landings_{year} \Leftrightarrow$$

$$total\quad bycatch_{year} = \frac{\sum_{y=Y1}^{Y2} obs\quad bycatch_y}{\sum_{y=Y1}^{Y2} obs\quad landings_y} * fleet\quad landings_{year}$$

where $total\ bycatch_{year}$ is the estimated bycatch within a fishery for a given year; *obs bycatch* and *obs effort* are the observed bycatch and effort from surveys; and *Y1* and *Y2* are the first and last year in a survey for a specific fishery.

Total annual bycatch was estimated by fishery and season (see Table 1), however, the fishery and season indices have been left out of the notation for clarity.

The 'landings' method was used for an estimate of the 1994-1998 average bycatch and later for an estimate of annual bycatch in the period 1990-2000[1].

However, the fisheries' annual landings (Fig. 2) and effort varied considerably in the period 1987-2001, and an assumption of constant CPUE of the target species is clearly

[1] In litt. Danish Minister of Food, Agriculture and Fisheries to EU Commissioner Fischler (ASCOBANS AC8/Doc. 18).

not met, as CPUE of cod, hake and turbot have varied by a factor of around two (Fig. 3). Plaice CPUE seems more stable, even though the annual landings have varied by a factor of five.

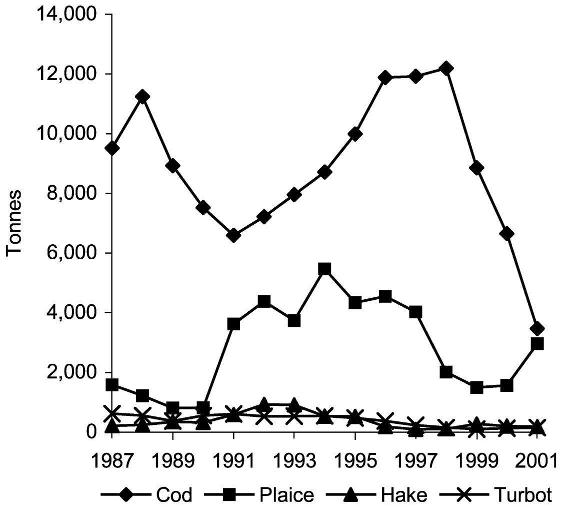

Fig. 2. Annual landing weights of the target species in four Danish North Sea set-net fisheries for the period 1987-2001.

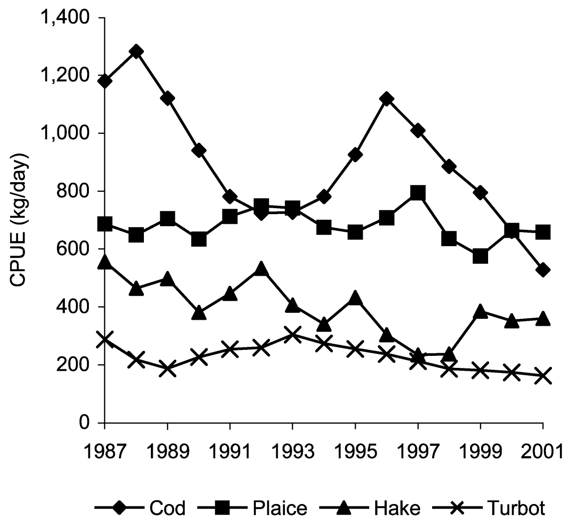

Fig. 3. Target species CPUE (in kg landings per day at sea) for the Danish North Sea set-net fleet for the period 1987-2001.

The 'effort' method estimates bycatches on the basis of annual fleet effort and observer data on bycatches and fish landings. This method also assumes constant CPUE, but just in the observer period.

'Effort' method

$$total \quad bycatch_{year} = \frac{\sum_{y=Y1}^{Y2} obs \quad bycatch_y}{\sum_{y=Y1}^{Y2} obs \quad landings_y} * \frac{\sum_{y=Y1}^{Y2} fleet \quad landings_y}{\sum_{y=Y1}^{Y2} fleet \quad effort_y} * fleet \quad effort_{year}$$

Definitions are as for the 'landings' method.

The fleets show a highly variable fish CPUE (Fig. 3), which also should be reflected in the observer data. A generalised linear model (GLM), using a Gamma error distribution and a log link function, was used to model the observed, or survey CPUE (kg/length of net) in the cod fishery. This fishery has had the most extensive observer coverage (1,701 hauls) and has a highly variable historical CPUE. The cod fishery takes place over shipwrecks or similar objects with a relatively high density of cod, using relatively short lengths of nets; or on other bottom types with a relative low density of cod, using relatively longer chains of nets. The highest catches in the non-wreck fishery are obtained when cod are moving actively around, e.g. during spawning migration, such that a possible seasonal effect on CPUE might be different for the two types of cod fishery. The model includes an overall cod density term (year), the two types of fishery (bottom) and an interaction effect between season (quarter) and type of fishery (quarter*bottom):

Model: CPUE = year bottom quarter*bottom.

All model variables are categorical.

RESULTS

All parameters in the GLM model for the survey cod CPUE were highly significant (Table 3). The estimated year factor for survey CPUE (Fig. 4) follows the trend in the fleet CPUE reasonably well, taking the relatively low sampling intensity for the years after 1997 into account. The estimated Spawning Stock Biomass (SSB; ICES, 2003) can be seen as a proxy for the 'fishable' biomass of cod, as the gillnet fishery mainly targets the larger cod. There is a high correlation between the ICES SSB estimate and total fleet CPUE (Fig. 4).

Table 3

Likelihood ratio statistics for testing the significance of each effect specified (type III analysis) in the survey cod CPUE model.

Effect	Degrees of freedom	χ^2	Probability>χ^2
Bottom	1	380.6	<0.0001
Year	7	256.5	<0.0001
Bottom*quarter	6	23.3	0.0007

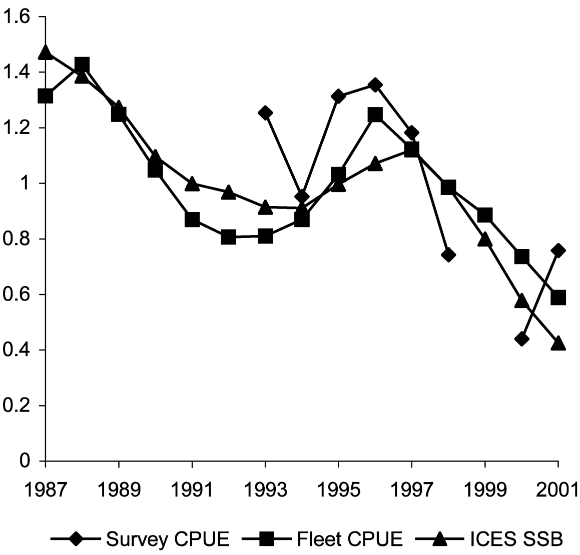

Fig. 4. Survey CPUE (year index from GLM model), total fleet CPUE index (target species landings per day at sea) and ICES cod Spawning Stock Biomass for the period 1987-2001. All values are scaled to the series mean.

The estimated total porpoise bycatch in the period 1987-2001 using the two methods is presented in Table 4. The overall mean bycatch for the two methods is quite

Table 4

Estimated annual bycatch (in numbers) of harbour porpoise in the Danish North Sea set-net fisheries by fishery and quarter for the years 1987–2001 for both the 'landings' and the 'effort' methods of extrapolation.

Fishery	Quarter	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Mean
'Landings' method																	
Cod, wreck	1, 2 and 4	136	146	116	115	96	98	96	109	122	153	154	152	117	84	40	116
	3	320	595	468	133	188	314	529	526	654	660	650	752	443	397*	259*	459
Cod, other	1 and 3	2,034	2,028	1,732	1,154	1,037	1,125	1,416	1,394	1,680	1,883	1,813	1,983	1,582	1,029	535	1,495
	2 and 4	268	459	318	384	326	361	332	423	454	583	614	580	368	336	175	399
Hake	All	283	319	451	437	776	1,233	1,212	718	704	246	119	144	357	272	242	501
Turbot	2 and 3	3,122	2,818	1,905	2,792	3,084	2,676	2,731	2,782	2,413	1,896	1,193	770	533	685	742	2,009
Plaice	All	468	362	239	242	1,066	1,290	1,105	1,614	1,281	1,342	1,188	594	441	463	872	838
Sole	All	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All	All	6,630	6,727	5,230	5,257	6,573	7,099	7,421	7,566	7,308	6,762	5,731	4,974	3,840	3,266	2,867	5,817
'Effort' method																	
Cod, wreck	1, 2 and 4	97	99	89	104	102	117	116	123	117	121	130	148	126	106	67	111
	3	276	405	383	173	291	386	606	555	568	475	587	738	511	570*	405*	462
Cod, other	1 and 3	1,410	1,342	1,217	919	1,076	1,307	1,603	1,578	1,546	1,472	1,514	1,943	1705	1,420	950	1,400
	2 and 4	236	323	294	401	386	443	428	456	435	445	538	565	411	413	261	402
Hake	All	119	160	212	268	405	541	697	493	381	189	119	142	217	181	158	285
Turbot	2 and 3	2,719	3,229	2,547	3,067	3,033	2,577	2,245	2,534	2,366	1,999	1,402	1,034	737	985	1,144	2,108
Plaice	All	465	380	231	260	1,018	1,172	1,014	1,627	1,325	1,292	1,018	636	521	475	903	822
Sole	All	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All	All	5,322	5,938	4,973	5,191	6,312	6,543	6,709	7,366	6,737	5,991	5,308	5,206	4227	4,149	3,887	5,591

* Bycatch is overestimated, as the effect of the use of pingers has not been taken into account.

similar for each fishery except for the hake fishery where the 'effort' method gives a 43% reduction. The hake fishery illustrates clearly the difference between the two methods as the observer programme includes just one year's (1997) data for this fishery. Therefore, the two methods estimate the same bycatch for 1997, but the 'effort' method estimates a relatively lower bycatch for years with a higher CPUE than in 1997. The time series had the lowest recorded CPUE in 1997 (Fig. 3), such that the 'effort' method estimates a considerably lower bycatch for the whole period.

The decrease in CPUE for cod and turbot in the most recent years (see Fig. 3) results in a higher estimated bycatch in these years for the 'effort' method, such that the decline in bycatch due to lower landings of target species is less than with the 'landing' method.

DISCUSSION

The estimates of porpoise bycatch presented here rest on a number of assumptions, some common to both methods employed in this study and some special to one or the other. This discussion section focuses on the most important of these assumptions and, where possible, ways of resolving the problems identified are recommended.

Two assumptions are common to both methods employed. The first is that porpoise densities in the areas covered by the fisheries are constant in the extrapolation period. Changes in porpoise densities in the areas covered by the fisheries could be caused by changes in porpoise population size, changes in porpoise distribution, changes in the distribution of the fisheries, or a combination of these. There are currently no data to explore changes in porpoise distribution or abundance, but the results from SCANS-II, an abundance survey of small cetaceans planned for 2005-2006, can potentially provide information on this. There are no indications of systematic changes in fisheries distribution that could give rise to the downward trend in total bycatch seen since the mid-1990s, and it is hard to imagine how this, although theoretically possible, could happen in practice. A more parsimonious explanation for the reduced bycatch is the reduction in effort which has taken place in most fisheries.

The second assumption common to both methods is that the observer data are representative for the whole fleet, not just regarding bycatch rate but also regarding target species CPUE and fishing area. This assumption is probably to some degree violated, as primarily larger vessels are chosen for the observer programme for cost/benefit and safety reasons. The larger vessels tend to fish further offshore and bycatch rates in these areas may be different from bycatch rates in more coastal areas. At present there are insufficient data to evaluate the effect of this bias in observer coverage, and an effort to include the smaller vessels in future sampling programmes is recommended.

A known bias common to both methods employed is created because the effects on bycatch rates of using acoustic alarms (pingers) in the wreck fishery are ignored. Use of pingers since August 2000 has been mandatory in the Danish cod wreck-fishery in August-October, and the effect of using pingers is reported to be close to a 100% reduction in bycatch in the observed part of the wreck fishery (Larsen, 1999; Larsen *et al.*, 2002). However, there are no ways to assess the efficacy of pinger use in the unobserved part of the wreck fishery. Thus the bycatch numbers for the wreck fisheries in Table 4 are overestimated by an unknown amount for both methods employed.

Another potential source of bias common to both methods stems from the extremely uneven distribution of bycaught porpoises on trips in the plaice fishery. As mentioned earlier, 17 of the 21 animals recorded in this fishery were taken by the same vessel on two trips in January-February 1998, although sampling has covered 24 trips in 8 years. Two types of nets (called 'snehvidegarn' and 'bastardgarn') are used in this fishery, and all porpoise bycatches have been taken in the 'bastardgarn'. The relative occurrence of the two net types in the fleet is, however, not known, so it is not possible to extrapolate observed bycatch rates to the 'bastardgarn' effort only. For this reason, the total porpoise bycatch in the plaice fishery is over-estimated by an unknown amount. We recommend that an effort is made to establish the relative occurrence of these two net types in the fishery, so that extrapolations can be carried out on a basis that better reflects how the fishery is performed.

A negative bias common to both methods results from missed bycatches or drop-outs, i.e. entangled animals which are shaken out or spontaneously fall out of the nets before being observed and recorded. Such drop-outs will most often go undetected, unless the observer is watching the nets as they are hauled out of the water. However, the observers in the sampling programme from which these data originate, are usually busy working up samples of the catch and have little time to watch the nets being hauled. In some bycatch observer programmes, where an effort has been made to scan for drop-outs, the proportion of porpoises found floating at the surface out of the total number recorded is relatively high (e.g. Bravington and Bisack, 1996; Tregenza *et al.*, 1997). How large a fraction of the entanglements go undetected probably depends on a number of factors such as observer routines, the strength of the netting, type of net hauler employed, sea state during hauling, soak time as well as others, which means that drop-out rates cannot be used from one fishery on another fishery. Thus we recommend that an effort is made to establish drop-out rates for the relevant Danish fisheries.

A specific assumption for the 'landings' method is constant target species CPUEs during the whole period for which porpoise bycatch is estimated. Fig. 3 shows that this assumption is clearly violated, which was the main reason for developing the 'effort' method of extrapolation.

The 'effort' method also assumes constant target species CPUEs, but only during the years covered by the observer programme. However, CPUE may vary considerably even within a relatively short period, as shown in Fig. 3 and confirmed for cod by the GLM results. For the cod fisheries, the change in CPUE during the observer period 1993-2000 has varied between 661 and 1,119kg per day with the highest values in the middle of the period. Sampling activity has not been equally distributed between years, but was highest in 1993 and 1997, which represent a low and a high CPUE year. Therefore the effect of a varying CPUE is somewhat levelled out. The assumption of constant CPUE has, however, been violated and the bycatch estimates might be biased. As an alternative, the observer time series could have been divided into more, but shorter series. However, the gain of using a long observer time series, in contrast to two shorter series, is reduced sampling variance. This is illustrated by the plaice fishery, where sampling has been modest throughout the whole sampling period 1994-2001, but as CPUE seems relatively stable in this fishery (Fig. 3) even a sparse sampling programme can give rise to an estimate of total bycatch with a low sampling variance.

If the observed bycatch rate were measured as bycatch per days at sea, it would be possible to extrapolate directly to the effort for the whole fleet without the assumption of constant CPUE during the observer programme. There are, however, a number of problems associated with that approach. For cost/benefit and safety reasons, larger vessels are chosen for the observer programme and the observed bycatch rate would have to be adjusted with an unknown vessel-size factor if effort was recorded as days at sea. Moreover, on some of the observer trips, a mix of fishing gears have been used (with and without pingers) of which only data from nets without pingers were used. So the observed days at sea must be adjusted for the period using pingers and divided by various types of gear when different species were targeted on the trip. The major problem is, however, the way the effort measure, 'days at sea', is defined. 'Days at sea' is a derived value from logbook and sales slip data and includes the number of days between the date of the first fishing operation (actually the date for the first catch record in the logbook) and the date when the fish is landed (date on the sales slip), plus one. For fisheries where the nets are set on one trip and hauled during the next trip (e.g. in the turbot and plaice fisheries) the 'days at sea' is misleading for the total effort. To avoid problems caused by the 'days at sea' definition, it is assumed that the logbooks and sales slips have been completed in the same way throughout the period, such that the catch statistics can be used to calculate fleet CPUE. We believe this is a reasonable assumption, but have no way of verifying whether it is actually true.

To use 'days at sea' as an unbiased estimator of effort for extrapolating the observed bycatch rates to fleet level, the net length used per day is assumed to be constant throughout the period of extrapolation. It could be expected that fishermen seeing a decrease in CPUE would try to compensate for this by increasing the number of nets used per day. However, this seems not to be the case, judging from information from the observed part of the fleet and from the correlation between the ICES SSB index and the CPUE for the Danish fleet. The reason is that most of the time at sea is used for steaming between the fishing positions (e.g. shipwrecks) and to set, haul and clean the nets. Less time is actually used for handling the landings, especially for the larger and 'rare' fish like cod, hake and turbot. Therefore a decrease in landings per net does not necessarily free much time that could be used to deploy more nets on a trip. Consequently, we feel that this assumption is justified.

The ICES assessment of the North Sea cod has been criticised, but it is nevertheless comforting that there is a high correlation between the ICES SSB index and the CPUE for the Danish fleet (Fig. 4). Assuming that a higher stock size gives a higher CPUE, the correlation indicates that the 'days at sea' effort used throughout the period is fairly unbiased. It also indicates that the fishermen are not increasing the number of nets operated as a reaction to decreasing CPUE, since this would have resulted in relatively stable fleet landings per day, more or less independent of the stock size of cod.

There has been a downward trend in trip duration from approximately six days in 1987 to three days in 2001 in the cod fishery. Taking the definition of 'days at sea' into account, this trend might have biased the estimate of total bycatch, as a relatively larger part of the trip duration will be used on steaming from the fishing ground to the harbour on shorter trips, assuming that the same fishing grounds are chosen. The real CPUE has therefore been underestimated in the most recent years, with the shorter trips leading to an over-estimated bycatch using the 'effort' method.

The two methods extrapolate observed bycatch to total fleet level for a rather long period and the time series of estimated bycatch should be treated with caution for years without an observer programme. Both methods give a similar average bycatch, but the 'effort' method is less optimistic about the reduction in bycatch in the most recent years. We believe that the 'effort' method is a more appropriate way to extrapolate the observer data to the whole fleet, but raise caution about continuing the extrapolation without obtaining new data from the relevant fisheries. The severe reductions in cod quotas since 1998 have changed the fishing practices of the Danish gillnet fleet in the North Sea such that the data analysed here may no longer represent the current situation in the fisheries with respect to bycatch of harbour porpoises.

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