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Discarding in the North Sea and on the historical efficacy of gear-based technical measures in reducing discards

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ABSTRACT

We describe and analyse newly available catch and discard data from the English and Welsh fishing fleet operating in the North Sea. In this fleet we estimate that between 2003 and 2006 discard rates averaged 36% by number and 25% by weight. Additionally, we analyse historical discard data from the fleet to evaluate the efficacy of square-mesh panels and increases in codend mesh size. These various gear-based technical measures have been introduced into the fisheries for the purpose of reducing discarding; we demonstrate that these technical measures have been effective in this respect.

1. Introduction

In commercial fisheries, discards (or discarded catch) is defined as the portion of the total organic material of animal origin in the catch, that is thrown away or dumped at sea for whatever reason (Kelleher, 2005). Discarding is widely regarded as running counter to fisheries and marine conservation objectives worldwide, and global discards are estimated to be around seven million tonnes per year (Kelleher, 2005).

Kelleher (2005) reported that the North Sea (ICES subarea IV, 600,000 km^2 in area) accounts for the highest level of discarding in the world, some 13% (909,109 t) of global discards. We examined the source data used in Kelleher's North Sea estimate and find that of this North Sea quantum, 84% (759,409 t) were fish, cephalopods and *Nephrops norvegicus*, and the remaining 16% were miscellaneous benthic invertebrates. Seven countries border the North Sea (UK, France, Belgium, The Netherlands, Germany, Denmark and Norway). Fish caught in the North Sea accounts for >50% of the European Union (EU) combined total allowable catches (TAC) (Koundouri et al., 2004). Kelleher's estimates are based largely on data that are over a decade old and here we present new catch and discard data from the English and Welsh fishing fleet operating in the North Sea. Such data have not been previously available and is obtained from the English and Welsh national sea-going observer programme.

Since the 1990s fisheries managers have introduced a number of gear-based technical measures in the North Sea that are intended to improve fishing gear selectivity and reduce discarding. In the towed gear fisheries, many of the technical measures have stipulated changes to codend mesh size or the inclusion of square-mesh escape panels (SQMPs). However, little evidence has subsequently emerged in the scientific literature to quantify how effective these measures have been since their introduction. Here we use historical catch data from the study fleet to investigate the efficacy of such technical measures post-introduction.

2. Materials and methods

2.1. New catch and discard information from the North Sea (English and Welsh registered fishing vessels)

We collected catch data (fish, cephalopods and *Nephrops norvegicus*) onboard English and Welsh registered otter trawlers, demersal fish beam trawlers, *Nephrops* trawlers and netters. All of these vessels were greater than 10 m in length overall and were active in the North Sea (ICES subarea IV) between 2003 and 2006. We refer to them as the study fleet. We do not present data from beam trawlers targeting brown shrimp (*Crangon crangon*) as these were recently described by Catchpole et al. (2008).

We estimated the total numbers and weights of fish, cephalopods and *Nephrops norvegicus* discarded and retained by

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Table 1
Sampling effort on board the fishing fleet of England and Wales in the North Sea (>10 m) 2003–2006, with mean raising factors per sample, trip and fleet by gear group

Gear group	Number of sampled trips	Number of sampled hauls	Sample to haul raising factors		Fleet raising factors
			Discarded	Retained	
Beam trawling	11	237	15.4 (0.84)	5.9 (0.22)	378 (192.8)
Otter trawling	65	434	5.2 (0.49)	3.64 (0.13)	169 (43.2)
Nephrops trawling	101	268	13.6 (0.83)	25.3 (2.24)	104 (8.4)
Netting	14	41	2.7 (1.08)	1.1 (0.07)	201 (103.12)

Figure in parentheses refer to one standard error of annual estimate.

the study fleet following the approach of Enever et al. (2007). This approach uses fishing effort as the basis for raising (hours fished for static gears and number of trips for towed gear groups). All fish were measured to the nearest centimetre below (total length) except *Nephrops norvegicus* that was measured to the nearest millimetre (carapace length). Our estimates are derived from an analysis of catch and discard data from 191 fishing trips (980 hauls) recorded by observers accompanying the study fleet between 2003 and 2006 (Table 1 and Fig. 1).

2.2. Analyses of the efficacy of various gear-based technical measures at reducing discard levels after their introduction

2.2.1. The effect of codend mesh sizes and SQMPs on discards

Here we examine the associated catches and discards of the study fleet over a longer time period (1999–2006) and excluded *Nephrops norvegicus* from the analyses, because earlier data were not available.

We evaluated whether technical gear measures led to significant changes in discard patterns in the catches by *Nephrops*, otter and beam trawlers. We compared discard rates (numbers) before and after the introduction of certain technical measures, between different mesh sizes of net and also between nets with and without SQMPs. An analysis of covariance was carried out on the total numbers of fish discarded (all fish species combined) at a haul level, using the total catch (at a haul level) as a covariate. Initially, vessel lengths, vessel tonnage, engine power, haul duration, haul depth and trip duration were also entered as covariates. Covariates that were initially not significant were removed from the model, and the analysis was then repeated. Rates of discarding (and their standard errors) were calculated from the marginal mean number discarded for each category. The time of year (quarter) was included as a fac-

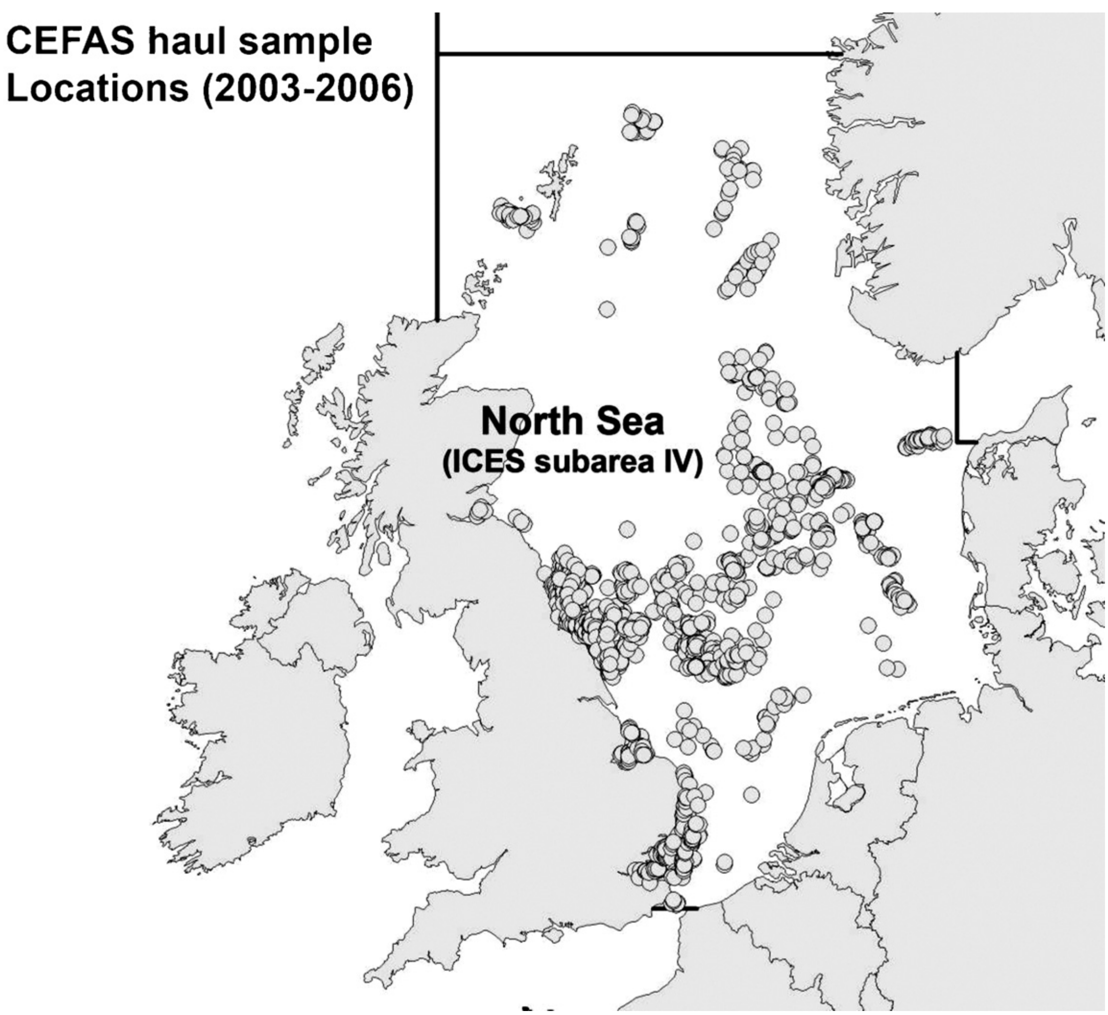

Fig. 1. Map of the North Sea showing the Cefas catch and discard sample locations on vessels registered in England and Wales between 2003 and 2006.

Table 2
Mean annual estimates of fish numbers discarded by the English and Welsh fishing fleet in the North Sea (>10 m) 2003–2006

Rank	Gear group	Numbers of fish (×10⁶)				
		Discarded		Retained		Percent discarded ($a/(a+b)$)
		Mean (a)	Range (min/max)	Mean (b)	Range (min/max)	
1	Beam trawling	18.1	2.6–30.6	12.4	3.8–16.8	59
2	*Nephrops* trawling	14.2	9.5–19.1	51.3	20.7–119.6	22
3	Otter trawling	10.5	4.7–18.9	13.5	12.3–15.5	44
4	Netting	<0.1	<0.1–0.2	<0.1	<0.1–0.2	47
Total		42.9		77.3		36

Table 3
Mean annual estimates of fish weights discarded by the English and Welsh fishing fleet in the North Sea (>10 m) 2003–2006

Rank	Gear group	Weight (t)				
		Discarded Mean (a)	Range (min/max)	Retained Mean (b)	Range (min/max)	Percent discarded ($a/(a+b)$)
1	Otter trawling	2109	1,419–3,238	9,628	6,885–12,164	18
2	Beam trawling	1962	363–3,479	4,311	969–6,324	31
3	*Nephrops* trawling	1344	591–1,998	2,395	1,687–3,471	36
4	Netting	12	2–32	36	12–63	25
Total		5427		16,370		25

tor in all models to allow for seasonal variations in the fisheries. The factors used were:

(a) Beam trawling: codend mesh size categories of 80–89 mm, 90–109 mm and 110–120 mm.
(b) Otter trawling: codend mesh size category and the presence or absence of a SQMP. Three codend mesh size categories were selected, 80–99 mm, 100–119 mm and 120–130 mm. For the SQMP we used presence/absence as a factor. Data on SQMP mesh size, position and dimension, were not available.
(c) *Nephrops* trawling: the period categories 1999–2001 and 2003–2006. These periods were selected because the technical measures under scrutiny were introduced in 2002 (increase in codend and SQMP mesh size) (Anon, 2001).

2.2.2. The effect of gear changes on whiting catches in Nephrops fisheries

In 2002, a combination of EU and national (UK) regulations (Anon, 2001) were introduced to the North Sea which stipulated an increase in the minimum codend mesh size in the *Nephrops* fishing fleet from 70 to 80 mm and an increase in the SQMP mesh size from 80 to 90 mm. The measures were designed to reduce discarding of juvenile gadoids. In this case, we use a longer time period again and examine the length–frequency distributions (LFDs) of whiting (*Merlangius merlangus*) caught on board commercial fishing vessels targeting *Nephrops* before (1994–2001) and after (2003–2006). Whiting was selected as the model species to test whether the legislation produced a change in discard levels because it has consistently been the most prevalent bycatch species in the *Nephrops* fisheries and so provides the most stable indicator. We additionally contrast the LFDs of whiting caught by the commercial fishing fleet with those obtained from the international bottom trawl survey (IBTS). Such a comparison can demonstrate that changes in the commercial catches of whiting have not arisen from changes in the fish population. Both the commercial catch data and the survey data were collected during quarters one and four (the *Nephrops* fishing season) and between 1994 and 2006 (the study period). All IBTS trawl surveys were undertaken using a specific survey trawl to a rigid protocol (Anon, 1999). The survey trawl codend was lined with 20 mm mesh to catch fish across the full-length range.

Table 4
Top 10 most discarded species and other commercial species by number in the North Sea (England and Wales registered Beam, otter and *Nephrops* trawlers combined)

Rank	Common name	Latin name	Numbers × 10⁶		Percent discarded
			Annual mean	Range (min/max)	
1	Dab	*Limanda limanda*	11.7	4.8–17.5	89
2	Whiting	*Merlangius merlangus*	7.2	2.6–12.3	52
3	European plaice	*Pleuronectes platessa*	6.2	2.5–12.7	36
4	Norway lobster	*Nephrops norvegicus*	4.4	2.5–5.9	15
5	Gurnards	*Trigla* spp.	3.9	2.2–6.0	74
6	Cod	*Gadus morhua*	1.3	0.9–1.9	40
7	Long rough dab	*Hippoglossoides platessoides*	1.1	0.6–1.6	98
8	Haddock	*Melanogrammus aeglefinus*	0.9	0.4–1.3	35
9	Lemon sole	*Microstomus kitt*	0.8	0.3–1.2	39
10	Dover sole	*Solea solea*	0.6	0.1–1.4	20
12	Herring	*Clupea harengus*	0.5	0.2–1.0	98
21	Thornback ray	*Raja clavata*	0.2	0.1–0.2	56
22	Saithe	*Pollachius virens*	0.1	<0.1–0.2	28
25	Spotted ray	*Raja montagui*	0.1	<0.1–0.3	51
27	Mackerel	*Scomber scombrus*	0.1	<0.1–0.1	75
Rest (122 species)			3.8	3.8–3.8	66

Ranked according to annual mean discard numbers.

3. Results

3.1. New catch and discard information from the North Sea (fishing vessels registered in England and Wales)

An estimated annual average of 120 million fish (21,797 t) were caught by the study fleet. Of this total annual mean catch, 43 million fish (36%), or 5427 t (25%), were subsequently discarded (Tables 2 and 3). Of these discards, 42% (18.1 million fish; 1962 t) originated from beam trawlers. The *Nephrops* trawlers were responsible for 33% of the discards (14.2 million fish; 1344 t) and otter trawlers 24% (10.5 million fish; 2109 t); whereas netting contributed <1% of the discards. We use the independent official landings data reported by the study fleet to quality control our estimates. These show that the official landings for the study fleet were 16,270 t and compares favourably to our estimated total landings of 16,370 t (Table 3).

The most commonly discarded species for beam trawlers, otter trawlers and *Nephrops* trawlers (numbers combined) are detailed in Table 4. They were dab (*Limanda limanda*), whiting (*Merlangius merlangus*), plaice (*Pleuronectes platessa*), Norway lobster (*Nephrops norvegicus*), cod (*Gadus morhua*), long rough dab (*Hippoglossoides platessoides*), haddock (*Merlanogrammus aeglefinus*), lemon sole (*Microstomus kitt*), Dover sole (*Solea solea*) and five species of gurnard (Triglidae).

The length–frequency distributions of the catches (fish, cephalopods and *Nephrops norvegicus*) were derived from over 260,000 measurements and are presented for beam trawlers, otter trawlers, netters and *Nephrops* trawlers in Fig. 2. The LFDs for the fish caught by beam trawlers show that all fish below 20 cm are discarded. There is some overlap of discarded and retained fish in the 20–30 cm length range. Otter trawler and *Nephrops* trawler LFDs showed that both the retained and discarded fish spanned a broad length range. The peak in the *Nephrops* trawler LFD around 5 cm relate to *Nephrops norvegicus*, and the peaks >10 cm to finfish. The netting LFD showed the broadest overlap of discarded and retained fish of all the gear types.

Discarding was widespread throughout the region, however highest levels were recorded off the northeast coast of England (Fig. 3). This region is fished mainly by *Nephrops* and otter trawlers whereas beam trawl effort is more widely dispersed throughout the North Sea.

3.2. Analyses of the efficacy of various gear-based technical measures at reducing discard levels after their introduction

3.2.1. The effect of codend mesh sizes and SQMPs on discards

For beam trawlers, otter trawlers and *Nephrops* trawlers, there was considerable variation in codend mesh size used by the fleet. Beam and otter trawlers fished with codend mesh sizes ranging from 80 to 130 mm and *Nephrops* trawlers with codend mesh sizes between 70 and 100 mm. As a result, we were able to assess the proportions of fish discarded from hauls using different codend mesh sizes.

Beam trawlers: From 1999, the average codend mesh size used by the beam trawl fleet of England and Wales remained relatively constant at around 95 mm. However, the effect of codend mesh size on discard rates was significant for beam trawls (Fig. 4) ($P < 0.01$), reducing from 83% by number for mesh sizes <90 mm to 60% by number for the two larger mesh size categories.

Otter trawlers: In the otter trawl fleet, the codend mesh size varied considerably over the 8-year study period, with annual averages ranging from 92 to 105 mm. Throughout the study period, around half of the otter trawlers had SQMP attached while the other half had none. Therefore, our data also allow us to assess the impact of SQMP on discarding rates. For otter trawls with a codend mesh of <120 mm, the effect of mesh size on discard rates was not significant ($P = 0.27$), but discard rates were significantly lower when a SQMP was attached ($P < 0.01$), reducing from 63% by number without a SQMP to 45% by number with one attached (Fig. 4). Only five hauls with codend mesh sizes >120 mm had a SQMP attached, so the precision of the estimated mean discard rate was poor and is not plotted in Fig. 4. Discard rates for trawls of larger mesh were significantly lower than for nets with mesh sizes <120 mm ($P < 0.01$) and were similar to those for smaller mesh nets with SQMP, i.e. 44% by number (Fig. 4).

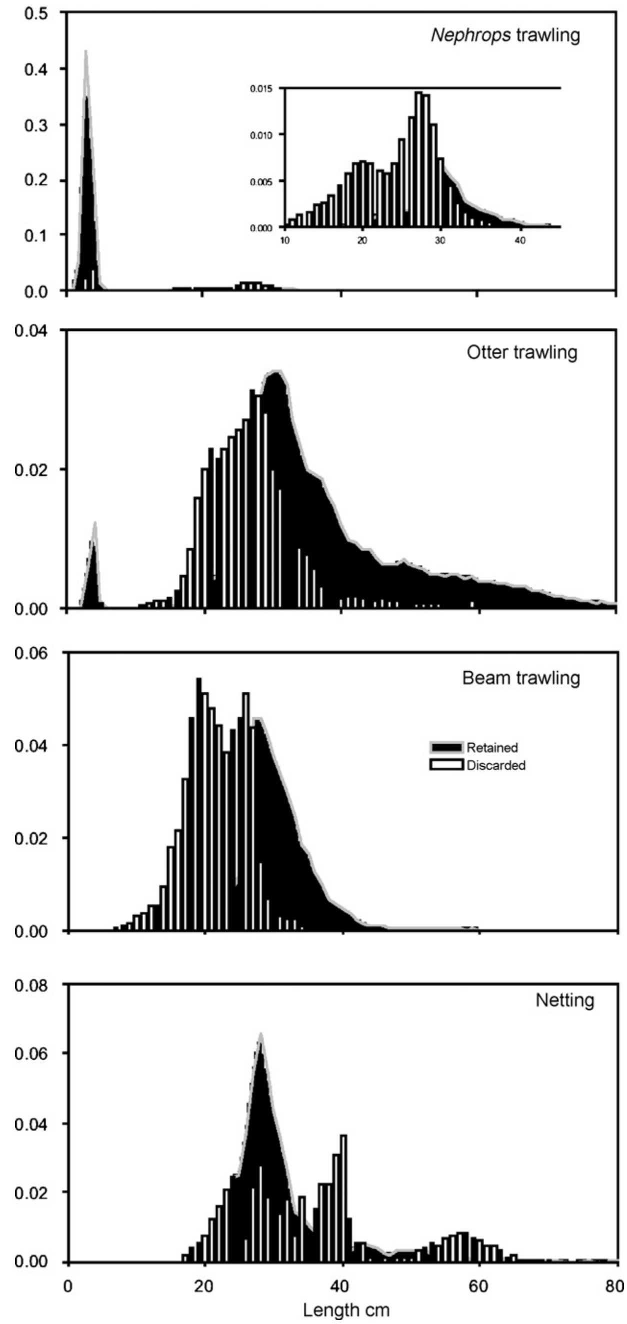

Fig. 2. Length–frequency distributions of the catches (fish, cephalopods and *Nephrops norvegicus* combined), 2003–2006 by English and Welsh registered fishing vessels in the North Sea.

Nephrops trawlers: For the *Nephrops* fishery, the average codend mesh size as a result of technical measures introduced in 2002,

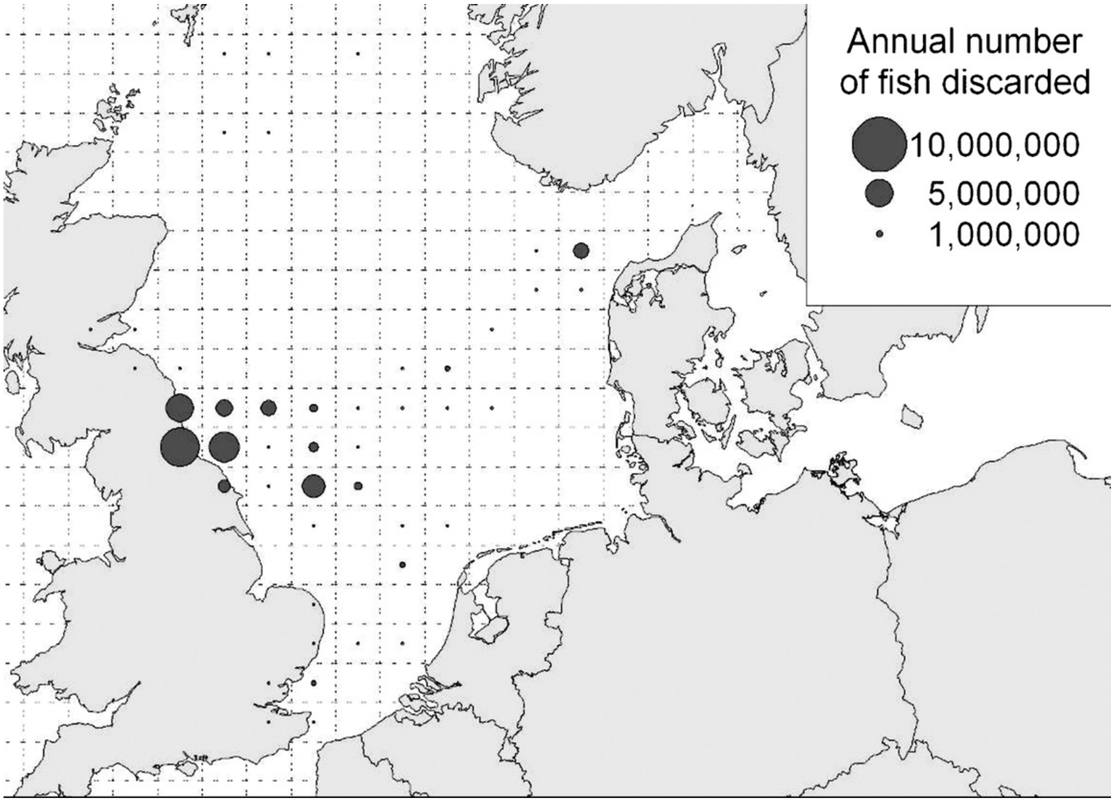

Fig. 3. Spatial distribution of discarded fish, *Nephrops* and cephalopods by the English and Welsh fishing fleet in the North Sea (>10 m) 2003–2006.

increased from 72 mm in 1999–2001 to 82 mm in 2003–2006 (Fig. 5). Also, the existing SQMP mesh size was increased from 80 to 90 mm. At the same time, the discarding of finfish (mainly whiting) decreased significantly ($P = 0.02$; Fig. 4). Essentially, the mesh size of the whole fleet increased at the same time, so statistically we cannot distinguish the effect of increased codend mesh size from an increase square-mesh panel mesh size. We are also unable to differentiate whether the discard reduction was due to the temporal changes, although it is very likely that the reduction in discarding was a result of the new technical measures. The whiting length–frequency evidence presented in Section 3.2.2 further supports this hypothesis.

3.2.2. The effect of gear changes on whiting catches in Nephrops fisheries

The IBTS survey LFDs of whiting in the time periods 1994–2001 and 2003–2006 show similar and consistent catch patterns, with bimodal length distributions (Fig. 6). These reflect the whiting fish population size structure, and overall show a fairly unchanging pattern of LFD throughout the entire study period.

The LFDs from the commercial trawls confirm that their catches were composed of a greater proportion of larger fish than the survey trawl, as would be expected because of their larger codend mesh. However, there was a consistent difference between the catches of whiting in the commercial trawls before and after the introduction of technical measures in 2002. Prior to 2002, commercial trawls yielded more juvenile whiting (<20 cm), some 22% of the catch, than subsequently, when just 3% of the catch was this size class of small whiting (Fig. 6).

4. Discussion

Our data indicate that most discards in the study fleet originate from towed gears, so if discards are to be reduced further, mitigation measures should first be developed for these gear groups. Beam trawlers discard the most (fish, cephalopods and *Nephrops norvegicus* combined) (42%) within the study fleet and also the greatest proportion of their catches by number (59%) (Tables 2 and 3). These values compare well with earlier estimates of discarding by beam trawl fleets operating in the North Sea (Lindeboom and de Groot, 1998) and in ICES subarea VII (Borges et al., 2005b; Enever et al., 2007).

Kelleher (2005) estimated that the discarding of fish, cephalopods and *Nephrops norvegicus* in the North Sea amounted to 759,409 t per year. This estimate was, for the most part, cited from data collected by Garthe et al. (1996), who in turn drew upon studies dating back to the late-1980s and early-1990s. Internationally, fleet size in the North Sea has almost halved since then, mainly through vessel decommissioning and reduction in quotas (Koundouri et al., 2004). Moreover, there have been several gear-based technical measures introduced to North Sea fleets aimed at reducing discards, such as changes to codend mesh size and the requirement to use SQMPs. These factors suggest that discard levels may have fallen below those estimated by Kelleher (2005).

A reduction in North Sea discards is also supported by the work of Votier et al. (2004) and their studies on seabird ecology. These workers demonstrate that the great skua (*Stercorarius skua*) has changed its feeding habits by increasingly predating upon other seabirds as a consequence of reduced discard availability in the North Sea.

Our evidence indicates that the technical measures introduced into the North Sea have been effective in reducing discards post-implementation. We see evidence of this in the reduced capture of small fish where SQMPs have been used and the significant reductions in discard rates when larger codend mesh sizes are in use.

Similarly in the *Nephrops* fleet, the size of whiting in the commercial catch changed in size structure (Fig. 6), after the new

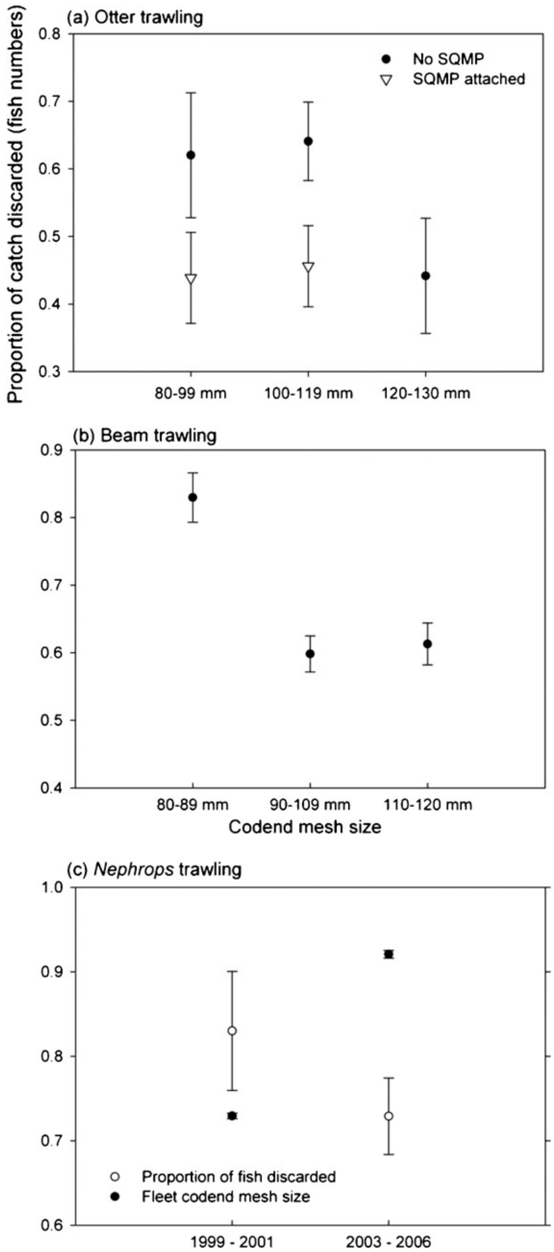

Fig. 4. $(a+b)$ Proportion of catch discarded (all finfish numbers combined) by English and Welsh registered otter trawlers (a) and beam trawlers (b) in the North Sea between 1999 and 2006 with and without square-mesh panels (SQMP) (otter trawlers only) fitted for varying codend mesh size groups. (c). Proportions of catch discarded (all finfish numbers combined) by English and Welsh registered *Nephrops* trawlers in the North Sea before (1999–2001) and after (2003–2006) an increase in codend mesh size (EU regulation EU2056/01).

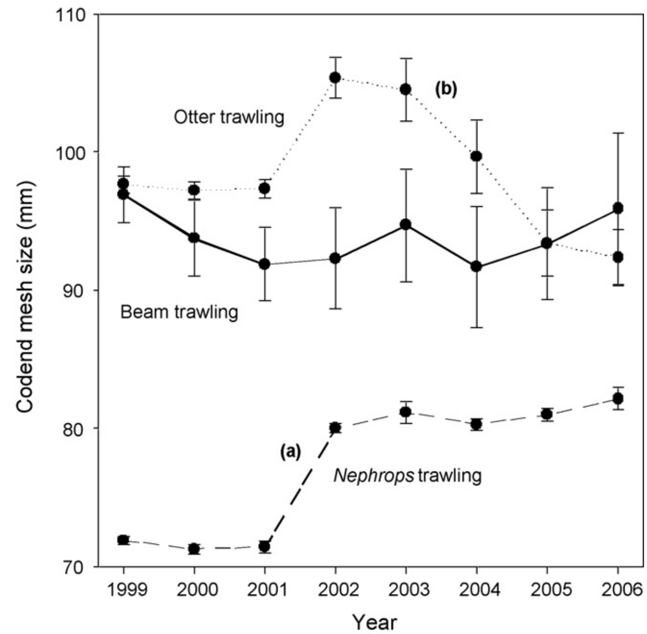

Fig. 5. Codend mesh sizes used by English and Welsh beam, otter and *Nephrops* trawlers in the North Sea (source: UK fishery landings database 1999–2006 (42,000 records)). (a) Reflects the increase in mesh size of the *Nephrops* fleet due to EU regulation EU2056/01. (b) Reflects the disincentive for fishers in the otter trawl fleet to utilise larger codend meshes as a result of the days at sea scheme (Graham et al., 2007.) Error bars show ±2S.E.

legislation had been introduced. We estimate that some 1344 t were discarded each year by the *Nephrops* fleet from 2003 to 2006 (Table 3). Using independently gathered catch and discard data, Catchpole et al. (2005) estimated that the total quantity discarded by the same *Nephrops* fleet in 2001 and 2002 was 3682 t per year, lending further evidence to support our hypothesis that discarding has reduced since 2002.

These findings should go some way to reassuring fisheries managers that gear-based technical measures can indeed improve the selectivity of fisheries and can be effective means of reducing discarding. Catchpole et al. (2008) further demonstrated that the use of sieve nets (another gear-based technical measure) successfully reduced discards in the UK North Sea *Crangon crangon* fisheries following the introduction of the measure in 2002. In that fishery discarded numbers of 24 of the 26 most commonly caught species dropped following the introduction of sieve nets, with plaice, dab, whiting, and cod discards being reduced by 33, 45, 27, and 70%, respectively.

There is evidence in the literature that adherence to technical measures can be low if suitable incentives are not in place. Graham et al. (2007) noted that reduced fishing opportunities acted as a disincentive to North Sea fishers to use trawls with larger mesh. Our work (Fig. 5) supports this specific observation and we note the average mesh size in the otter trawl fleet has fallen since 2003/2004, coinciding with the emergence of this disincentive. Suuronen et al. (2007) provided another example of poor incentives undermining the adoption by fishers of gear-based technical measures. In that case, significant short-term economic losses associated with a technical measure (the BACOMA panel) introduced into the Baltic Sea cod fishery acted as a disincentive to fishers. As a consequence, there was adulteration of the panel, circumvention and non-compliance with the regulation.

In summary, our work has provided new information on a component of North Sea discards and on the efficacy of technical measures already introduced into these fisheries. The results indicate that discard levels may have fallen in the North Sea, although our analysis does reveal that towed gears still have relatively high rates of discarding.

We believe that Kelleher (2005) analysis of the North Sea requires updating and presently overestimates the discard levels. If similar new catch and discard data were made available from other North Sea fishing nations, an accurate and comprehensive update of Kelleher's estimates would be possible. With this in hand, managers could establish how effective existing interventions (i.e. technical measures/de-commissioning/effort control, etc.) have been in reducing discards and catches. Furthermore, such

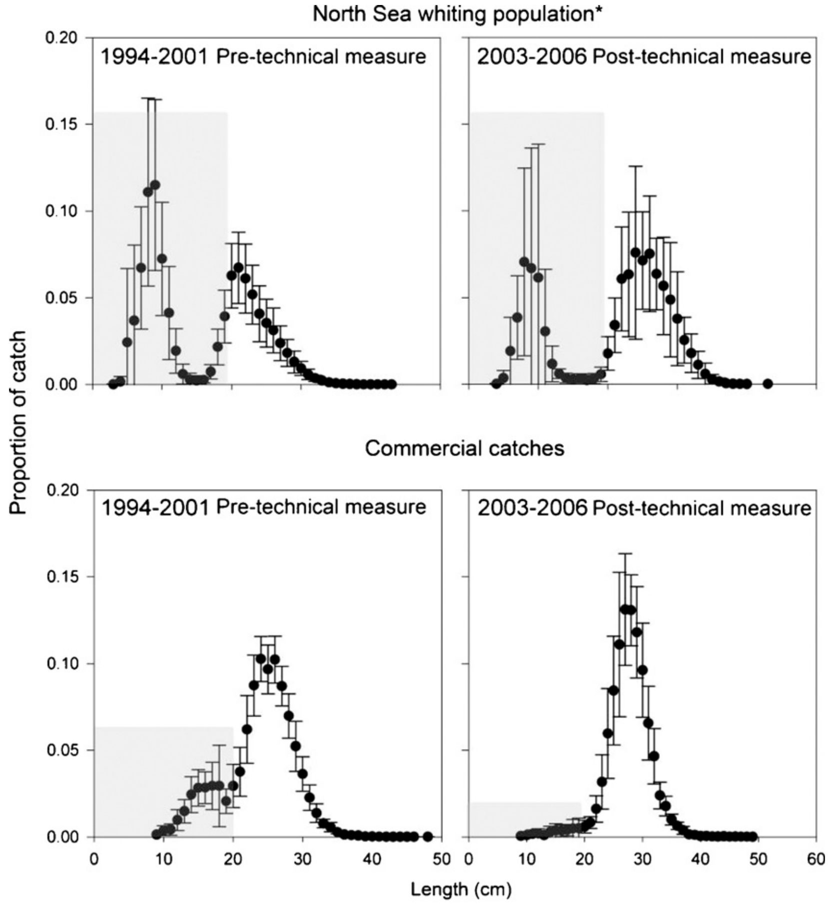

Fig. 6. Comparison of commercial catches of whiting by English and Welsh *Nephrops* trawlers in the North Sea before (1994–2001) and after (2003–2006) the introduction of gear technical measures (EU regulation EU2056/01, SI 2001/649, SSI 2000/227). The data collected from IBTS surveys (top) show that there is a generally unchanged size structure of the whiting population. Shaded boxes show a reduction in the commercially caught small whiting (<20 cm) from 2003 onwards (bottom). *Source: International Bottom Trawl Survey Data (IBTS). Data presented are mean annual proportions of whiting at length. Error bars show ±2S.E.

an update would facilitate more focused discard management measures for the future.

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