Evaluating the efficacy of technical measures: a case study of selection device legislation in the UK *Crangon crangon* (brown shrimp) fishery

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Bycatch reduction devices are being introduced into a wide range of fisheries, with shrimp and prawn fisheries particularly targeted owing to the heavy discarding common in these fisheries. Although studies are often undertaken to estimate the impact of a technical measure on the fishery before implementation, rarely have the impacts been assessed *ex post*. Here, the efficacy of the UK legislation pertaining to the use of sievenets in the North Sea *Crangon crangon* fishery is assessed. Three impacts were evaluated: on fisher behaviour (social), on the level of bycatch (biological), and on vessel profitability (economic). An apparent high level of compliance by skippers was identified despite a low level of enforcement. The estimated reduction in fleet productivity following the introduction of the legislation was 14%, equalling the mean loss of *Crangon* landings when using sievenets calculated from catch comparison trawls. Sievenets did reduce the unnecessary capture of unwanted marine organisms, but were least effective at reducing 0-group plaice, which make up the largest component of the bycatch. Clearly the legislation has had an effect in the desired direction, but it does not address sufficiently the bycatch issue in the *Crangon* fishery.

Keywords: catch comparison, fisher behaviour, North Sea, *Pleuronectes platessa*, productivity, profitability.

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Introduction

Crangon crangon (brown shrimp) are caught primarily in estuaries and inshore areas of countries bordering the North Sea. German and Dutch vessels catch ~85% of the total European landings, and Danish, Belgian, and UK vessels take the balance. The brown shrimp fisheries are economically important, producing annual landings with a market value of €70–90 million annually. There has been also an overall trend of increasing brown shrimp landings, from a total of ~20 000 t per year in the mid 1990s to 37 000 t in 2006 (ICES, 2006a).

The main fishing areas for brown shrimp also correspond to the nursery grounds of important commercial whitefish caught in the North Sea, including plaice (*Pleuronectes platessa*), whiting (*Merlangius merlangus*), and cod (*Gadus morhua*). Brown shrimp grow to 9 cm long (Hayward and Ryland, 1996), requiring a net with small meshes to catch them. The minimum mesh size for nets in EU waters is 20 mm. A consequence of this small mesh size and the location of the fishery in the nursery grounds is that a large bycatch of juvenile fish is taken.

The discarding of juvenile fish species in brown shrimp fisheries has been extensively reported (Revill *et al.*, 1998, 1999; van Marlen *et al.*, 1998; Graham, 2003; Revill and Holst, 2004); of particular concern is the bycatch of juvenile plaice. Before the introduction of new legislation, it was estimated that more than 900 million juvenile plaice were discarded every year (van Marlen *et al.*, 1998), a level of discarding considered likely to be having a significant biological and economic impact on the North Sea plaice stock and its fishery potential. It was estimated that the numbers of discarded 0- and 1-group plaice could result in 7000–19 000 t of annually foregone plaice landings (Revill *et al.*, 1999).

These and similar findings provided the impetus to implement a new technical measure designed to reduce fish bycatch in the brown shrimp fisheries. In January 2000, legislation was enacted requiring all fishers in the European brown shrimp fisheries to use selective gear that reduced the incidental bycatch of juvenile commercial fish species. EC Fisheries Technical Conservation Regulation (Council Regulation 850/98) requires that vessels engaged in brown shrimp beam trawl fisheries in Community waters must use trawls fitted with either a sievenet (veilnet; Revill and Holst, 2004) or a selection grid (Polet, 2002; Graham, 2003).

Each member state was responsible for implementing their own legislation, enforceable within their national waters. All legislation came into force in January 2003, 3 years from the initial enactment, to allow fishers to adjust their fishing operations. The UK legislation covers England and Wales in Statutory Instrument 2002 No. 2870 (The Shrimp Fishing Nets Order). The legislation details the specifications of the sievenets or sorting grids that must be used.

Sievenets are constructed with larger meshes than the brown shrimp trawls into which they are inserted. The sievenet is attached to the full circumference of the shrimp trawl near the beam, and tapers to an apex where it is attached to the belly of the shrimp trawl. An exit hole is cut where the sievenet and shrimp trawl join, allowing organisms too large to pass through the sieve to escape, whereas the shrimp can pass through the sieve and into the codend (Revill and Holst, 2004). In UK waters, the mesh size of the sieve must measure at least twice that of the codend, and no more than 70 mm, and the exit hole must be large enough to allow all fish that do not pass into the codend to escape.

Selection grids consist of a series of longitudinal bars positioned at the entrance to the codend. The grid acts as a barrier to the passage of fish too large to pass between the bars, which instead are guided to an escape hole in the upper section of the net (Graham, 2003). Vessels fishing for brown shrimp in UK waters must use a grid with a bar spacing of no more than 20 mm, fitted so that fish cannot reach the codend without passing through the grid.

This study is an evaluation of the efficacy of the UK Shrimp Fishing Nets Order. The study is multidisciplinary, incorporating information on fishing patterns, fleet structure, biological effects, economics, and on levels of enforcement and compliance. Few studies on the impacts, efficacy, and validity of fishery technical measures in Community waters have been made. Previous studies have carried out either predictive or retrospective evaluations on the social, biological, and/or economic impacts of technical measures (e.g. Pastoors *et al.*, 1998; Pawson and Pickett, 2003; Suuronen and Tschernij, 2003). For the UK brown shrimp fishery, the substantial social, biological, and economic empirical datasets generated before and following the legislation's introduction permit a holistic evaluation of the technical measure. The study therefore provides a unique opportunity to evaluate the efficacy of this technical measure and aid the development of a framework to evaluate other technical measures.

Methods

The method of evaluating the efficacy of the Shrimp Fishing Nets Order consisted of three components: (i) a social analysis, to identify changes in fleet structure and fishing patterns since the introduction of the legislation, along with the extent of compliance and enforcement of the legislation; (ii) a biological analysis to evaluate the performance of commercially used selective gear and to identify changes in fish stocks; and (iii) an analysis of the economic implications of the legislation.

Social analysis

Information from previous surveys on the UK brown shrimp fishing fleet conducted in 1996 (Revill, 1996) and 2000 (ASR, unpublished) were utilized for the study. The 1996 survey collected quantitative information, including vessel and engine size, deck and wheelhouse equipment, and the number of days each vessel spent working on different fisheries. The 2000 survey collected data on the level of voluntary uptake of sievenets and the problems encountered by UK fishers when using this gear.

In 2006, a list of active shrimp vessels was produced with the assistance of local enforcement organizations and skippers. The 1996 survey was repeated in 2006 to identify changes in the structure and fishing patterns of the shrimp fleet since the initial survey. The format of the survey was unchanged but an additional question was asked in the 2006 survey: "What do you think of sievenets?" Information was collected on 60% of the known active vessels; half the skippers responded to a postal survey, others were questioned face to face.

There are two organizations responsible for enforcing fishery regulations in UK waters, the Marine Fisheries Agency (MFA) and the Sea Fisheries Committees (SFCs). The MFA is a national body that conducts both quayside and at-sea inspections. SFCs are regional associations; the seaward limit of SFC districts is 6 nautical miles. The main UK brown shrimp fishing grounds fall within the jurisdiction of the Eastern Sea Fisheries Joint Committee (ESFJC). Both organizations provided data on the number of inspections performed in UK shrimp beam trawlers per year from 2003, along with any evidence of non-compliant behaviour towards the selection device legislation. Semi-structured interviews on enforcing the legislation were conducted with enforcement agents.

Biological analysis

To test the ability of sievenets to reduce discards, a series of catch comparison trials was performed. In all, 106 hauls were sampled between 17 January 2006 and 6 January 2007 on board five commercial vessels (Table 1). In seven hauls, large amounts of weed were caught and the catch could not be sorted, and in one haul nothing was caught, so no data were collected from these eight hauls. All vessels sampled had twin beam trawls; their skippers fished for brown shrimp during the sampling period and were willing to conduct trials with a researcher on board. Vessel selection was considered random within these criteria.

Catch comparison trials were conducted in which the sievenet in one of the two beam trawls was disabled and that in the other beam trawl was left unchanged. The portside sieve was disabled in 56% of sampled hauls, the starboard side in 44%. Haul durations were in each case 1 h. The skipper chose the location of fishing, and if the area was characterized by steep sandbanks, he ensured that each beam trawl fished for an equal time uppermost on the sandbank during each haul (Figure 1).

On retrieval of the two trawls, the catch in each was sorted separately and into three fractions using the normal commercial sorting procedure. A rotary or shaking riddle separated the largest organisms from the shrimp and other fish. Marketable shrimp and fish of intermediate size were then separated from the smaller unmarketable shrimp and the smallest fish. The total weight of each fraction was recorded, and samples of fish from a known weight of each fraction were returned to the laboratory for analysis.

All plaice, dab (*Limanda limanda*), whiting, and cod in the samples were measured, and all other species identified and counted. Where subsampled, sample numbers were raised to give the total number of fish in each trawl. The total weights of fish bycatch, marketable shrimp, and unmarketable small shrimp were calculated for each trawl and compared (ANOVA). The mean numbers per trawl and the difference in total numbers caught with and without sieves were calculated for all species.

For each haul, the proportions of each length class of plaice, whiting, dab, and cod caught in the trawl without the sieve relative to the total number caught by both the trawls (the split parameter; Revill and Holst, 2004) were analysed using a generalized linear mixed model (glmm) with multivariate normal random effects, using penalised quasi-likelihood (glmmPQL; Breslow and Clayton, 1993; Venables and Ripley, 2002). A proportion of 1 indicated that all the fish of that length were caught in the beam trawl

Table 1. Specifications of the five UK shrimp beam trawlers used in catch comparison trials in 2006/2007.

Vessel	Length overall (m)	Engine power (kW)	Beam length (m)	Number of hauls	Months sampled
1	9.9	112	6.0	36	January and February 2006
2	9.9	90	4.6	33	October 2006
3	11.6	95	5.0	5	November 2006
4	9.9	106	5.0	16	November 2006, January 2007
5	17.6	226	8.6	8	December 2006

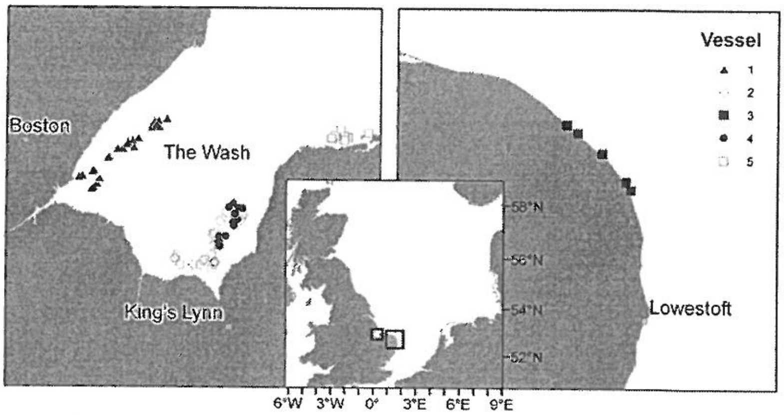

Figure 1. Location of catch comparison trawls conducted on board UK commercial vessels targeting brown shrimp in 2006/2007.

without the sievenet and that none were caught when using the sieve. A value of 0.5 indicated that using a sievenet did not affect the numbers of fish caught at that length. The analyses accounted for variation between hauls within vessels and between vessels, to generate a fitted model and its limits of significance.

In 1999 and 2000, before the implementation of the legislation, experimental versions of the sievenets were tested, so an equivalent glmm analysis was performed on data from those gear trials. Catch comparison trials of sievenets were conducted using the same sampling procedure as in the 2006/2007 trials, and 93 hauls were conducted on board two vessels (net designs I, III, and IV; Revill and Holst, 2004). The results from that analysis allowed comparison of the performance of sievenets when used commercially with that of the experimental designs.

The sample mean estimator method was used to raise the total numbers of plaice, dab, whiting, and cod in the hauls sampled by the official weight of *Crangon* landings in 2006. This generated the estimated total number of these fish caught in 2006/2007, on the assumption that all vessels used sievenets all year; this value was compared with an estimate assuming that no vessels had used sievenets.

Finally, ICES estimates of North Sea plaice recruitment and fishery-independent density estimates of plaice, cod, and whiting on the UK fishing grounds from the Cefas Young Fish Surveys of 2001–2006 were examined to identify any changes in the numbers of juvenile whitefish in the North Sea since the introduction of the selection device legislation.

Economic analysis

The economic analysis estimated changes in profitability following the introduction of the new technical measure. Information on fixed costs, including fishing gear and insurance, were obtained from vessels from two fishing companies, and more comprehensive information was collected from three independent vessels.

The analysis focused on the changes in revenue arising from the adoption of the new gear. The retrospective change in productivity of the brown shrimp fleet as a consequence of the use of sievenets was estimated using a production frontier approach (PFA; Aigner *et al.*, 1977). The PFA models the relationship between the level of inputs to outputs, while allowing for the presence of vessel-specific inefficiency. Only a summary of the analysis is given here; the results of the full study are presented by Innes and Pascoe (2007).

The analysis utilized vessel logbook data detailing brown shrimp landings by trip during the period January 1999–August 2006. The exact time when vessels started using the sieves could not be determined in most instances, so given this uncertainty, and the increased likelihood of measurement error resulting from unaccounted sieve use, data for the period July 2000–June 2002 were not included. For those vessels with a reliable date for the uptake of sievenets, the model was adjusted accordingly. The final dataset consisted of 1156 monthly observations for 51 vessels.

An important factor affecting the catch of any vessel is the level of stock size, but there are no data on *Crangon* stock biomass. A proxy measure for stock size, such as landings per unit of effort (lpue), also could not be used because this can be affected by changes in fleet composition and technical change (Pascoe and Herrero, 2004). Instead, dummy variables were used to represent year and month effects on landings. A constant seasonal pattern running from July to June (base periods July and 1998/1999) was assumed to reduce the number of month dummies required. This pattern is consistent with the assumption that *Crangon* recruit to the fishery in July (ICES, 2005). The dummy variable shifts the production frontier up or down. Implicit in the model is that the proportional impact of the sievenets is identical for all vessels.

Table 2. Specifications and fishing patterns of the UK brown shrimp fleet during the surveys of 1996 and 2006 (± s.e.).

Parameter	1996 (n = 78)			2006 (n = 35)		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Vessel specification						
Length overall (m)	6.8	19.1	11.9 ± 0.3	9.4	17.9	12.3 ± 0.5
Main engine power (kW)	22	223	112 ± 5.0	46	226	149 ± 10
Gearbox ratio (x:1)	2	5	2.6 ± 0.1	2	5	2.9 ± 0.1
Fuel tank (l)	45	10 000	1 558 ± 209	168	10 000	3 097 ± 483
Beam length (m)	3.6	9	5.9 ± 0.1	4	9	6.4 ± 0.2
Fishing pattern						
Days per year shrimp-fishing	30	275	131 ± 5	6	270	147 ± 13
Tows per day	3	12	5.8 ± 0.1	3	14	7.1 ± 0.5
Duration of tow (h)	0.5	2.5	1.3 ± 0.05	1	3	1.6 ± 0.09
Towing speed (knots)	1	4	2.3 ± 0.06	1	4	2.5 ± 0.1

Results

Social analysis

The main UK brown shrimp fishery is located on the east coast of England in the area of the Wash. There is some fishing throughout the year, but the main season runs from August to April. Most of the fleet operates from the ports of Boston and Kings Lynn, and fishing trips are generally 12–48 h duration. Most vessels use one of two types of mechanical grader, a shaker riddle (or sieve) or a rotary riddle, to sort their catch, and the shrimp of commercial size are cooked on board. Discards are returned overboard either manually or by water-flow system.

Fleet structure

In 1996, the shrimp beam trawl fleet comprised 98 vessels, of which 78 actively fished. By 2006, the number of active vessels had fallen by 23%, to 60, and 60% of the vessels identified in the 1996 survey were no longer registered as commercial fishing vessels. There was a marginal increase in the mean length of vessels during the period 1996–2006 (Table 2). The smallest vessels in 1996 operated single beam trawls, but none of these were left in 2006 (Table 3). Local bylaws restricting the areas where large vessels were permitted to operate are likely to have influenced the mean vessel length.

Table 3. Percentage of vessels with various wheelhouse and deck equipment in 1996 and 2006.

Equipment	1996 (%)	2006 (%)
Twin beams	88	100
Shaking sieve	85	74
Rotary sieve	33	40
Power take-off	73	81
VHF	100	100
Autopilot	46	82
Fish finder	42	74
Colour echosounder	52	82
Ground discrimination	13	26
Track plotter	40	94
Radar	90	100

The main engine power of vessels in 2006 was an average of 33% higher than in 1996, and the mean fuel storage capacity doubled in the same period. The number of vessels with power take-offs to run auxiliary equipment also increased. By 2006, more vessels were using rotary riddles, which are considered to be more efficient than shaker riddles. There was also a large increase over the period 1996–2006 in the number of vessels fitted with autopilots, fish finders, colour echosounders, ground discriminators, and track plotters.

Fishing patterns

The skippers' descriptions of their fishing effort and exploitation pattern were similar in 1996 and 2006. For both surveys, there was great variation between vessels in the numbers of days spent fishing for brown shrimp. From the 2006 survey, it was clear that skippers took part in 11 other fisheries, including longlining, gillnetting, sprat trawling, otter trawling, beam trawling for fish, crab potting, scalloping, hand-raking for cockles, and beam trawling for pink shrimp. Some skippers spent most of the year on one of these, others worked on up to six fisheries per year.

The time spent targeting brown shrimp varied annually, and was affected by catch rates, the market price of the shrimp, and the availability of other fishing opportunities. The weight of brown shrimps landed by UK vessels in 2006 was the lowest in 10 years (Figure 2), likely because of the combined effects of low catch rates, low market prices, and high fuel prices. In 2006, vessels concentrated their effort on dredging for mussels and cockles, when permitted, and hand-raking for cockles.

Compliance

Legislation requires UK shrimp beam trawlers to use either selection grids or sievenets in UK waters. In 2006, 91% of vessels were using sievenets (Table 4); none used selection grids.

In all, 14 skippers responded to both 2000 and 2006 surveys, and of the six skippers not using sieves in 2000, all were using them by 2006, suggesting that most skippers not using sieves before 2003 did so following the introduction of the legislation. In 2000, most skippers were already using sievenets (Table 4), but 71% of respondents stated that sieves could not be used when large amounts of weed accumulated on the fishing grounds, because it clogged the nets and was difficult to remove. The period in which large amounts of weed are present was

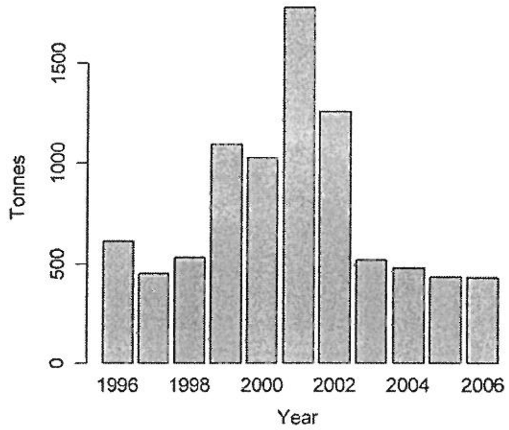

Figure 2. Official UK brown shrimp landings, 1996–2006.

Table 4. Percentage of vessels in compliance with the UK brown shrimp fishery selection device legislation.

Year	In compliance
1996	35% (27 of 78)
2000	62% (19 of 31)
2002	80%[a]
2006	91% (32 of 35)

[a]Source: Defra (2002).

estimated at 2–4 months of the year, although in some inshore areas it was present most of the time. Other criticisms of the sievenets were the loss of shrimp catches (19% of respondents), and the loss of marketable fish (7% of respondents).

In 2006, 14 skippers provided detailed feedback on the use of sievenets. Six of these stated that catches were cleaner when using sievenets and that sorting time was reduced, two considered that sievenets resulted in no loss of shrimp, and five believed there was a 10–25% loss. The rigging of the sievenet was considered crucial both to its effectiveness at reducing fish bycatch and at retaining shrimp. Several skippers said that they disabled sievenets when weed was prevalent on the fishing grounds.

Other modifications that had been made to some sievenets included reducing the size of the exit hole to retain skates and rays (*Raja* spp.) and attaching a bag to the exit hole to retain Dover sole (*Solea solea*) of marketable size, which are found for a few months of the year on the shrimp fishing grounds. Both these modifications contravene the legislation.

Enforcement

Over the period 2003–2006, the MFA conducted 19 at-sea inspections and 112 quayside inspections of shrimp beam trawlers working in UK waters, and during the same period, the ESFJC conducted 26 at-sea inspections (Table 5). No infringements were reported relating to sievenets.

In interviews with inspectors at the district MFA office, it was stated that the number of at-sea inspections would be higher but for the relatively small scale of the fishery, the absence of any quota restrictions for brown shrimp, and the location of the fishing grounds. The shallow depth of the Wash makes navigating

Table 5. Number of inspections and tasks performed on board brown shrimp vessels in UK waters.

Inspection	2003	2004	2005	2006
MFA				
At-sea	4	5	3	7
Quayside	38	45	21	8
ESFJC				
At-sea	9	5	0	12
Main net measured	2	1	0	11
Attachments noted	1	0	0	10
Sievenets present	0	0	0	3

fishery protection vessels difficult. Similarly, members of the ESFJC enforcement team considered the number of inspections on shrimp beam trawlers to be relatively low. They were aware of a problem with the wording of The Shrimp Fishing Nets Order, which states that "The prohibition in this article shall not apply to fishing boats with either (a) an aggregate beam width of 8 metres or less; or (b) a net headline of 8 metres or less".

Vessels using two beam trawls of width 4 m or less, i.e. having an aggregate beam width of 8 m or less, are exempt from the legislation. Also exempt are those vessels with an aggregate headline of 8 m or less. During the 2006 survey, only one vessel was exempt from the legislation. However, by omitting the word "aggregate" in "(b)", one interpretation of the legislation would be that if neither of the two beam trawls employed has a headline that exceeds 8 m, then selection devices need not be used. For this reason, the ESFJC did not consider that the legislation was legally enforceable, and with many vessels using two beam trawls of width <8 m each, they concentrated their resources elsewhere.

Biological analysis

The weight of marketable shrimp caught by one beam trawl in 1 h varied from 4 to 71 kg. The weight of fish bycatch, and the catches of marketable shrimp and small shrimp were significantly less when using beam trawls with sievenets than when the sievenets were disabled (ANOVA, $p < 0.01$ for all variables). The mean weight of fish bycatch when using a sievenet was 6.2 ± 0.5 kg, compared with 11.4 ± 1.0 kg when not. There was a mean reduction of 36 ± 4% in fish bycatch and of 14 ± 3% in marketable shrimp using sievenets (Table 6). Plaice, whiting, and herring (*Clupea harengus*) were present in >90% of hauls, and overall reductions in catch numbers were observed in 24 of the 26 most commonly caught species when sievenets were operating (Table 7). Total catch numbers of plaice, dab, whiting, and cod were

Table 6. Catches made by one beam trawl with and without sievenets sampled by UK brown shrimp trawlers in 2006/2007 (± s.e.).

Catch	No sieve mean catch (kg)	With sieve mean catch (kg)	Mean reduction %
Marketable shrimp (uncooked)	26.8 ± 1.5	22.3 ± 1.3	14 ± 2.6
Unmarketable small shrimp	29.6 ± 46.0	23.7 ± 30.7	8 ± 3.1
Fish bycatch	11.4 ± 10.4	6.2 ± 5.3	36 ± 3.8

Table 7. Numbers (± s.e.) of the most common species caught in 1-h tows ($n = 98$) in one beam trawl with and without sievenets, and the percentage reduction in total numbers from all hauls when operating sievenets.

Species	Common name	% of hauls present	No sieve mean number	Sieve mean number	Overall percentage reduction
Pomotoschistus minutus	Sand goby	100	647 ± 97	492 ± 65	24
Pleuronectes platessa	Plaice	99	307 ± 34	206 ± 25	33
Merlangius merlangus	Whiting	96	99 ± 10	72 ± 7	27
Clupea harengus	Herring	92	171 ± 32	141 ± 26	17
Limanda limanda	Dab	82	103 ± 14	57 ± 10	45
Sprattus sprattus	Sprat	78	142 ± 23	113 ± 18	20
Agonus cataphractus	Pogge	74	22 ± 4	10 ± 3	53
Osmerus eperlanus	Smelt	72	70 ± 17	74 ± 22	−6
Carcinus maenas	Shore crab	65	57 ± 12	16 ± 4	71
Gadus morhua	Cod	60	19 ± 5	5 ± 1	70
Syngnathidae	Pipefish	60	37 ± 7	32 ± 7	14
Platichthys flesus	Flounder	59	9 ± 3	2 ± 1	72
Pegusa lascaris	Sand sole	54	16 ± 3	9 ± 2	40
Liparis liparis	Sea-snail	52	14 ± 5	2 ± 0.4	83
Taurulus spp.	Scorpion fish	36	3 ± 1	0.7 ± 0.2	73
Liocarcinus spp.	Swimming crab	35	79 ± 45	15 ± 8	81
Asterias rubens	Starfish	33	4 ± 1	2 ± 5	51
Ophiothrix fragilis	Brittlestar	18	8 ± 30	5 ± 2	28
Dicentrarchus labrax	Bass	18	5 ± 2	4 ± 0.2	26
Echiichthys vipera	Lesser weaver	18	3 ± 1	0.8 ± 0.3	66
Sepiola atlantica	Little cuttlefish	14	3 ± 1	3 ± 0.8	−4
Macropodia spp.	Tiny spider crab	13	0.8 ± 0.3	0.3 ± 0.1	59
Solea solea	Sole	13	0.3 ± 0.1	0.04 ± 0.03	86
Ciliata mustela	5bearded rockling	11	0.6 ± 0.2	0.2 ± 0.1	48
Raja clavata	Thornback ray	11	0.2 ± 0.06	0.01 ± 0.01	92
Lycodes esmarkii	Eelpout	10	1.0 ± 0.3	0.1 ± 0.08	77

reduced by 33%, 45%, 27%, and 70%, respectively, when sievenets were used (Tables 7 and 8). The between-vessel variance was <1% of the between-haul variance.

In general, the larger the fish, the less their retention capacity; few fish >25 cm were caught using trawls with sieves (Figure 3). In the 2006/2007 trials, significantly fewer plaice of all lengths were retained in trawls with sievenets, and significantly fewer dab, whiting, and cod >8 cm long were retained in trawls with sieves (Figures 3 and 4).

Length frequency data from beam trawls with codend mesh sizes of ~20 mm and no sieves attached provided length profiles for the populations of the four main demersal fish species. The fishing grounds were dominated by 0-group fish (Figures 3 and 4) and, because sievenets were less effective at releasing small fish, even with sieves attached, large numbers of small fish were caught. Plaice was the most abundant non-target commercial species, with a mean length of 6 cm (Table 7).

Table 8. Catch comparison and results from the glmmPQL analysis comparing the number of fish caught using a beam trawl with and without a sievenet.

Species	Total number caught with sieve	Total number caught with no sieve	Number of hauls	*p*-value
Plaice	20 211	30 085	97	<0.01
Dab	5 544	10 142	84	<0.01
Whiting	7 027	9 865	98	<0.01
Cod	503	1 889	62	<0.01

The efficiency of sievenets in 2006/2007 was consistent with those tested in 1999 and 2000 (Figure 3). The commercial sieves displayed a slightly better release of plaice and dab of intermediate length than the experimental versions of the sieves. Unlike the experimental sieves, significantly more of the smallest dab (<4 cm) were caught in trawls with commercial sievenets.

Assuming that all vessels used sievenets throughout 2006, an estimated 4.5 ± 0.5 million plaice, 1.2 ± 0.2 million dab, and 1.6 ± 0.2 million whiting were caught by UK shrimp beam trawlers, compared with an estimated 6.8 ± 0.8 million, 2.2 ± 0.3 million, and 2.2 ± 0.2 million, respectively, had sieves not been used (Table 9). Brown shrimp landings in 2006 were 430 t, an estimated 70 t less than if sievenets not been used.

Estimates of recruitment for plaice (age 1) in the North Sea have not shown a notable increase since 2003 (ICES, 2006b; Figure 5). Similarly, fishery-independent data show no localized change in plaice, whiting, and cod density in the Wash between 2001 and 2006 (Cefas, upublished data).

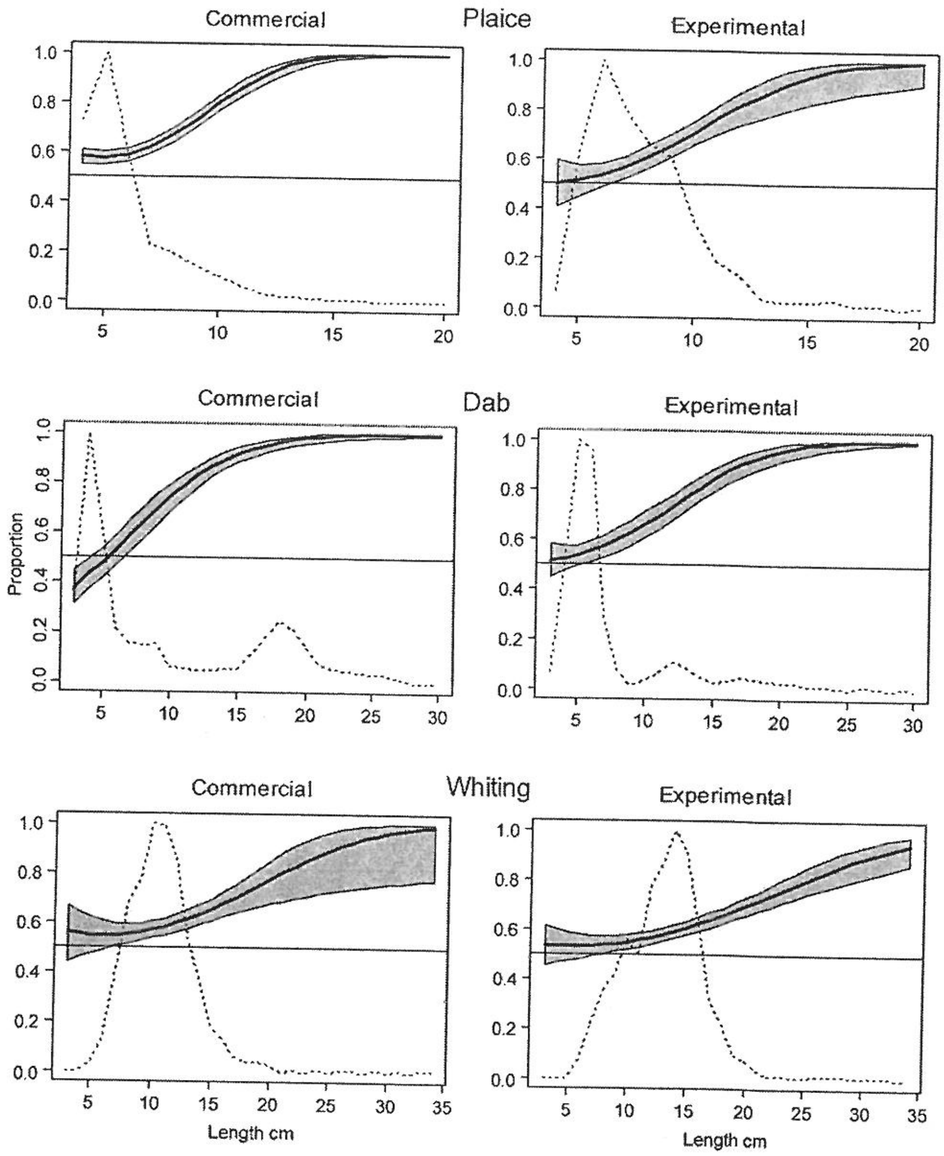

Figure 3. Modelled proportion of the number of plaice, dab, and whiting by length caught in trawls without sieves relative to the total caught in both beam trawls (with and without sieves); a value of 0.5 indicates an equal number caught in both trawls. Grey areas depict significance around the modelled fit, and the dotted line is the length frequency of the population (pooled total catch in trawls without sieves). Commercial data were derived from commercially used sievenets (2006/2007), and experimental data from experimental versions of sievenets (1999/2000).

Economic analysis

The model indicated a 14% reduction in output following the introduction of the legislation [estimated as $(1-e^{-0.146}) \times 100 = -13.58\%$), all other things being equal. The elasticity associated with effort was not significantly different from 1 (p ;> 0.05), suggesting constant returns to effort.

Inadequate information on when individual vessels started using sievenets potentially underestimates the full effect. An implicit assumption of the sievenets coming into use on 1 January 2003 is that the vessels were not using them before. Where this assumption is not satisfied, the true consequence of using sievenets is diluted.

Discussion

There was evidence of good compliance with The Shrimp Fishing Nets Order. Some skippers disabled the sievenets when weed was prevalent, and some modified the exit hole to retain marketable fish. The extent of this non-compliant behaviour could not be ascertained, however, but it is likely to occur only at certain times of the year.

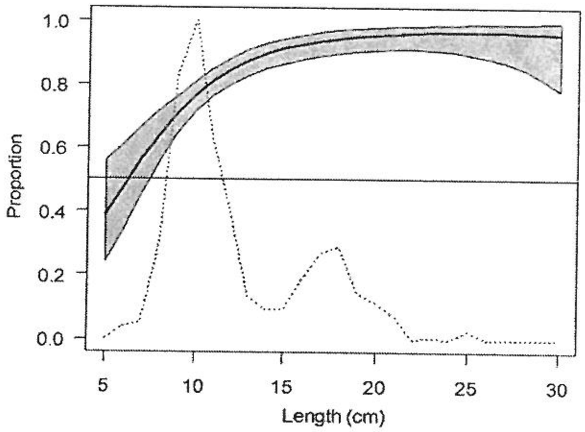

Figure 4. Modelled proportion of the number of cod by length caught in trawls without commercial sievenets (2006/2007) relative to the total caught in both trawls (with and without sieves). Grey areas depict significance around the modelled fit, and the dotted line is the length frequency of the population (pooled total catch in trawls without sieves).

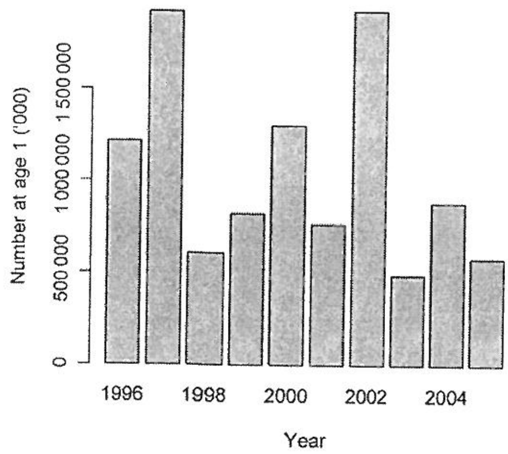

Figure 5. ICES estimates of annual recruitment (age 1) of North Sea plaice.

Table 9. Estimated numbers (± s.e.) of whitefish caught by brown shrimp beam trawlers in 2006, and the predicted numbers caught had sievenets not been used.

Catch/landings	Estimate with sieves	Prediction if no sieves
Plaice	4 544 441 ± 5 552	6 764 221 ± 7 662
Dab	1 246 634 ± 2 260	2 280 288 ± 3 168
Whiting	1 579 957 ± 1 611	2 218 041 ± 2 203
Cod	113 093 ± 290	424 762 ± 1 123
Shrimp	430 t (official landings)	500 ± 1.8 t

There are exemptions for the use of sievenets and grids used in brown shrimp fisheries in other member states. For instance, vessels working in German waters need not use selection devices between 1 May and 30 September, and there may also be further exemptions if good reason can be given. Similarly, the legislation for Dutch waters does not apply for the period 15 April–15 November. The timing of these exemptions corresponds with periods of high weed abundance. UK fishers requested an exemption for periods when weed was prevalent, and they also argued for the use of bags over the exit holes (Defra, 2002), but neither request was granted. A good level of compliance by UK skippers was apparent despite the low level of enforcement. The Shrimp Fishing Nets Order was sufficiently legitimized by most skippers for them to comply with it most of the time.

Between 1996 and 2006, the UK brown shrimp fleet shrank by 23%. The reduction in single beam trawlers is a trend that began in the 1980s (Revill, 1996), and there is no direct evidence that the smaller fleet size is an effect of the new legislation. Since the introduction of the legislation in 2003, UK brown shrimp landings have been relatively small. Catch comparison trials with and without sievenets operating illustrated a mean loss of 14% (uncooked weight) when sieves were used, a result consistent with the results from the trials of experimental sievenets, where losses were 7–12% (Revill and Holst, 2004). As stated above, this reduction in catchability equates to an estimated reduction in UK brown shrimp landings in 2006 of 70 t.

Revenue is a function of both output and prices. Earlier studies suggested that price increases for brown shrimp would offset production decreases, resulting in little change in revenue (Pascoe and Revill, 2004). However, at a European level, output has been maintained despite the reduced productivity. Increases in lpue in areas other than those exploited by UK fishers (ICES, 2006a) have largely offset the productivity effects of the gear restrictions. Prices have therefore remained fairly constant in real terms, and the productivity decrease (14%) has resulted in a revenue decrease of similar proportions for the UK fishers.

A central motivation for the introduction of selection devices in brown shrimp fisheries was to protect and enhance the North Sea stock of plaice. Based on the 2005 estimate of spawning-stock biomass and fishing mortality, ICES classified the North Sea plaice stock as being at risk of reduced reproductive capacity, and as such being harvested unsustainably (ICES, 2006b). Moreover, there is no indication that recruitment of North Sea plaice has increased since 2003.

The UK fishery contributes <5% of the total EU brown shrimp landings and associated fish bycatch. Even with the good uptake of The UK Shrimp Fishing Nets Order, there is likely to be no discernible effect on the North Sea stock of plaice. There are no equivalent studies examining the efficacy of the sievenet legislation in other member states, but assuming compliance with legislation by other fleets is comparable with that of the UK fleet would indicate that the original legislation was not sufficient to deliver the predicted improvements to North Sea plaice.

In gear trials, the commercially used sievenets worked as effectively as the experimental versions. The number of fish caught using trawls with sieves was less than when using trawls without, but substantial numbers of 0-group fish were still retained when sieves were operating. The prevalence of 0-group fish on the fishing grounds, in the size range for which the sieves are least effective, and the exemptions applying to the main EU brown shrimp fleets of Germany and the Netherlands, will have lessened the benefits for North Sea plaice of the legislation.

The nursery areas on the eastern side of the North Sea contribute most of the total plaice recruitment. There is evidence that in recent years the main North Sea flatfish beam trawl fleet has shifted its effort inshore. Combined with the distribution of juvenile plaice moving more offshore, this has led to an apparent increase in discarding (ICES, 2007). In some areas, >90% of the plaice caught are discarded in the flatfish fishery (ICES, 2006b). Although there is no proof of a direct relationship between total discard mortality and recruitment (ICES, 2007), it is possible that discarding of such a magnitude may have masked any benefit that the sievenets might be delivering to the flatfish fisheries.

The Shrimp Fishing Nets Order was effectively implemented, largely because fishers were willing to comply with it. The legislation reduces the unnecessary capture of unwanted marine organisms and, as such, is consistent with the requirements of the precautionary principle and the ecosystem approach, as defined in EU legislation. However, although no positive effect on North Sea plaice stocks resulting from the legislation has been identified, that is not to say that none has transpired. There is scope for further reductions in discarding in the UK brown shrimp fishery, but it is unlikely that any enhancement of North Sea whitefish stocks will be detected unless this is complemented with changes to the exploitation patterns in other fisheries.

This study has illustrated some of the tools required to evaluate comprehensively technical measures that have been introduced. Of particular value was the collection of comparable and consistent data before and following the introduction of the legislation. The social data clearly illustrated the uptake of the technical measure. The consistent methods used in the gear trials allowed a direct comparison of the actual and the predicted performance of the technical measure. However, the study was limited to the UK, so definitive conclusions relating to any EU-wide technical measure on fish stocks could not be made. We conclude that future evaluations of the efficacy of technical measures would benefit from utilizing social, biological, and economic data collected before and after implementation, from all fisheries to which the legislation applies, and using consistent methods.

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References

Aigner, D., Lovell, C. A. K., and Schmidt, P. 1977. Formulation and estimation of stochastic frontier production function models. Journal of Econometrics, 6: 21–37.

Breslow, N. E., and Clayton, D. G. 1993. Approximate inference in generalized linear mixed models. Journal of the American Statistical Association, 88: 9–25.

Defra. 2002. Regulatory impact assessment of the shrimp fishing nets order 2002. Accessed 8 December 2006 from DEFRA website wwww.defra.gov.uk/corporate/regulat/ria/default.htm.

Graham, N. 2003. By-catch reduction in the brown shrimp, *Crangon crangon*, fisheries using a rigid separation Nordmore grid (grate). Fisheries Research, 59: 393–407.

Hayward, P. J., and Ryland, J. S. 1996. Handbook of the Marine Fauna of North West Europe. Oxford University Press, Oxford, UK. 800 pp.

ICES. 2005. Report of the Working Group on *Crangon* Fisheries and Life History, 4–9 October 2004, Copenhagen, Denmark. ICES Document CM 2005/G: 01. 85 pp.

ICES. 2006a. Report of the Working Group on *Crangon* Fisheries and Life History, 30 May–1 June 2006, IJmuiden, the Netherlands. ICES Document CM 2006/LRC: 10. 31 pp.

ICES. 2006b. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak, 5–14 September 2006, ICES Headquarters. ICES Document ACFM: 35. 1001 pp.

ICES. 2007. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak, Combined Spring and Autumn, 1–8 May 2007, ICES Headquarters. ICES Document ACFM: 18 and 30. 960 pp.

Innes, J., and Pascoe, S. 2007. Impact on the profitability of the commercial UK *Crangon* fishery, Research Paper P162. Final Report submitted to Cefas, available from http://www.port.ac.uk/research/cemare/publications/researchpapers/

Pascoe, S., and Herrero, I. 2004. Estimation of a composite fish stock index using data envelopment analysis. Fisheries Research, 69: 91–105.

Pascoe, S., and Revill, A. 2004. Costs and benefits of bycatch reduction devices in European brown shrimp trawl fisheries. Environmental and Resource Economics, 27: 43–64.

Pastoors, M., Rijnsdorp, A. D., and Van Beek, F. A. 1998. Evaluation of the effects of a closed area in the North Sea (Plaice Box) on the stock development of plaice (*Pleuronectes platessa*). ICES Document CM 1998/U: 2. 21 pp.

Pawson, M., and Pickett, G. 2003. The role of technical measures in the recovery of the UK sea bass (*Dicentrarchus labrax*) fishery 1980–2002. ICES Document CM 2003/Z: 06.

Polet, H. 2002. Selectivity experiments with sorting grids in the North Sea brown shrimp (*Crangon crangon*) fishery. Fisheries Research, 54: 217–233.

Revill, A. S. 1996. The UK (east coast) brown shrimp fishing fleet. Inventory of vessels and gear and analysis of fishing effort. University of Lincolnshire and Humberside. 47 pp.

Revill, A. S., Graham, N., and Radcliffe, C. 1998. The biological and economic impacts of discarding in the UK (east coast) *Crangon crangon* fishery. *In* European Association of Fisheries Economists Bioeconomic Modelling Workshop, 17–18 December 1997, Portsmouth, UK, pp. 34–42. Ed. by S. Pascoe, C. Robinson, and D. Whitmarsh. Report and abstracts. CEMARE Miscellaneous Publication, M39.

Revill, A. S., and Holst, R. 2004. The selective properties of some sieve nets. Fisheries Research, 66: 171–183.

Revill, A. S., Pascoe, S., Radcliffe, C., Riemann, S., Redant, F., Polet, H., Damm, U., *et al.* 1999. The Economic and Biological Consequences of Discarding in *Crangon* Fisheries (The ECODISC Project – EU (DG XIV A:3) Project 97/SE/23). Final Report to the European Commission, University of Lincolnshire and Humberside. 117 pp.

Suuronen, P., and Tschernij, V. 2003. The problems encountered in the adoption of improved selectivity in the Baltic cod demersal trawl fishery. ICES Document CM 2003/Z: 07.

van Marlen, B., Redant, F., Polet, H., Radcliffe, C., Revill, A. S., Kristensen, P. S., Hansen, K. E., *et al.* 1998. Research into *Crangon* fisheries unerring effect (RESCUE)—EU study 94/044. RIVO Report C054/97. 37 pp.

Venables, W. N., and Ripley, B. D. 2002. Modern Applied Statistics with S. Springer, New York. 256 pp.

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