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Selectivity experiments with sorting grids in the North Sea brown shrimp (*Crangon crangon*) fishery

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Abstract

The fishery for brown shrimp (*Crangon crangon*) is important in the North Sea and is carried out by more than 600 vessels, with total annual brown shrimp landings of around 20,000 t. Due to the small mesh size used the catches also contain large amounts of by-catch. To find ways of reducing this by-catch, experiments were carried out with a Nordmφre type sorting grid during two trips on a research vessel and three trips on a commercial vessel.

The results depended strongly on the catch composition in the brown shrimp fishery. If the catch composition did not cause clogging problems with the sorting grid, it met the objectives it was designed for. The reduction of fish (>70%) and benthos (65%) in the catch was quite high. The commercial brown shrimp catch was reduced by 15%. The cod-end catch consisted mainly of shrimps and required less sorting and the cod-end selectivity for shrimp increased. If, however, material occurred in the catch that caused clogging, the commercial brown shrimp catch was soon below the level acceptable to commercial fishermen.

Keywords: Selectivity; Sorting grid; Cod-end; *Crangon crangon*

1. Introduction

The fishery for brown shrimp (*Crangon crangon*) in the North Sea is carried out by more than 600 vessels with a total annual brown shrimp landing of around 20,000 t (Anon., 1996). Brown shrimps are caught in coastal and estuarine waters, by small beam trawlers with a maximum engine power of 221 kW (300 hp). Most of the vessels tow two beam trawls with a legal minimum cod-end mesh opening of 20 mm. The brown shrimp fishery on the Belgian and Dutch coast, primarily targets brown shrimp, but has an important by-catch of several round and flatfish species, such as cod (*Gadus morhua*), whiting (*Merlangius merlangus*), dab (*Limanda limanda*), plaice (*Pleuronectes platessa*), flounder (*Platichtys flesus*) and sole (*Solea solea*).

Because of the small mesh size necessary to catch brown shrimps (*C. crangon*), the nets contain large amounts of unwanted by-catch. Besides large quantities of undersized shrimp (over 2/3 in numbers of the shrimp catch — not reported data from discard observations 1996–1997), large amounts of juvenile commercial fish occur in the catches of North Sea brown shrimp trawlers (Table 1). Although these numbers are substantial, they tell little of the biological and economic effects of discarding. Elucidating the significance of discarding in the brown shrimp fishery, in terms of its potential impact upon recruitment and

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Table 1
Annual numbers (in millions) of discards in the European *Crangon* fishing fleets 1996/1997[a]

	Plaice	Sole	Whiting	Cod
Denmark	33.7	0.1	1.1	3.0
Germany	724.7	8.7	9.8	17.3
The Netherlands	157.5	4.0	22.3	16.9
Belgium	2.2	1.5	9.2	0.5
UK (East coast)	9.9	1.3	12.9	4.6
Total	928.1	15.7	55.3	42.3

[a] Source: Economic and Biological Consequences of Discarding in the European *Crangon* Fisheries, EU (DG XIV) Project No. 97/SE/025.

spawning stock biomass of the fish species concerned, and hence on the potential lost landings and their associated market values, was the main aim of the ECODISC-project.[1] The annual landings lost due to the current levels of discarding in the European *Crangon* fisheries have been estimated in this project to be around 2000 t for cod, 1500 t for whiting, 12,000 t for plaice and 600 t for sole. In relation to the current North Sea TAC, discarding of 0- and 1-group plaice in the *Crangon* fisheries has a significant biological and economic impact on the North Sea plaice stock and its fishery potential. The estimated impacts on cod, sole and whiting, however, are relatively small. Apart from commercial species, a wide variety of non-commercial fish and benthic species (mostly crustaceans, echinoderms and molluscs) (Polet, 1998) ends up in the catches, which are discarded together with the undersized fishes and brown shrimps.

To find ways of reducing by-catch, a national research programme was set up at the Belgian Sea Fisheries Department. Beside electric fishing and the selective sieve net, the selective sorting grid is one of the technical adaptations to the fishing gear which is currently being investigated. The results from grid study, obtained so far, are presented here. It is worth mentioning that the mandatory use of selective devices for the shrimp fisheries in the North Sea is being discussed within the European Commission. Fishermen will have the choice between sorting grids and sieve nets.

Sorting grids exist in different designs, like the Nordmφre grid, sort-X and sort-V, and are used in many fisheries to improve species and/or size selectivity (Anon., 1998). Sorting grids are already widely used in the commercial shrimp fishery in the northern Atlantic to separate *Pandalus borealis* from the fish catch and are often adopted on a voluntary basis by the fishermen. In the North Sea, however, the use of sorting grids is still in the experimental phase with tests carried out in the United Kingdom (Graham, 1997) and Germany (Wienbeck, 1997).

2. Materials and methods

2.1. Fishing area, vessels and trawls

The trials were carried out during two cruises in November 1996 and April 1997 on board of the RV "Belgica" (length = 50.9 m, GRT = 765 t, engine power = 1154 kW) and three cruises in July and September 1997 on the commercial shrimp trawler Z.582, "Asanat" (length = 19.8 m, GRT = 49 t, engine power = 107 kW). The data collected during the first trip on the RV "Belgica" was used for preliminary experiments to optimise the rigging of the grid whereas those collected in the other trips were used to for the selectivity estimates of the sorting grid. A commercial skipper was hired to select fish tracks and guide fishing operations in order to meet as close as possible commercial conditions. It has to be noted, however, that due to safety regulations and restricted access of the research vessel to shallow fishing grounds, the experiments were mainly carried out on flat and hard sand grounds with a rather low number of species in the catch. Contrary to the research vessel, the commercial boat towed two beam trawls simultaneously, one at each side of the vessel. The brown shrimp fishing grounds were located on the Belgian and southern Dutch coast, in ICES subdivision IVc. The towing speed was between 2 and 3 knots on the research as well as on the commercial vessel. The variability in towing speed was somewhat higher on the commercial vessel due to the influence of tide but the differences were very small. The warp length was three times the water depth.

The gear used was a commercial shrimp beam trawl (Fig. 1) with a beam length of 8 m and a vertical net

[1] Economic and Biological Consequences of Discarding in the European *Crangon* Fisheries, EU (DG XIV) Project No. 97/SE/025.

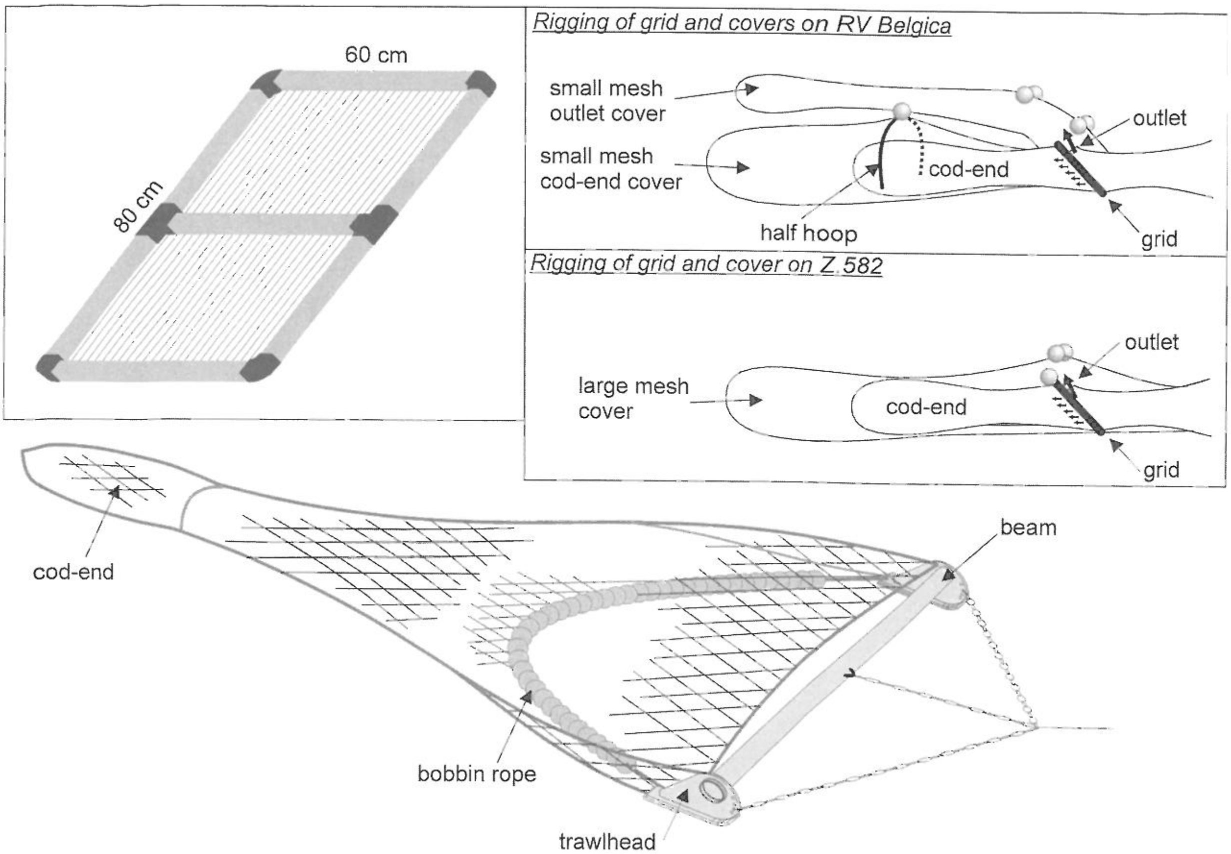


Fig. 1. The brown shrimp beam trawl.

opening of 0.5 m. The length of the headline and the groundrope was 7.8 and 9.8 m, respectively. The bobbin rope consisted of rubber bobbins with a diameter of 21 cm rigged on steel axes with a diameter of 20 mm. The net (Fig. 2) was made of knotted polyamide netting with a nominal mesh length of 28 mm in the front part decreasing to 22 mm in the aft part of the net. The cod-end was made of knotted polyamide netting with a nominal mesh size of 22 mm and protected by a polyamide lifting bag with a nominal mesh size of 80 mm. The same net design was used for all experiments.

The sorting grid used was 60 cm wide and 80 cm long with bars parallel to the 80 cm side and parallel to the longitudinal axis of the net. The bars had a diameter of 6 mm and were made of polyethylene. The grid-frame consisted of plastic tubes with a diameter of 30 mm during the tests on the research vessel but were replaced by stainless steel tubes with a diameter of 17 mm for the trials on the commercial vessel. The latter was rigged with two 1 l floats to prevent scraping on the bottom. The bar spacing was 12 mm during the experiments in November 1996 and was increased to 14 mm for the remaining ones. The grid was rigged with an angle of 45° sloping backwards and with an outlet all along the top side of the grid with a width of 15 cm.

2.2. The cod-end and the outlet covers

The cod-end selectivity was determined using the covered cod-end technique (Wileman et al., 1996). The cover was constructed of knotted polyamide netting with a nominal mesh size of 11 mm and was 800 meshes on the circumference and had a sufficient length to leave an open space behind the

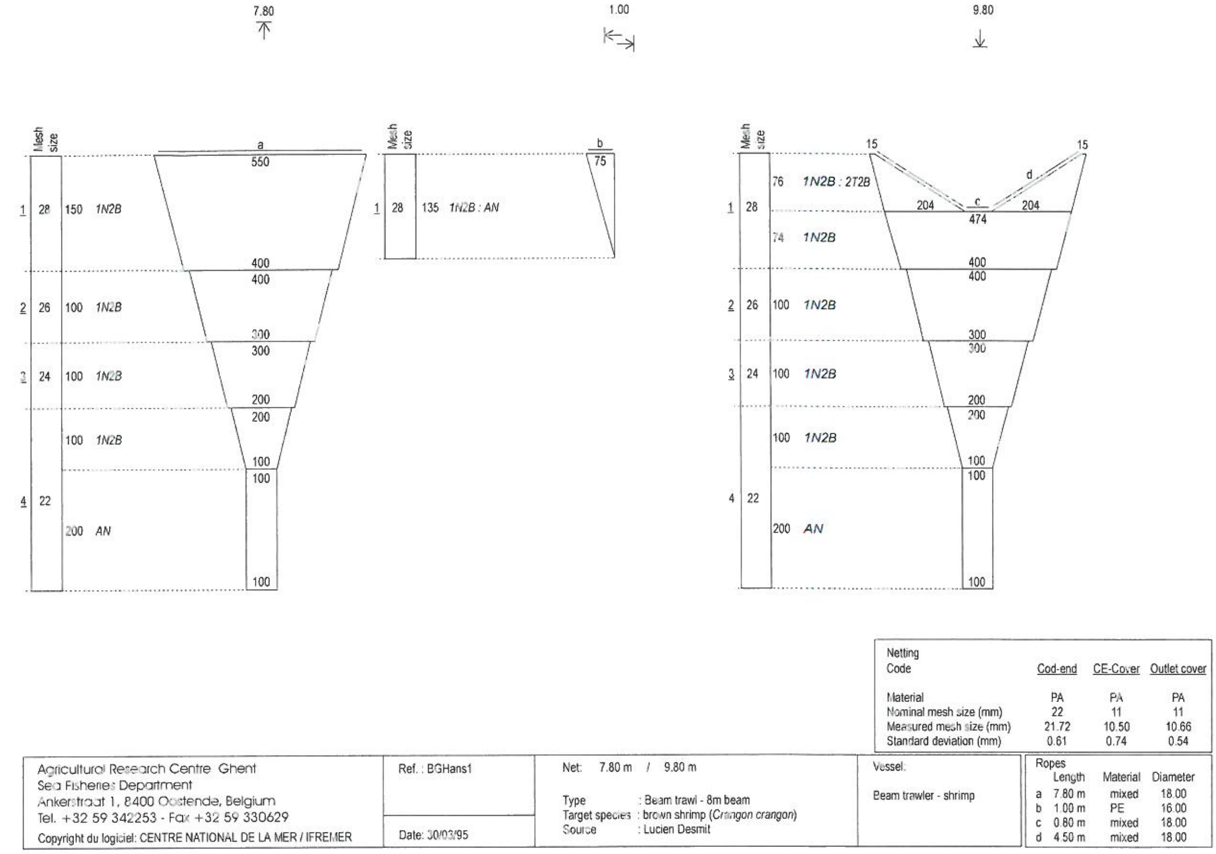


Fig. 2. The netplan.

aft end of the cod-end of 1.5 m. The cover was held open by a half hoop over the top panel of the cod-end and had a diameter of 1.5 m (Fig. 1). The application of full hoops was not feasible due to frequent damage caused by the close bottom contact of beam trawls. To study the selectivity of the grid on the research vessel, the outlet was covered by a small mesh cod-end (called the outlet cover) made of the same netting as the cod-end cover. To prevent obstruction of the outlet, the outlet cover was rigged with four 1 l floats (Fig. 1). On the commercial vessel, the outlet was covered by a large mesh (80 mm) cod-end in order to catch the marketable fish (Fig. 1). A small mesh cover was not necessary because catch comparison was possible between the standard gear at one side and the experimental gear at the other side of the vessel. The covered cod-end technique may have disadvantages, like a reduction of water flow, masking of the cod-end meshes and influence on the behaviour of the fish (Wileman et al., 1996). On the research vessel this method was, however, the best option but escapement of animals through the cod-end meshes and the grid outlet may have been underestimated.

Due to the small size of the meshes, the ICES mesh gauge could not be used to measure the opening of the meshes. Alternatively, a calliper was used, stretching the meshes with a weight of 2 kg. The weight of 2 kg was chosen according to the rules set up in EU-regulation 2108/84 for measuring meshes with a size below 35 mm. The mesh openings of the large mesh outlet cover were measured with the ICES mesh gauge set at 4 kg pretension. The average mesh openings (and standard deviations) of the cod-end used on the RV "Belgica", the cod-end cover, the small mesh outlet cover were 21.7 (0.61 mm), 10.5 (0.74 mm), 10.7 mm (0.54 mm), respectively. For the experimental and standard cod-end used on the commercial vessel and the large mesh outlet cover this was 21.3 (0.58 mm), 21.5 (0.78 mm) and 77.7 mm (2.16 mm), respectively.

2.3. Data collection and analysis

The species investigated on the research vessel were brown shrimp, plaice, sole, dab, whiting and cod. On the commercial vessel, all animal species occurring in the catch were investigated.

After each haul the cod-end and outlet cover catches were processed through a commercial rotating shrimp riddle to separate brown shrimps from the large by-catch and subdivide the brown shrimps into commercial and non-commercial sizes. After sorting, the catch was thus split into three catch fractions:

- The large by-catch containing the larger fishes, crabs, starfish, debris, etc.
- The commercial shrimps containing also 0- and 1-group flatfish together with occasional juvenile roundfish.
- The non-commercial shrimps also with the smallest 0- and 1-group flatfish.

The volume of each catch fraction was recorded. The fish in each catch fraction were measured, immediately after the haul. All fish were measured for total length (TL) to the centimeter below. A sample of 1.5 l of brown shrimps was taken from the commercial and from the non-commercial shrimp fraction for later analysis in the laboratory. There the TL of the shrimps was measured to the millimeter below from the tip of the scaphocerite to the distal margin of the fans on the stretched uropods. Following the results of a theoretical study on the effect of sample sizes on the estimation of selection parameters for shrimp trawl cod-ends (Polet and Redant, 1999), it was decided to measure at least 250 shrimps per catch fraction, which is a compromise between workload and accuracy, i.e. 500 from the cod-end, 500 from the outlet cover and 250 from the cod-end cover. The fish and the brown shrimps from the cod-end cover were manually sorted. All fish were measured and a sample of 1.5 l of shrimps was taken to be measured in the laboratory.

To estimate the amount of benthic animals sorted out by the grid, these were analysed during the experiments conducted with the commercial vessel. At each haul, a 6–10 l sample was taken from the large by-catch fraction from each of the two nets, after the fish were sorted out. In the laboratory all benthic animals were weighed and counted. This was also done for the benthic organisms in the brown shrimp samples. All these data were then recombined to estimate the composition of the total catch and this allowed the calculation of the extra selectivity due to the grid for each species entering the trawl.

The cod-end selectivity was studied only for brown shrimp. Fish were not found in the cod-end cover in sufficient numbers to determine any selection ogive. Based on the deviance residuals for selection curves, the logistic function was chosen to describe the selectivity for each species and fitted the data very well. This function is the cumulative distribution function of a logistic random variable and is specified by following equation (Wileman et al., 1996):

$$r(l) = \frac{\exp(a + bl)}{1 + \exp(a + bl)}$$

where $r(l)$ is the probability that an animal of length l is retained in the cod-end. a and b, the two parameters to be estimated, represent the intercept and the slope, after a logit transformation. These parameters were estimated with the maximum likelihood method using the CC software (Constat, Denmark). L25, L50 and L75 are the body lengths at which 25, 50 and 75% of the brown shrimps are retained in the cod-end. SR is the selection range, equal to the difference between L75 and L25 and gives an idea about the slope of the curve.

$$\mathrm{L50} = -\frac{a}{b}, \quad \mathrm{SR} = \frac{2\log_e(3)}{b}, \quad \mathrm{L25} = \mathrm{L50} - \frac{\mathrm{SR}}{2}, \quad \mathrm{L75} = \mathrm{L50} + \frac{\mathrm{SR}}{2}$$

Single hauls were combined by the variance component analysis method of Fryer (1991) by the CC software. 95% confidence limits are given between brackets.

The selectivity of the grid, in the case of the research vessel trials, was calculated as the ratio of the numbers in the cod-end and the cod-end cover to the total numbers in the cod-end, the cod-end cover and the outlet cover. In the case of the commercial vessel this was calculated as the ratio of the numbers in the cod-end of the experimental gear, towed at one side of the vessel, to the numbers in the cod-end of the standard gear, towed at the other side of the vessel. Except for sole and brown shrimp, the logit model was found to fit the data.

3. Results

3.1. Fishing conditions

A log of the sea trials is given in Table 2. During the first cruise (96/27) five hauls were carried out to optimise the rigging and the handling of the grid and the covers. A preliminary estimate was made on the loss of marketable shrimps.

During the second trip (97/08), 24 hauls were carried out with a trawl rigged with the sorting grid, a cod-end cover and an outlet cover. Shrimps with lengths within the SR were caught in sufficient numbers in each haul to calculate cod-end selectivity. The fish in the catch were, however, not small enough to find sufficient numbers of escapees in the cod-end cover to calculate any cod-end selectivity ogive. For the calculation of the grid selectivity ogives for the five fish species caught, all hauls were pooled since numbers were too small to determine the ogives at the haul level. Consequently, no confidence limits are given. Compared to commercial conditions, the catches were rather clean, i.e. with low amounts of benthos and debris.

During the three trips on the commercial vessel, 10 hauls were carried out with the standard gear at one side of the vessel and the experimental net with a sorting grid on the other side. Only five hauls were used for selectivity calculations since clogging of the grid occurred in the other five hauls. The numbers of brown shrimps were sufficiently large to determine the grid selectivity. For the calculation of the grid selectivity ogives for the four fish species analysed, again all hauls were pooled. The volumes of benthos and debris in the catches were large compared to the research vessel trips.

During each haul the towing direction was kept constant. Due to obstacles on the seafloor and the nature of the fishing ground, the maximum length of the fish tracks differed and haul duration could not be kept constant (Table 2). No correlation was found, however, between towing direction or haul duration and selectivity of the cod-end nor the grid.

3.2. Cod-end selectivity

The L50 for brown shrimp for all hauls, on the second research vessel trip, combined was 44.1 mm (42.2–46.0 mm) and the selection factor 2.03 (1.94–2.12). The selection range was 12.7 mm (10.9–14.5 mm). The selection ogive is shown in bold in Fig. 3 together with the length distribution for all brown shrimps that entered the codend. The selection ogives for the individual hauls are also shown in Fig. 3 and the L50 and SR values in Table 3. Most of the L50 values lied within the 40–50 mm range. The SR values were rather variable ranging from 8.5 to 29 mm. For most of the hauls the selectivity data were overdispersed. Inspection of the residuals, however, did not show a structure so that the model could be accepted. The overdispersion could be caused by the rather high sampling factors used (Fryer, 1991). For fish, no cod-end selectivity could be calculated since almost no fish were found in the cod-end cover.

3.3. Sorting grid selectivity

During the first research vessel trip it was found that the barspacing of 12 mm was too small. Almost 50% of the brown shrimps escaped through the outlet. It was therefore decided to increase the barspacing to 14 mm.

The bar spacing increase improved the grid selectivity for brown shrimp during the second research

Table 2
Log of the experimental hauls

Vessel	Number of hauls	Haul duration range (h)	Rigging and action
Belgica	5	0:28–0:55	Rigging grid and preliminary grid selectivity test
Belgica	24	1:00–1:40	Cod-end and grid selectivity — cod-end and outlet covers
Z.582	10	0:45–1:13	Grid selectivity — catch comparison

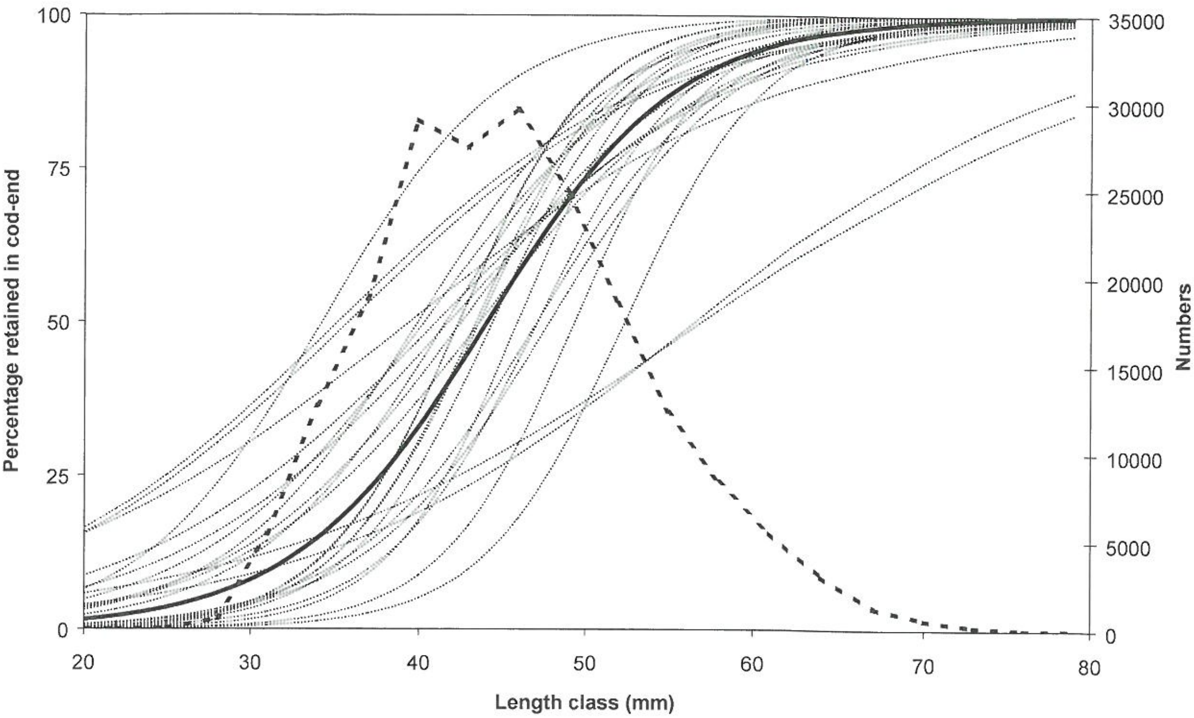


Fig. 3. The estimated overall selectivity ogive (bold line) together with the 24 selection ogives (dashed lines) of the single hauls and the length frequency distribution of *Crangon crangon* of the cod-end + cod-end cover catch (bold dashed line).

vessel trip. The percentage lost decreased to 14%. The reduction in catch of undersized brown shrimps (<45 mm) was somewhat higher (17%) compared to the reduction of commercially sized shrimps (13%), though a paired *t*-test did not show a significant difference ($p > 0.05$). In Fig. 4, the average loss of brown shrimps, over all hauls, is given in relation to the body length with the 95% confidence limits as error bars. The data points give the percentage of animals that do not pass through the grid spacings and escape through the outlet in front of the grid. There is a clear length dependence in the relative amounts of brown shrimps escaping through the outlet. In the mid-range of the length classes (35–65 mm) about 15% of the animals escape. Above 65 mm, the losses increased to almost 40%. Below 35 mm the losses were even higher and increased to over 90%.

The overall catch reduction in numbers of commercial fish species due to the grid was 75%. The grid selection ogives and the length frequency distributions (total number in the catch) for dab, plaice, sole, whiting and cod caught during the second research vessel trip are shown in Fig. 5A–E. The selection ogive gives the percentage of fish that do not go through the grid and escape through the outlet. The minimum landing size (MLS) is given as a dashed vertical line, except for dab for which there is no MLS. The L50 and SR values are given in Table 4.

During the trips on the commercial vessel, five hauls had to be discarded due to clogging of the grid with starfish and/or debris, preventing normal passage of the brown shrimps. This resulted in a loss of the commercial catch that ranged between 39 and 90% (Table 3).

For the five successful hauls the reduction in the commercial brown shrimp catch was between 0 and 26% with an average of 15% (Table 3). The average loss of undersized shrimps was 45% but the variability was very high. In Fig. 6, the average loss of brown shrimps, over the five hauls is given in relation to the body length with the 95% confidence limits as error

Table 3
Cod-end selection parameters and 95% confidence limits (between brackets) for brown shrimp and percentage of shrimps lost due to grid selection

Haul number	Cod-end L50 (mm)	Cod-end SR (mm)	Percentage lost		
			<45 mm TL	≥45 mm TL	All shrimps
97/08-01	45.9 (45.1–46.8)	8.5 (7.1–9.9)	1	4	2
97/08-02	43.4 (42.7–44.1)	9.2 (7.7–10.8)	14	18	16
97/08-03	52.4 (50.9–53.8)	9.3 (7.5–11.1)	1	4	3
97/08-04	35.8 (32.2–39.4)	20.7 (15.1–26.2)	16	13	14
97/08-05	39.9 (37.9–42.0)	12.7 (9.8–15.6)	19	14	15
97/08-06	39.4 (35.9–42.9)	25.2 (16.8–33.7)	15	12	13
97/08-07	34.2 (32.2–36.2)	11.7 (9.6–13.9)	15	16	16
97/08-08	41.0 (39.1–43.0)	19.7 (14.8–24.6)	15	9	11
97/08-09	43.6 (42.7–44.5)	9.5 (7.6–11.4)	25	17	21
97/08-10	56.6 (52.4–60.8)	25.1 (15.2–35.1)	5	3	3
97/08-11	44.4 (43.6–45.2)	9.4 (7.9–10.9)	1	9	3
97/08-12	41.6 (40.3–42.9)	12.7 (10.1–15.2)	28	19	23
97/08-13	35.2 (30.6–39.7)	20.5 (13.5–27.6)	15	10	12
97/08-14	42.5 (41.1–44.0)	15.1 (11.6–18.5)	20	16	18
97/08-15	40.3 (38.8–41.9)	15 (11.9–18)	21	12	16
97/08-16	42.4 (41.5–43.2)	9 (7.7–10.2)	9	18	14
97/08-17	47.9 (46.9–48.8)	12.4 (10.6–14.2)	4	6	5
97/08-18	42.4 (3.70–81.1)	8.9 (-8.8–26.6)	78	18	34
97/08-19	43.7 (42.5–44.8)	15.6 (12.4–18.7)	13	13	13
97/08-20	47.1 (46.1–48.1)	10 (8.5–11.6)	8	8	8
97/08-21	57.0 (53.6–60.3)	29.1 (20.6–37.7)	14	10	12
97/08-22	49.4 (48.6–50.1)	8.8 (7.6–10.1)	4	11	8
97/08-24	47.1 (46.1–48.2)	12.3 (10.2–14.5)	13	16	15
97/08-25	41.8 (40.0–43.5)	18.2 (14.4–22)	54	36	43
97A-01	(–)	(–)	58	8	37
97A-02	(–)	(–)	33	13	26
97B-03	(–)	(–)	21	−9	5
97B-04	(–)	(–)	62	22	47
97B-05	(–)	(–)	80	39	67
97C-06	(–)	(–)	58	26	38
97C-07	(–)	(–)	88	76	81
97C-08	(–)	(–)	90	70	79
97C-09	(–)	(–)	90	71	80
97C-10	(–)	(–)	93	86	90

Table 4
Grid selection parameters for fish

Species	RV Belgica		Z.582 — commercial vessel	
	Grid L50 (mm)	Grid SR (mm)	Grid L50 (mm)	Grid SR (mm)
Dab	8.6	11.5	−9.4	24.0
Plaice	9.4	9.7	9.5	7.3
Sole	9.9	5.2	NA	NA
Whiting	−0.9	17.3	6.7	10.5
Cod	14.2	15.2	NA	NA

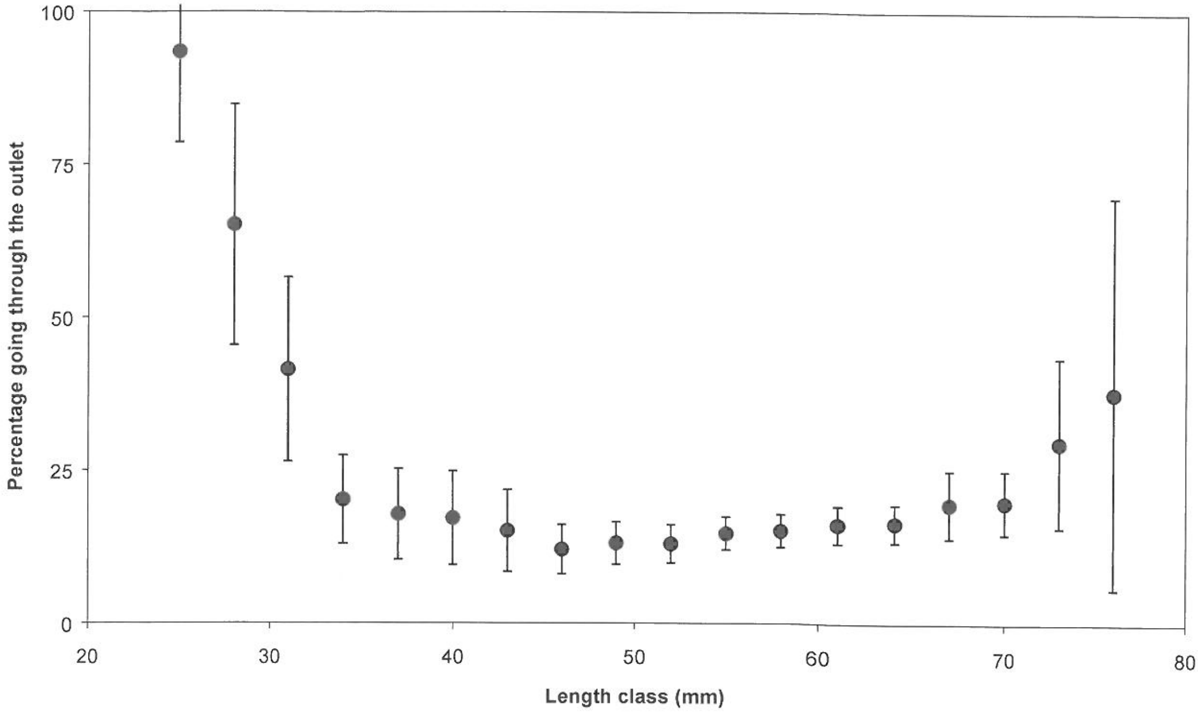


Fig. 4. Percentage of *Crangon crangon* escaping through the outlet with the 95% confidence limits indicated as error bars.

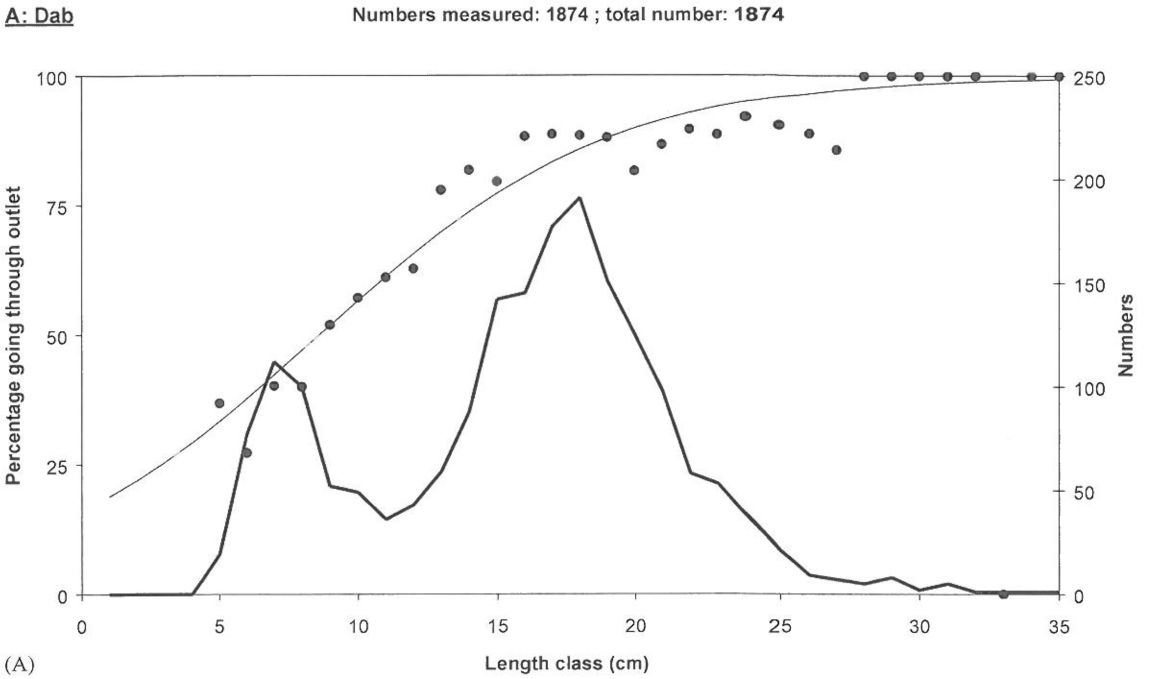
bars. Again there is a clear length dependence in the relative amounts of brown shrimps escaping through the outlet, although the error bars indicate a high variability. For lengths > 48 mm, between 10 and 20% of the animals escaped. For lengths < 48 mm, losses increased with decreasing length with a reduction around 90% for the smallest animals.

The overall catch reduction in numbers of commercial fish species due to the grid was 72%. In Fig. 7A–E, the grid selection ogives and the length distributions (total number in the catch) in the standard (solid line) and experimental (dashed line) gears for dab, plaice, sole and whiting are given. The L50 and SR values are given in Table 4. A selection ogive was not possible to be calculated for sole because of the high reduction in catch of the smallest fish.

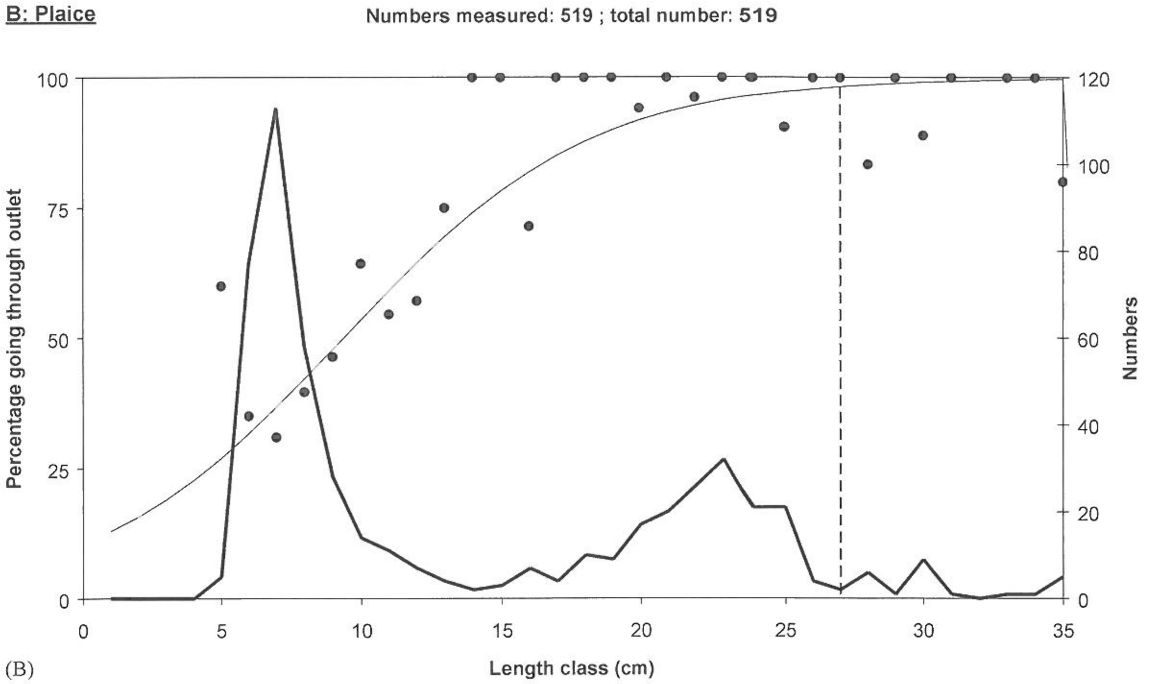
Overall, 12 benthic animal species were caught (Fig. 8). The average reduction was 65%. For most of the species, the sorting grid was very effective in releasing the animals and the reduction ranged from about 5% for *Liparis liparis* to almost 100% for *Ophiura* spp.

4. Discussion

The selectivity of the cod-end for brown shrimp in a net with a sorting grid seems higher compared with a cod-end in a net without grid. Previous cod-end selectivity experiments (Polet, 2000) with a commercial brown shrimp beam trawl, without grid, gave an L50 of 39.4 mm (37.0–41.4 mm) and a selection factor of 1.82 (1.71–1.91). Based on the t-value of the difference between the two means, this is significantly lower ($p < 0.001$) compared with the present results (see Section 3.2). This is probably due to the fact that the cod-end catch size in a net with a grid is smaller and the catch composition more homogenous and contains less large benthic animals and debris that can hinder shrimp escapes. In the literature the relation between catch size and selectivity differs. Erickson et al. (1996), Hodder and May (1964) and Madsen and Moth-Poulsen (1994) found a negative correlation between the selection factor and the size of the catch for roundfish. Dahm (1991) and Suuronen et al. (1991) did not find a significant relationship between catch

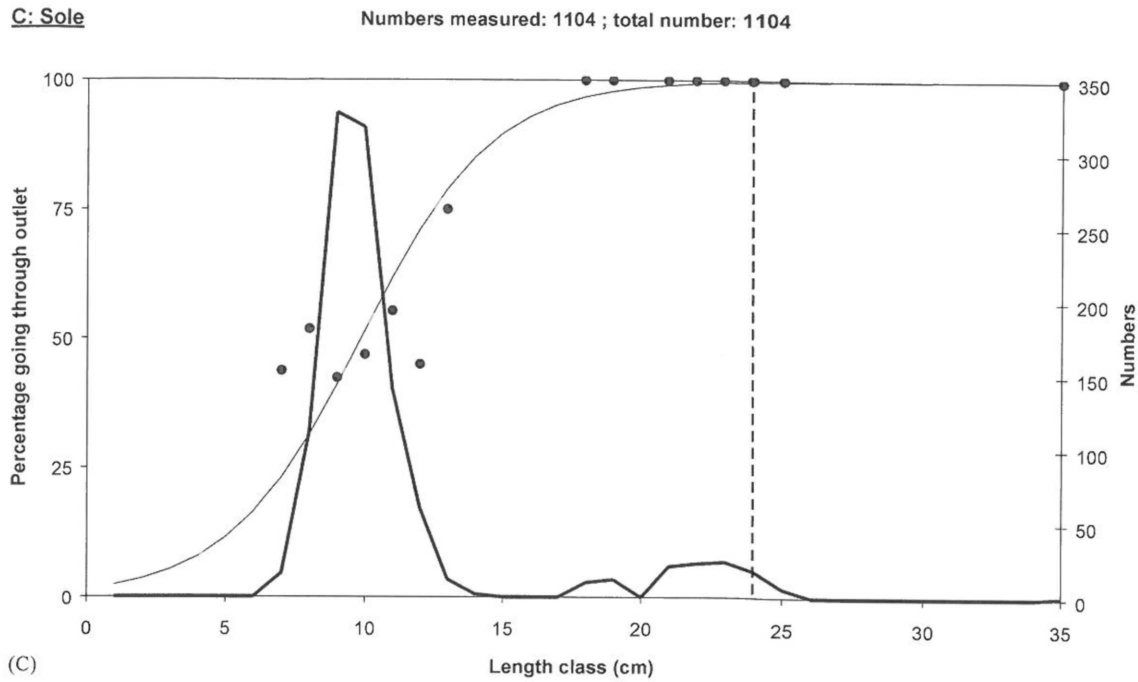


(A)

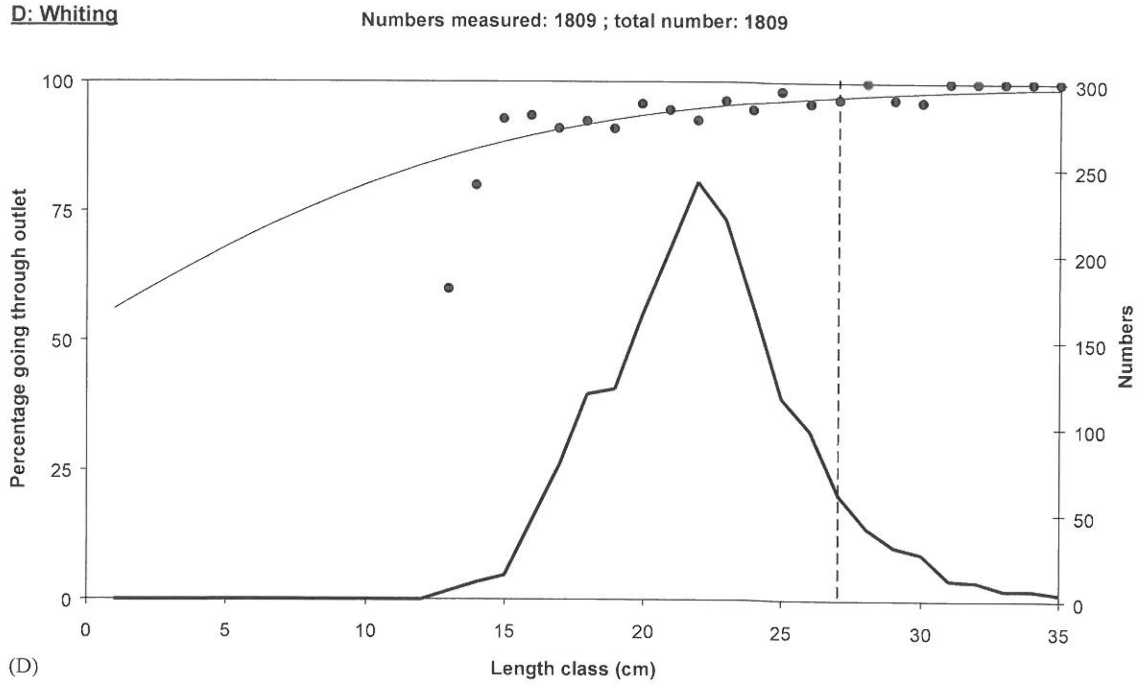


(B)

Fig. 5. Grid selection ogive and length frequency distribution (bold line) for dab, plaice, sole, whiting and cod (RV trip 97/08).



(C)



(D)

Fig. 5. (*Continued*).

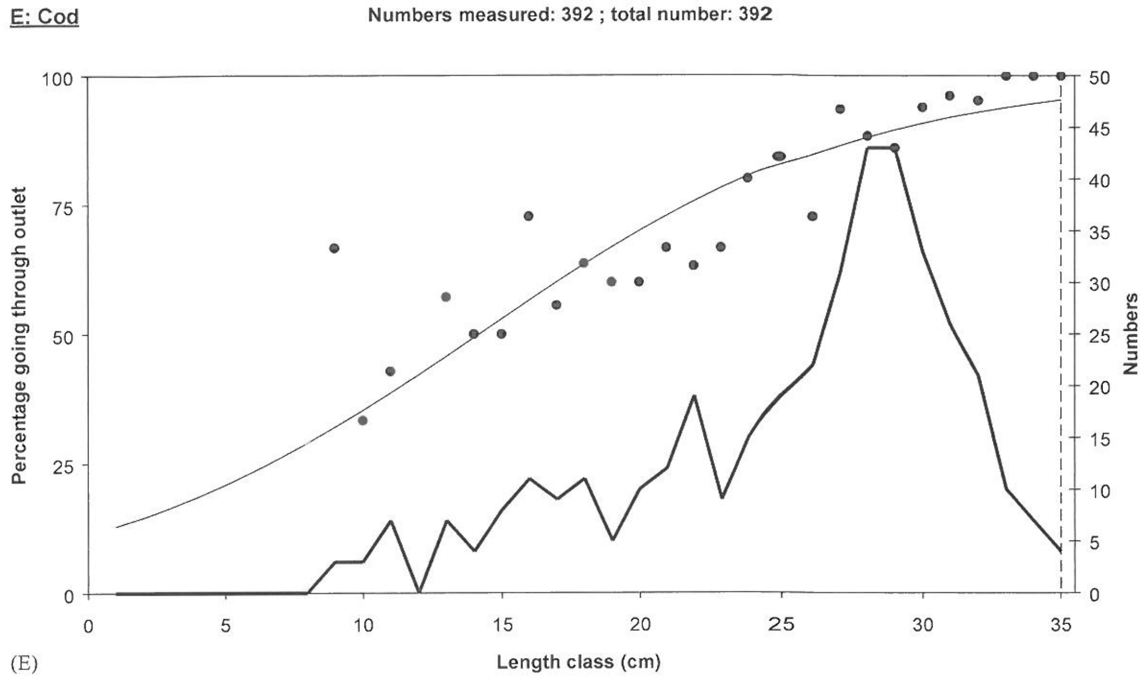


Fig. 5. (*Continued*).

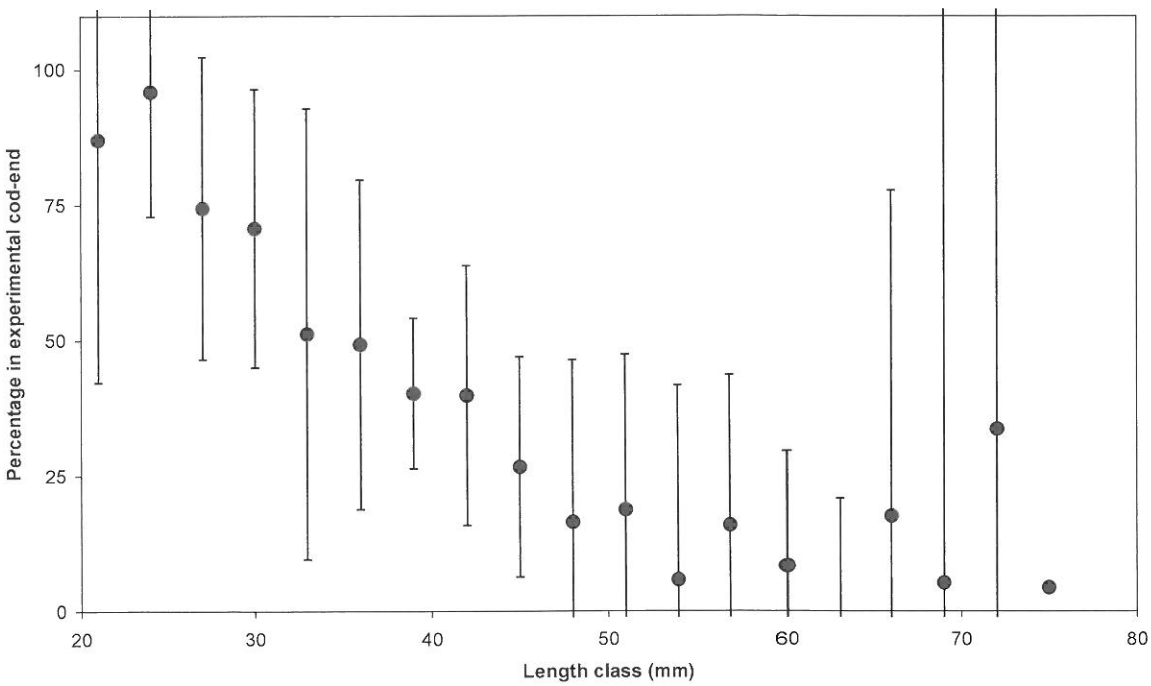


Fig. 6. Percentage of brown shrimps escaping through the outlet with the 95% confidence limits indicated as error bars.

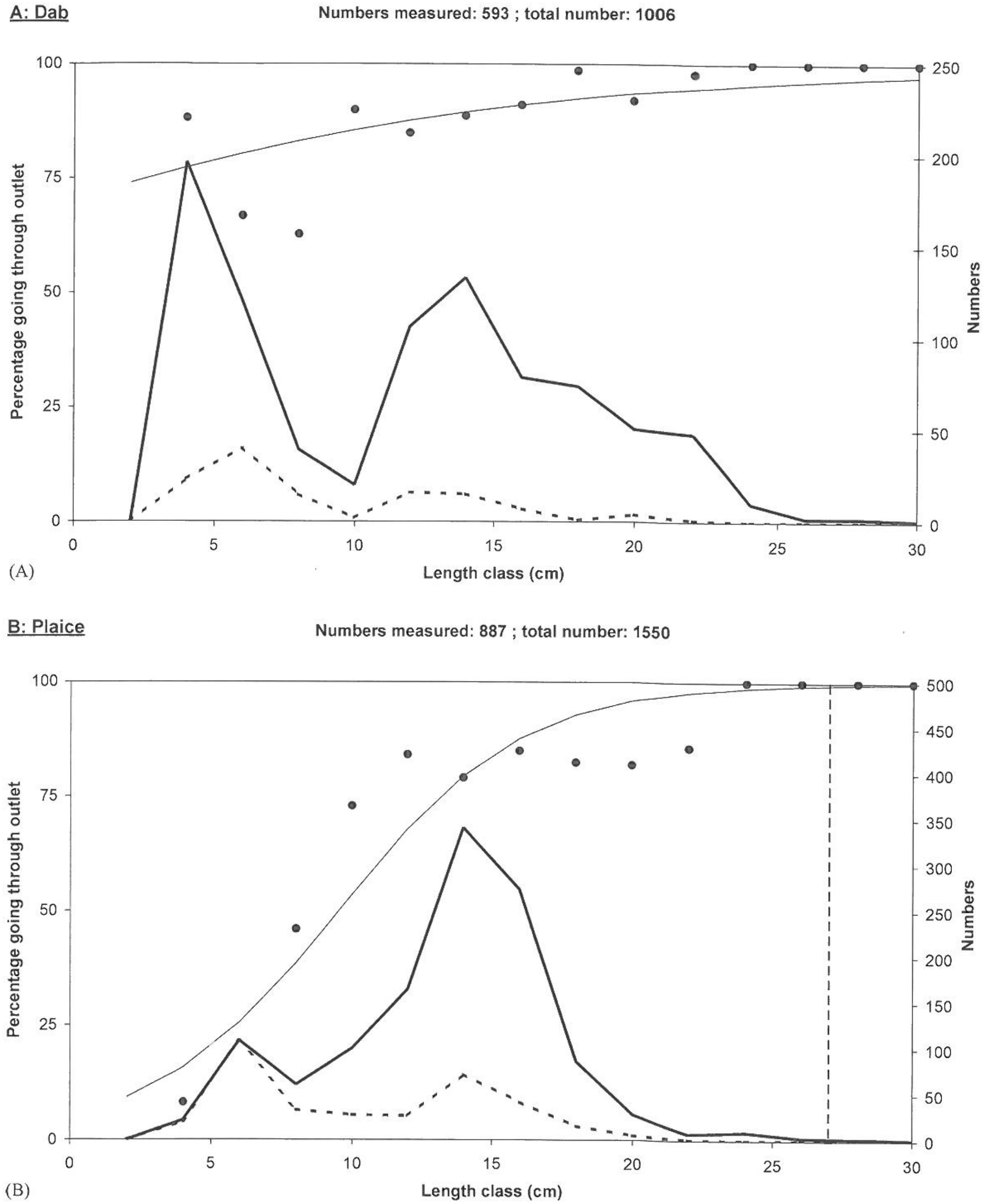
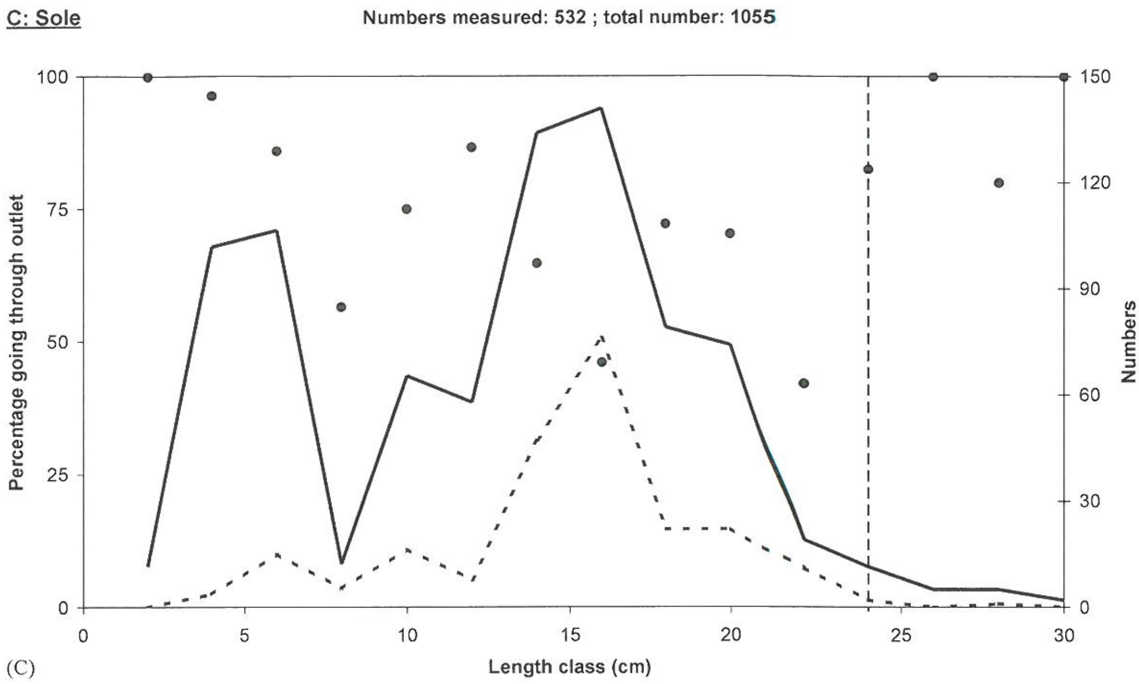
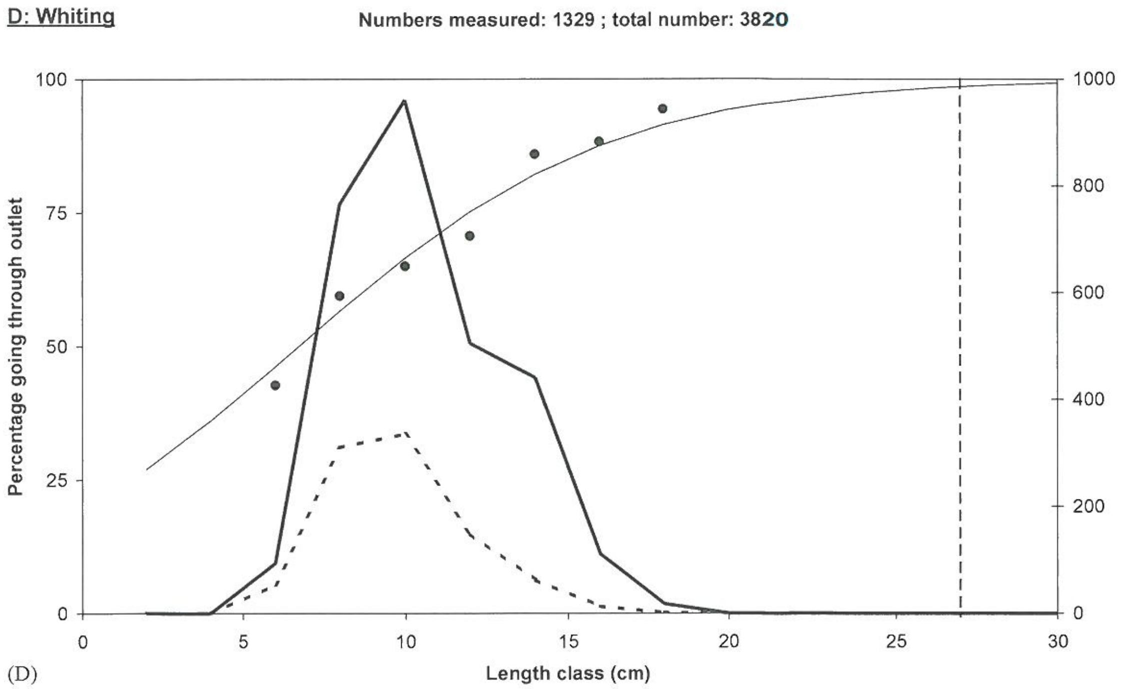


Fig. 7. Grid selection ogive (fine solid line) and length frequency distributions in the standard (bold solid line) and experimental (bold dashed line) gear for dab, plaice, sole and whiting during the trips with Z.582.



(C)



(D)

Fig. 7. (*Continued*).

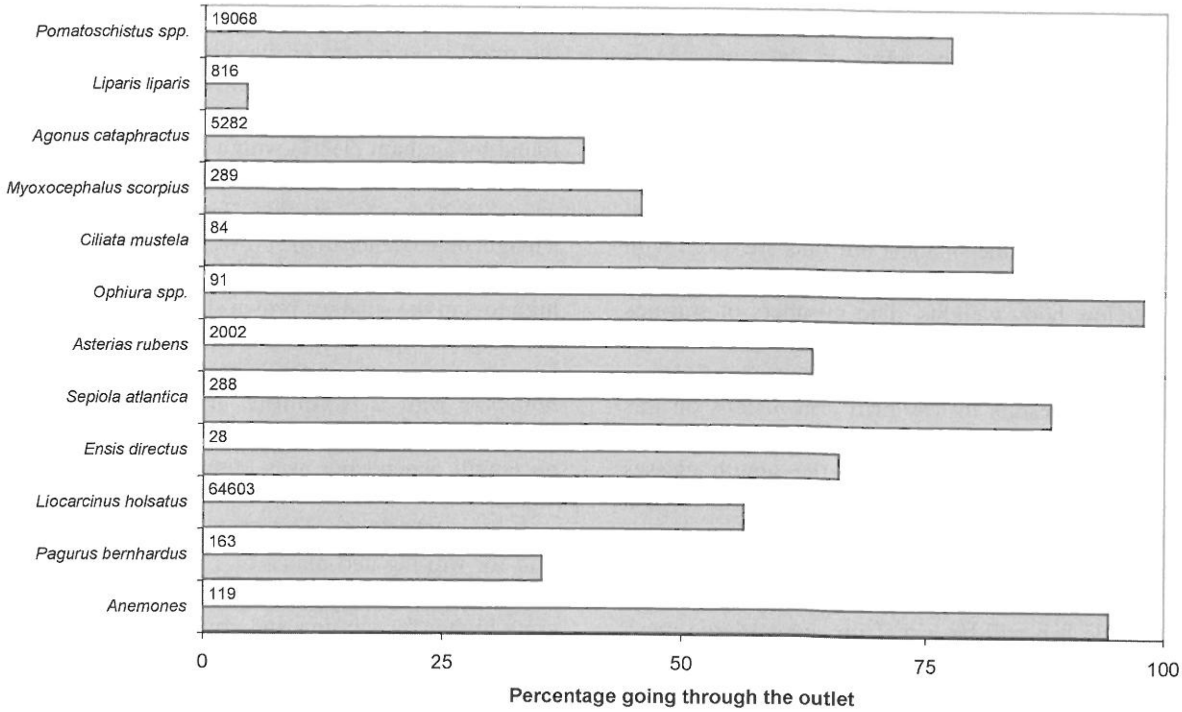


Fig. 8. The percentage reduction of the different benthos species in the catch of the experimental net.

size and L50 for herring in pelagic trawls. O'Neill and Kynoch (1996), on the other hand, found that L50 increased with increasing catch size. In a previous Belgian experiment (Polet, 2000) with a brown shrimp beam trawl, however, it was found that catch size and clogging of the meshes by seaweed and hydroids had a significant, negatively correlated effect on the cod-end selectivity of brown shrimp. Catches in a net with a grid have lower volumes and show less clogging of the cod-end meshes. Consequently, the higher selectivity parameters found in this study are in line with the previous results.

During the cod-end selectivity trials in 97/08 almost no fish escaped through the cod-end meshes. In a previous study (Polet, 2000) the cod-end L75 for dab and sole was 4.8 and 8.7 cm, respectively and no plaice with length above 4 cm escaped from the cod-end. The dab, sole and plaice caught during this cruise were not smaller than 5, 7 and 5 cm, respectively and, therefore, had very little opportunity to escape through the cod-end meshes. Consequently, the selectivity ogives were not possible to be calculated.

The loss of the commercial brown shrimp catch was estimated to be 13% on the research vessel. This number should be interpreted with caution since it is an average of all numbers in a pooled range of length classes and depends on the catch composition. The losses of shrimps are length-dependent and the amount of shrimps larger than 60 mm in the catches during the sea trials in this experiment was relatively low. Consequently, if the relative amount of large shrimps in the catches would be higher, the percentage commercial shrimps lost would also increase.

With the conversion formula to calculate the carapace width of a brown shrimp from its TL (Redant, 1978), it was found that the largest shrimps in the catches in this experiment had carapace widths below 11.5 mm. Theoretically these shrimps should be able to pass through the bar gaps of a grid with a 12 mm bar spacing. The tests have shown, however, that this was not the case. Even with a 14 mm bar spacing, a significant amount of the larger shrimps escaped through the outlet. Probably for some of the animals encountering the grid with their bodies not parallel to the gaps, time is too short to obtain the right orientation to pass through the gaps or their passage is hindered by other material lying against the grid. The results on the length dependence (Figs. 4 and 6) of small shrimps lost through the outlet, however, seem illogical since they should pass through the gaps more easily than the bigger ones. A possible explanation could be that the smallest animals are taken with the waterflow going through the outlet quite easily due to their low body weights. The numbers of shrimps caught in the lowest and highest length classes were rather low, however, and the confidence limits rather wide, which results in less firm conclusions on this matter.

Fig. 5A–E demonstrates that the length classes within the selection range of the sorting grid for fish lie far below the MLS for all species observed. The grid gives the opportunity to the larger fish (age 1 and higher) to escape through the outlet and almost all marketable fish will be lost if no second large mesh cod-end is attached over the outlet. Age 0 fish, however, still pass quite easily through the grid bars (50% and more) and are caught in the cod-end. This has consequences for the applicability of the sorting grid. If the unwanted by-catch of fish consists mainly of the larger fish, the grid can be useful. If mainly small fish are caught, like in nursery areas, the effectiveness of the grid is smaller.

When comparing the results of the research vessel and the commercial vessel, the variability in the data is higher on the latter, due to the rather low number of successful hauls. The grid selectivity results for brown shrimp and plaice were confirmed in commercial conditions (Figs. 4, 5B, 6 and 7B). For dab, however, more small fish escaped in the case of the commercial vessel (Figs. 5A and 7A). Although the opposite seems to be true for whiting, such a comparison is difficult to be made since small fish were not present in the catches on the research vessel (Figs. 5D and 7D). The results for sole were unexpected, since the smallest fish (<8 cm) showed a higher escape rate than the mid range of the length classes. It is possible that the smallest fish were more easily taken by the waterflow through the outlet. It is, however, also possible that due to the lower catch volume in the cod-end of the experimental gear that the selectivity for sole improved when compared to the standard gear. The set-up of the comparative fishing experiment, however, does not allow to attribute the higher escapes of the small soles to one or the other possible cause.

The loss of marketable brown shrimp recorded during this study was comparable with the 12% loss found by Graham (1997) with a grid with 14 mm bar spacing. Wienbeck (1997) recorded a 15% loss with a grid with 20 mm bar spacing. Both authors also found a length dependence in the brown shrimp selectivity of the grid with higher losses for the larger animals. The high loss of the smallest brown shrimps as recorded in the Belgian experiments was, however, not observed. During experiments in the Norway shrimp fishery (*P. borealis*) with a Nordmφre grid with 19 mm bar spacing, shrimp losses up to 5% were recorded but no length dependence was observed (Isaksen et al., 1992).

Graham (1997) found L50 values for the 14 mm grid for whiting and plaice of 11.8, 10.4 cm, respectively, which is, in comparison with the present study, quite higher for whiting and comparable for plaice.

Starfish and debris were an important problem for the functioning of the grid. Especially starfish had a tendency to stick their arms between the bars and hold on. This reduces the selective area of the grid and decreases the opportunities for brown shrimps to pass through the bar spacing. Any object, plant or animal that accumulates on the grid will have such an effect. Seaweed, hydroids, big jellyfish, starfish, plastic bags, pieces of wood, etc., are very common throughout the year or in certain seasons in the southern North Sea catches and are likely to cause loss of commercial catch in many hauls. Therefore, a sorting grid as designed in this experiment, with a small selection area and a tendency to accumulate part of the catch, will probably be difficult to be accepted in the commercial fishery.

5. Conclusions

If the catch composition in the brown shrimp fishery does not cause clogging problems the sorting grid meets the purpose it was designed for. The reduction of age 1 and older fish in the catch was very satisfactory. Age 0 fish were sorted out as well, but to a lesser extent. Most benthic animals are selected out by the grid. The commercial brown shrimp catch is reduced but usually not more than 15% gets lost. The cod-end catch consists mainly of brown shrimps and requires less sorting and the cod-end selectivity for brown shrimp increases. In this case, the sorting grid seems a very favourable choice to improve the selectivity of the brown shrimp beam trawl.

If, however, material occurs in the catch that can cause clogging, the commercial brown shrimp catch is soon below the level acceptable to commercial fishermen. Starfish and debris were the main causes of clogging during these experiments. Seaweeds, hydroids, jellyfish and other debris, however, often occur in the brown shrimp catches in the southern North Sea and can be expected to cause the same problems. In this case it can be anticipated that acceptance by the fishing industry will be difficult.

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