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Codend and whole trawl selectivity of a shrimp beam trawl used in the North Sea

H. Polet*

Agricultural Research Centre — Ghent, Sea Fisheries Department, Ankerstraat 1, B-8400 Oostende, Belgium

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Abstract

In preparation of a by-catch reduction program for the Belgian brown shrimp fishery, a study was carried out on the codend and whole trawl selectivity of the beam trawl widely used in this fishery. The codend cover technique was used to determine the codend selectivity, whereas the whole trawl selectivity was estimated using small mesh pockets attached to several positions on the body of the net. Codend selectivity for shrimp proved to be very variable and was significantly influenced by clogging of the meshes, catch volume and state of the sea. The L50 for shrimp, for all hauls combined, was 39.4 mm and the selection factor 1.82 for a mesh size of 21.7 mm. The selection range was 11.6 mm. The selectivity of the net body was quite important and allowed more shrimps to escape than the codend did. It was mainly the rounded lateral part of the belly that contributed to this selectivity. Due to the small mesh size, the codend selectivity for flatfish was very poor. The selectivity of the net body for flatfish was negligible. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Codend selectivity; Whole trawl selectivity; *Crangon crangon*

1. Introduction

In the North Sea brown shrimps (*Crangon crangon*) are caught in the coastal zone and estuaries by small beam trawlers with a maximum engine power of 221 kW (300 hp). Each vessel tows two beam trawls with a legal minimum codend mesh opening of 20 mm. The shrimp beam trawl fishery carried out on the Belgian and Dutch coast targets brown shrimps but has an important by-catch of several flat- and roundfish species. Besides brown shrimp, which is the main target species, the landings of the shrimp trawler fleet consist of several round- and flatfish species like cod (*Gadus morhua*), whiting (*Merlangius merlangus*), dab (*Limanda limanda*), plaice (*Pleuronectes platessa*), flounder (*Platichtys flesus*) and sole (*Solea solea*).

Due to the small mesh size, necessary to catch the shrimps, the catches contain high amounts of unwanted by-catch. Besides large quantities of undersized shrimps (over 2/3 in numbers of the shrimp catch — data from discard sampling program 1996–1997), high amounts of juvenile commercial fish (mainly whiting, plaice, dab and sole) (van Marlen et al., unpublished report, 1998), non-commercial fish and a wide variety of benthic species (mostly crustaceans, echinoderms and molluscs) (Polet, 1998) end up in the catch. After sorting the catch on board of the vessel with a rotating shrimp riddle the undersized fishes and shrimps and the non-commercial animals are discarded.

In 1995, a research program aiming at a reduction of the by-catches in the brown shrimp fishery was started

* Tel.: +32-59-320805; fax: +32-59-330629.
E-mail address: hpolet@unicall.be (H. Polet)

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at the Belgian Sea Fisheries Department. One of the preparatory phases of this program was the study of the selective properties of the shrimp beam trawl, the results of which are presented in this paper.

In general, selectivity studies concentrate on the codend. Observations made by divers and towed underwater vehicles show that large amounts of fish escape from the codend and for most species this is where the main mesh selection is thought to occur (Wileman et al., 1996). Hillis and Earley (1982), however, demonstrated that the selectivity of the net can be far more important than codend selectivity when they found that over 40% of *Nephrops* entering a typical Irish prawn otter trawl escaped through the net meshes, compared to only 10% through the codend meshes. A study by Thorsteinsson (1981) showed that many small shrimps (*Pandalus borealis*) escaped through the sidepanels of the net. Experiments carried out by Bohl (1963) comparing two nets with identical codends but with different mesh sizes in the net also demonstrated that some part of the shrimps (*C. crangon*) escaped through the net meshes. Therefore, it was decided to study the whole trawl selectivity of the shrimp beam trawl and not only the codend selectivity. To complete the picture, the selectivity of the ground rope was also included in the study.

The selectivity experiments were carried out during six sea trips in May and November 1995, March and November 1996 and December 1997.

2. Materials and methods

2.1. The fishing area, the vessel and the trawl

The sea trials were carried out on board of the research vessel 'Belgica' having an overall length of 50.9 m, a GRT of 765 t and an engine power of 1154 kW. Since a large team was necessary to handle the gear, empty the codends and pockets and measure the high amount of catch fractions for each haul, it was not feasible to use a commercial vessel for the sea trials. A commercial skipper, however, was hired to select the fish tracks and to guide the fishing operations in order to meet as close as possible commercial conditions. The shrimp fishing grounds on the Belgian and southern Dutch coast, located in ICES subdivision IVc, were fished during the six sea trips. The towing speed was between 2.5 and 3 knots and the warp length was three times the water depth.

The gear studied was a commercial shrimp beam trawl (Fig. 1) with a beam length of 8 m and a vertical net opening of 0.5 m. The length of the headline and the ground rope 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 was made of knotted polyamide netting with nominal mesh sizes of 28 mm in the front part decreasing to 22 mm in the aft part. The codend 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. A net plan is given in Fig. 2.

During each haul the following variables were recorded: haul duration, speed through the water, state of the sea, total catch volume, clogging of the codend meshes, water temperature and light conditions. The state of the sea was expressed as the standard deviation of the wave heights recorded each second by the heave compensator on the vessel's echo sounder. The clogging of the codend meshes was a subjective measure of the amounts of seaweed and hydroids that were stuck on the mesh bars, thus decreasing the opening of the meshes. This was a number between 0 (fully open meshes) and 10 (fully clogged meshes), always recorded by the same person.

2.2. The codend and the net covers

The codend selectivity was determined with the covered codend technique. 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 aft end of the codend of 1.5 m. The cover was held open by a half hoop over the top panel of the codend and had a diameter of 1.5 m. The application of full hoops was not feasible due to frequent damage caused by the close bottom contact of beam trawls.

To study the whole trawl selectivity, the net was subdivided into different sections (Fig. 3) to be sampled for escaping shrimps and fishes. Longitudinally as well as vertically, the net was subdivided into four sections. Each section was named with a letter, A, B, C or D, indicating the vertical position and a

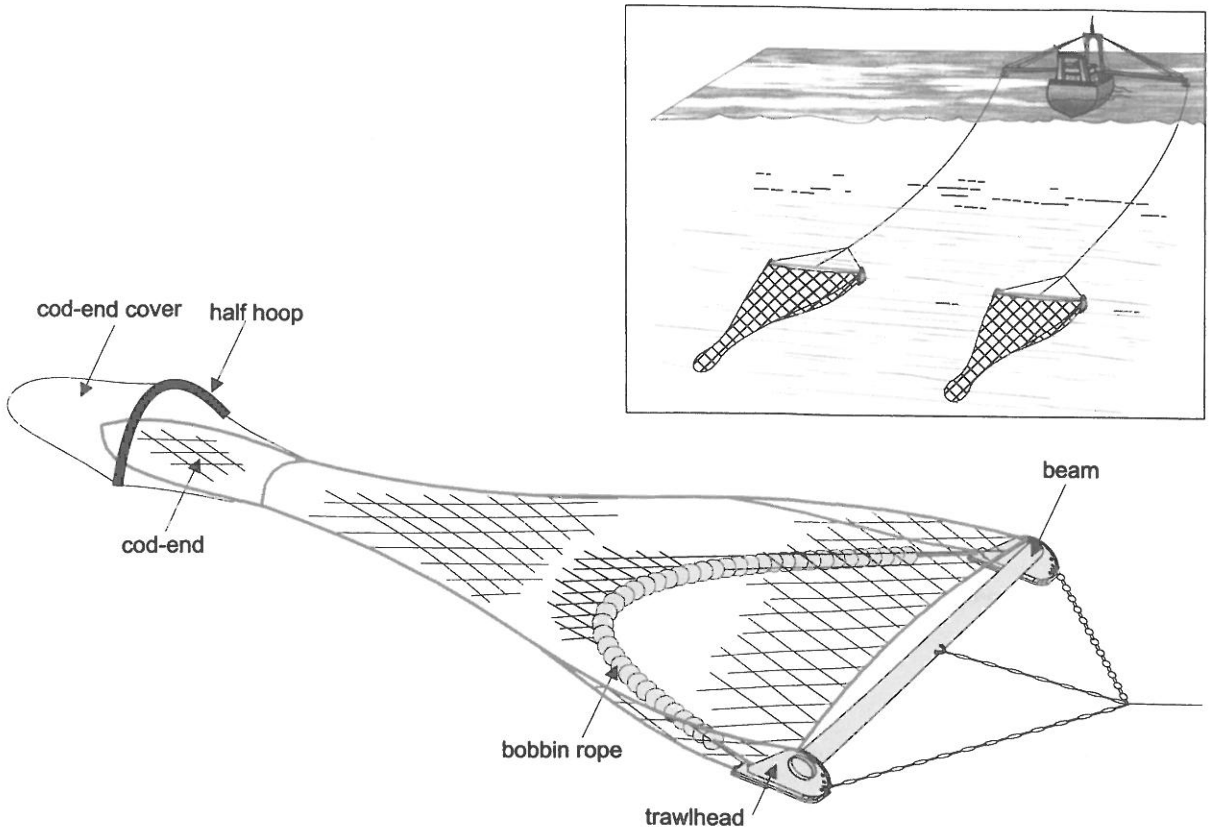


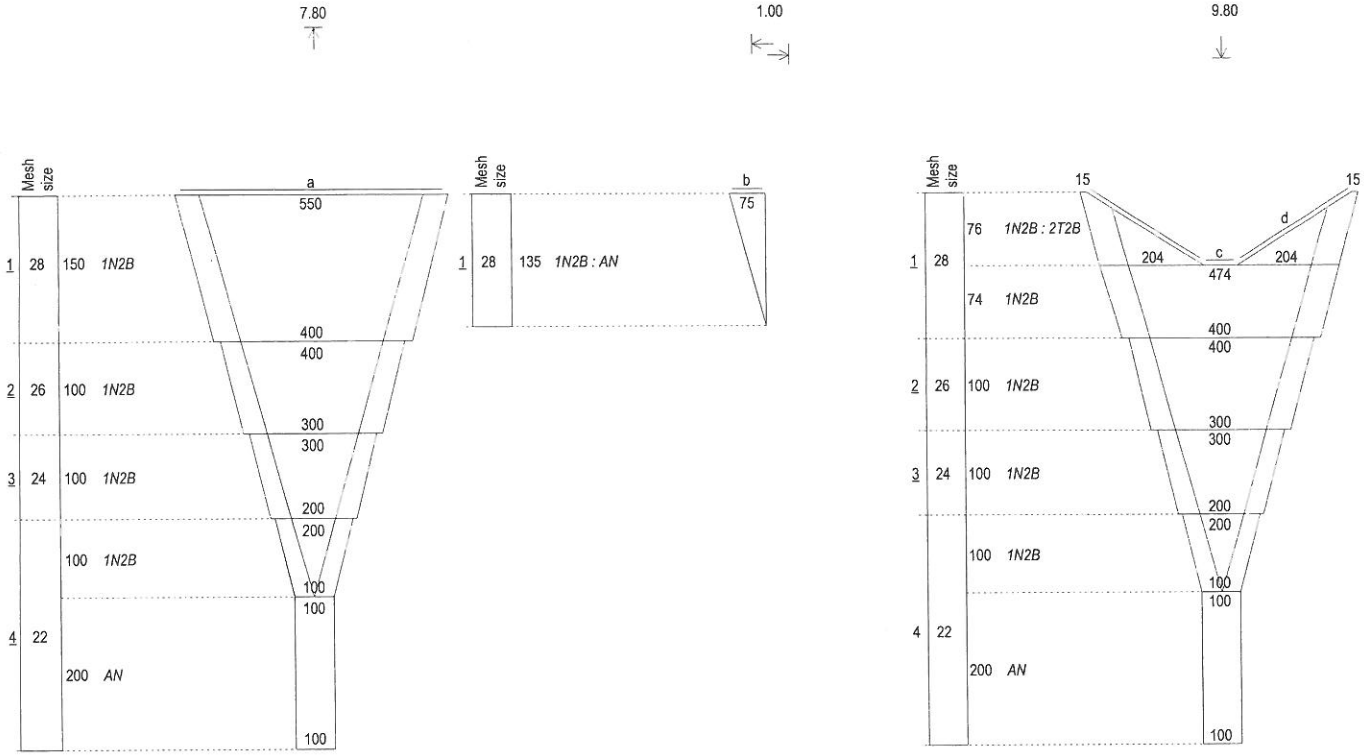
Fig. 1. A commercial shrimp beam trawl.

number, 1, 2, 3 or 4, indicating the longitudinal position (Fig. 3). The vertical subdivision was based upon the shape of the netting observed during earlier flume tank trials. The top panel as well as the belly of the net was thus divided in flat (A and D) and rounded (B and C) pieces of netting. For the longitudinal subdivision, the first section was located in the area of the bobbin rope. The net behind the bobbin rope was divided into three parts, based on the different mesh sizes.

Each of the 16 sections was provided with a small mesh pocket to collect the escapees. The material and mesh size of the pockets were the same as in the codend cover. The size of the pockets was kept small in order to keep the change in the waterflow through the net meshes as small as possible. Each pocket covered a rectangular area of the net. The opening of the pockets measured 120 by 69 pocket meshes or 75 by 69 pocket meshes depending on whether they covered the flat net sections (A and D) or the rounded net sections (B and C), the latter being too narrow to hold a wide pocket. The number of net meshes covered by the opening of the pockets ranged from 1100 to 2800 depending on the size of the pocket and the mesh size in the net. The total number of meshes in a section divided by the number of net meshes covered by a pocket, rigged to that section, was the raising factor used to estimate the escapes from the whole section from the pocket catch. The pockets were rigged with small floats or weights, where necessary, in order to keep the masking of the net meshes as small as possible.

Just behind the ground rope, underneath the belly of the net, two small mesh nets were rigged to catch the animals escaping underneath the ground rope. Each net covered 1 m of the path of the trawl.

The net, the cover and the pockets were observed with an underwater camera. The netting of the cover



Netting Code	1	2	3	4	Cod-end	Cover	Pockets
Material	PA	PA	PA	PA	PA	PA	PA
Nominal mesh size (mm)	28	26	24	22	22	11	11
Measured mesh size (mm)	26.16	25.54	22.79	21.64	21.70	10.50	10.8
Standard deviation (mm)	0.59	0.68	0.71	0.47	0.70	0.90	0.38

Agricultural Research Centre Ghent
Sea Fisheries Department
Ankerstraat 1, 8400 Oostende, Belgium
Tel. +32 59 320805 - Fax +32 59 330629

Ref. : BGHans1

Date: 30/03/95

Net: 7.80 m / 9.80 m

Type : Beam trawl - 8m beam
Target species : brown shrimp (*Crangon crangon*)
Source : Lucien Desmit

Vessel:
Beam trawler - shrimp

Ropes	Length	Material	Diameter
a	7.80 m	mixed	18.00
b	1.00 m	PE	16.00
c	0.80 m	mixed	18.00
d	4.50 m	mixed	18.00

Fig. 2. Net plan of the shrimpnet used during the experiments.

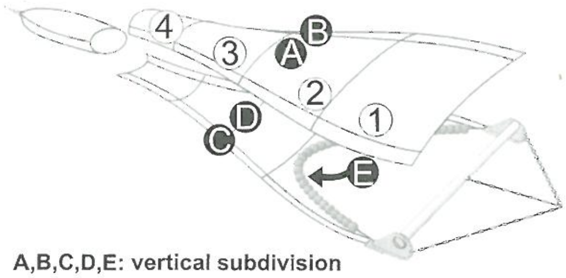


Fig. 3. The subdivision of the net into the sections that were sampled with small mesh pockets.

and the pockets was seen to be well away from the net meshes during the fishing operation.

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 were measured at several occasions during the sea trips in series of 25 meshes per panel. The average and standard deviations for the different net panels and covers are given on the net plan (Fig. 2).

2.3. Data collection and analysis

The species investigated were brown shrimp, plaice, sole and dab.

After each haul the codend catch was processed through a rotating shrimp riddle to separate the shrimps from the large by-catch fraction and next to separate the shrimps into commercial and non-commercial sizes. After sorting, the catch was thus subdivided into three catch fractions:

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

The volumes of each catch fraction were recorded. As a rule all fish in each catch fraction were measured, immediately after the haul. The fish were measured t the cm below from the tip of the nose to the tip of th stretched tail fin. A sample of 1.5 l of shrimps wer taken from the commercial and from the non-com mercial shrimp fraction for later analysis in the lal There the total length of the shrimps was measured t the mm below from the tip of the scaphocerite to th distal margin of the fans on the stretched uropod: Following the results of a theoretical study on th effect of sample sizes on the estimation of selectio parameters for shrimp trawl codends (Polet an Redant, 1999) it was decided to measure at leas 250 shrimps per catch fraction.

The fish and the shrimps from the codend cove were manually sorted. Again all fish were measure and a sample of 1.5 l of shrimps were taken to b measured in the lab. The catches in the small mes pockets were collected in numbered buckets. All fis as well as all shrimps were measured immediatel after the haul on board of the vessel.

The codend selectivity was investigated for the fou species measured. Based on the deviance residuals fc selection curves, the logistic function was chosen t describe the selectivity for each species and fitted th data very well. This function is the cumulative dis tribution function of a logistic random variable and i specified by the following equation:

$$\mathrm{RR(TL)} = \frac{\exp(a + b\mathrm{TL})}{1 + \exp(a + b\mathrm{TL})},$$

where RR(TL) is the probability that an animal o length TL is retained in the codend. a and b, which ar the two parameters to be estimated, represent th intercept and the slope, respectively, after a logisti transformation. These parameters were estimated witl the maximum likelihood method by the CC softwar (Constat, Denmark). L25, L50 and L75 are the bod lengths at which 25, 50 and 75% of the shrimps ar retained in the codend. SF is the selection factor and i the L50 divided by the mesh size. SR the selectio range and is equal to the difference between L75 an L25 and gives an idea about the slope of the curve Single hauls were combined by the variance compo nent analysis method of Fryer (1991) by the CC software. 95% confidence limits of the selection para meters are given in brackets in the text as well as in th tables.

A data exploration of the selectivity parameters was conducted to get an idea of the variability and correlations with the covariates. A linear regression was carried out to obtain an estimate of the level of association between L50 and SR. A multiple linear regression was then carried out to model the L50 and SR with haul duration, speed through the water, state of the sea, total catch volume, clogging of the meshes, water temperature and light conditions as possible explanatory variables.

In order to determine the whole trawl selectivity the numbers of shrimps and fish escaping from the different net sections and underneath the ground rope were calculated for each length class observed.

3. Results

3.1. Fishing conditions

A log of the sea trials is given in Table 1. For shrimp, 63 successful hauls were conducted, of which 59 had a codend cover to determine codend selectivity. For 39 hauls the catches of the pockets were measured and these were valid for the whole trawl selectivity calculations. Shrimps with lengths within the SR were caught in sufficient numbers in each haul to calculate codend selectivity. Shrimps below 35 mm were caught in low numbers relative to the total catch. In absolute numbers, however, in most hauls there were sufficient shrimps to calculate reliable retention points in the lower length range as well. In the upper length range numbers were always high. The length–frequency distribution of all shrimps used to calculate codend selectivity and whole trawl selectivity are given in Figs. 4 and 5, respectively.

A total of 23 hauls were carried out to determine the codend selectivity for fish (Table 1). Dab and plaice occurred in all 23 hauls but sole was only found in 8 hauls. Whiting and cod were not caught in sufficient numbers to carry out any selectivity calculations. The length distributions of dab, plaice and sole in the codend and codend covers are given in Figs. 6–8, respectively. For dab, 8 hauls contained sufficient numbers of fish in the codend and cover to compute single haul selectivity. The other 15 hauls were pooled to determine one combined ogive. For none of the hauls, however, were the numbers of fish in the codend

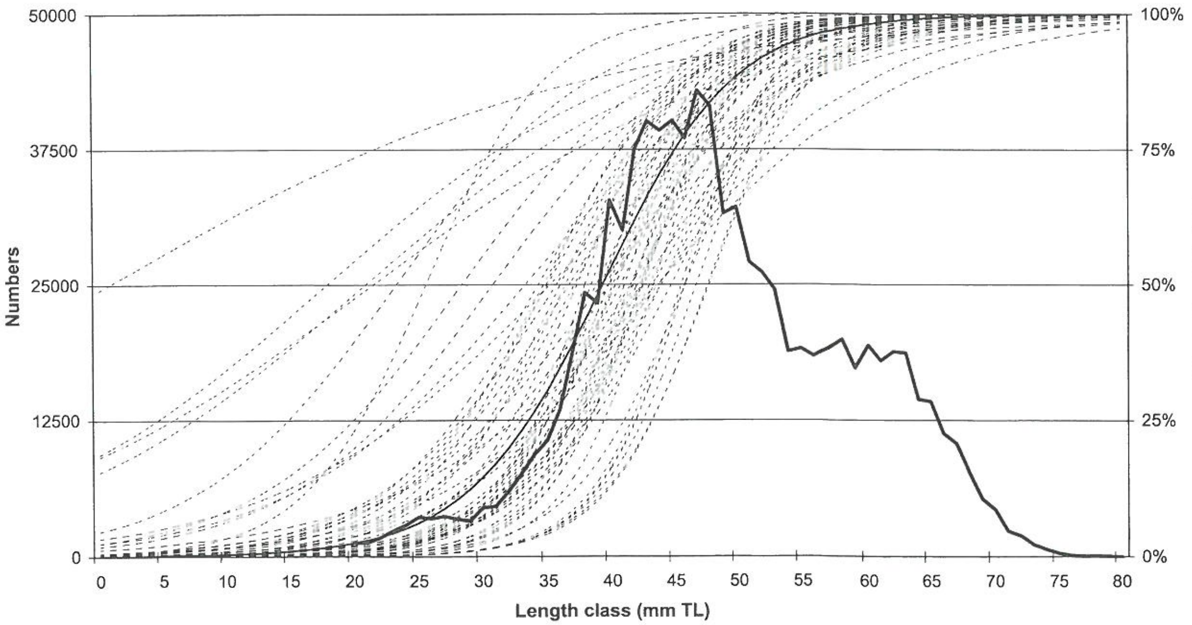


Fig. 4. The estimated overall selectivity ogive (in bold) together with the 59 selection ogives of the single hauls and the length distribution of the codend+codend cover catch.

Table 1
The log of the experimental hauls

Haul number	Date	Haul start time	Haul duration (h)	Codend selectivity shrimp	Whole trawl selectivity shrimp	L50 (mm) shrimp	SR (mm) shrimp	Codend selectivity fish	Whole trawl selectivity fish	L50 (mm) dab	SR (mm) dab	L50 (mm) sole	SR (mm) sole
95/13-01	29-05-95	13:35	0:30	Yes	No	43.4 (42.7–44.1)	7.9 (6.9–8.9)	No	No	(–)	(–)	(–)	(–)
95/13-03	30-05-95	6:25	0:30	Yes	No	45.9 (26.4–65.4)	8.0 (−0.2–16.1)	No	No	(–)	(–)	(–)	(–)
95/13-04	30-05-95	7:20	0:30	Yes	No	18.0 (12.7–23.3)	26.9 (20.3–33.6)	No	No	(–)	(–)	(–)	(–)
95/13-05	30-05-95	8:45	0:45	Yes	No	34.4 (32.4–36.4)	13.1 (11.1–15.2)	No	No	(–)	(–)	(–)	(–)
95/13-06	30-05-95	11:00	0:45	Yes	No	21.6 (15.0–28.2)	31.7 (21.8–41.7)	No	No	(–)	(–)	(–)	(–)
95/13-08	30-05-95	20:55	0:45	Yes	No	21.0 (17.6–24.5)	27.2 (21.6–32.8)	No	No	(–)	(–)	(–)	(–)
95/13-09	30-05-95	21:10	0:50	Yes	No	0.8 (−7.6–9.2)	41.8 (17.1–66.5)	No	No	(–)	(–)	(–)	(–)
95/13-12	31-05-95	9:35	0:35	Yes	No	30.9 (29.5–32.4)	17.1 (15.1–19.2)	No	No	(–)	(–)	(–)	(–)
95/13-13	31-05-95	10:45	0:45	Yes	No	39.3 (38.1–40.4)	17.2 (15.0–19.4)	No	No	(–)	(–)	(–)	(–)
95/13-14	31-05-95	11:40	0:40	Yes	No	39.9 (37.8–42.1)	15.6 (12.7–18.5)	No	No	(–)	(–)	(–)	(–)
95/13-15	31-05-95	20:55	0:45	Yes	No	33.4 (31.0–35.7)	19.8 (15.9–23.6)	No	No	(–)	(–)	(–)	(–)
95/13-16	31-05-95	22:06	0:44	Yes	No	23.4 (19.6–27.2)	17.0 (13.7–20.4)	No	No	(–)	(–)	(–)	(–)
95/27-03	13-11-95	16:32	1:00	Yes	Yes	43.1 (42.3–44.0)	11.4 (10.1–12.8)	No	Yes	(–)	(–)	(–)	(–)
95/27-05	13-11-95	20:35	1:00	Yes	Yes	39.4 (38.7–40.1)	8.8 (7.9–9.7)	No	Yes	(–)	(–)	(–)	(–)
95/27-06	13-11-95	22:05	1:15	Yes	Yes	36.1 (35.1–37.2)	11.2 (10.0–12.5)	No	Yes	(–)	(–)	(–)	(–)
95/27-07	13-11-95	23:50	1:20	Yes	Yes	38.5 (37.8–39.3)	8.8 (7.9–9.7)	No	Yes	(–)	(–)	(–)	(–)
95/27-08	14-11-95	1:35	1:25	Yes	Yes	34.8 (33.5–36.1)	12.1 (10.6–13.5)	No	Yes	(–)	(–)	(–)	(–)
95/27-09	14-11-95	13:17	1:10	Yes	Yes	35.0 (33.5–36.5)	11.3 (9.6–13.0)	No	Yes	(–)	(–)	(–)	(–)
95/27-10	14-11-95	15:00	1:10	Yes	Yes	41.8 (41.2–42.5)	8.1 (7.3–9.0)	No	Yes	(–)	(–)	(–)	(–)
95/27-11	14-11-95	16:50	1:00	Yes	Yes	37.2 (36.3–38.1)	12.5 (11.3–13.8)	No	yes	(–)	(–)	(–)	(–)
95/27-12	14-11-95	20:08	1:17	Yes	Yes	28.5 (25.1–31.8)	17.0 (13.3–20.6)	No	Yes	(–)	(–)	(–)	(–)
95/27-13	14-11-95	21:50	1:15	No	Yes	(–)	(–)	No	Yes	(–)	(–)	(–)	(–)
95/27-14	14-11-95	23:35	1:25	Yes	Yes	(–)	(–)	No	Yes	(–)	(–)	(–)	(–)
95/27-15	15-11-95	1:30	1:20	Yes	Yes	36.5 (35.4–37.6)	11.1 (9.7–12.5)	No	Yes	(–)	(–)	(–)	(–)
95/27-16	16-11-95	5:38	1:17	No	Yes	(–)	(–)	No	Yes	(–)	(–)	(–)	(–)
95/27-17	16-11-95	9:20	1:00	Yes	Yes	35.1 (33.3–36.9)	13.1 (10.8–15.5)	No	Yes	(–)	(–)	(–)	(–)
95/27-18	16-11-95	10:45	1:05	Yes	Yes	38.0 (37.1–38.9)	7.7 (6.6–8.7)	No	Yes	(–)	(–)	(–)	(–)
95/27-19	16-11-95	12:30	1:00	Yes	Yes	41.1 (40.3–42.0)	8.2 (6.9–9.5)	No	Yes	(–)	(–)	(–)	(–)
95/27-20	16-11-95	14:00	1:00	Yes	Yes	25.7 (22.6–28.9)	10.3 (8.4–12.1)	No	Yes	(–)	(–)	(–)	(–)
95/27-21	16-11-95	15:40	1:00	Yes	Yes	38.9 (37.7–40.0)	11.8 (9.7–14.0)	No	Yes	(–)	(–)	(–)	(–)
95/27-22	16-11-95	17:13	0:47	Yes	Yes	35.8 (34.8–36.9)	14.9 (12.8–16.9)	No	Yes	(–)	(–)	(–)	(–)
95/27-23	16-11-95	18:40	1:05	Yes	Yes	39.9 (39.1–40.7)	9.7 (8.3–11.2)	No	Yes	(–)	(–)	(–)	(–)
96/05-02	04-03-96	16:33	2:25	Yes	Yes	42.1 (41.3–43.0)	10.5 (9.0–12.0)	No	Yes	(–)	(–)	(–)	(–)
96/05-03	04-03-96	20:30	2:30	Yes	Yes	42.6 (42.1–43.1)	8.5 (7.6–9.3)	No	Yes	(–)	(–)	(–)	(–)
96/05-04	04-03-96	23:30	2:30	Yes	Yes	36.8 (−3.2–76.8)	14.6 (−10–39.9)	No	Yes	(–)	(–)	(–)	(–)
96/05-05	05-03-96	11:10	3:05	Yes	Yes	45.6 (45.1–46.1)	8.0 (7.1–9.0)	No	Yes	(–)	(–)	(–)	(–)
96/05-06	05-03-96	15:00	3:00	Yes	Yes	40.8 (39.9–41.6)	11.6 (9.9–13.2)	No	Yes	(–)	(–)	(–)	(–)
96/05-07	05-03-96	18:30	3:00	Yes	Yes	42.5 (41.8–43.2)	9.0 (7.9–10.1)	No	Yes	(–)	(–)	(–)	(–)

Table 1 (*Continued*)

Haul number	Date	Haul start time	Haul duration (h)	Codend selectivity shrimp	Whole trawl selectivity shrimp	L50 (mm) shrimp	SR (mm) shrimp	Codend selectivity fish	Whole trawl selectivity fish	L50 (mm) dab	SR (mm) dab	L50 (mm) sole	SR (mm) sole
96/05-08	05-03-96	21:50	2:40	Yes	Yes	42.3 (41.5–43.0)	10.4 (9.1–11.6)	No	Yes	(–)	(–)	(–)	(–)
96/05-10	06-03-96	12:00	2:45	Yes	Yes	39.3 (38.5–40.1)	9.6 (8.3–10.9)	No	Yes	(–)	(–)	(–)	(–)
96/05-11	06-03-96	15:05	2:40	Yes	Yes	47.7 (47.1–48.2)	8.9 (8.0–9.9)	No	Yes	(–)	(–)	(–)	(–)
96/05-12	06-03-96	18:00	2:00	Yes	Yes	41.7 (41.0–42.3)	10.0 (8.9–11.1)	No	Yes	(–)	(–)	(–)	(–)
96/05-13	06-03-96	20:15	2:17	No	Yes	(–)	(–)	No	Yes	(–)	(–)	(–)	(–)
96/05-14	06-03-96	22:45	2:30	Yes	Yes	45.9 (45.1–46.7)	7.9 (6.9–8.9)	No	Yes	(–)	(–)	(–)	(–)
96/25-01	04-11-96	12:45	0:30	Yes	Yes	40.2 (18.3–62.1)	9.4 (−1.2–20.1)	Yes	Yes	4.4 (–)	0.2 (–)	7.9 (–)	0.3 (–)
96/25-03	04-11-96	15:30	1:00	Yes	Yes	42.4 (12.0–72.8)	8.2 (−5.2–21.5)	Yes	Yes	4.8 (–)	0.4 (–)	7.9 (7.2–8.3)	1.8 (1.0–2.7)
96/25-04	04-11-96	17:00	1:15	Yes	Yes	40.4 (39.4–41.4)	9.8 (8.4–11.2)	Yes	Yes	4.3 (–)	0.6 (–)	8.3 (7.7–8.8)	1.3 (0.6–2.1)
96/25-05	04-11-96	18:45	1:15	Yes	Yes	43.4 (42.3–44.5)	12.8 (11.0–14.6)	Yes	Yes	4.9 (–)	0.4 (–)	8.6 (7.7–9.3)	1.7 (0.8–2.7)
96/25-06	04-11-96	20:30	1:30	Yes	Yes	40.4 (38.1–40.9)	10.7 (10.1–14.6)	No	Yes	(–)	(–)	7.8 (7.1–8.3)	1.7 (0.8–2.7)
96/25-07	04-11-96	22:30	1:30	Yes	Yes	41.6 (40.6–42.5)	10.2 (8.8–11.6)	Yes	Yes	5.2 (–)	0.6 (–)	7.8 (7.1–8.3)	1.7 (0.9–2.5)
96/25-08	04-11-96	0:30	0:30	Yes	Yes	39.8 (14.8–64.7)	8.4 (−3.1–19.9)	Yes	Yes	Combined		7.5 (5.6–8.1)	2.3 (0.8–3.9)
97/28-01	01-12-97			No	No	(–)	(–)	Yes	No	Combined		(–)	(–)
97/28-02	01-12-97			No	No	(–)	(–)	Yes	No	Combined		(–)	(–)
97/28-03	01-12-97			No	No	(–)	(–)	Yes	No	Combined		(–)	(–)
97/28-04	01-12-97			No	No	(–)	(–)	Yes	No	Combined		(–)	(–)
97/28-05	01-12-97			No	No	(–)	(–)	Yes	No	Combined		(–)	(–)
97/28-06	01-12-97	21:42	1:03	Yes	No	44.8 (43.6–46.0)	12.5 (9.8–15.1)	Yes	No	Combined		(–)	(–)
97/28-07	02-12-97	7:05	1:40	Yes	No	42.6 (41.3–43.9)	15.3 (12.7–17.9)	Yes	No	5.1 (–)	0.3 (–)	(–)	(–)
97/28-08	02-12-97	9:00	1:30	Yes	No	43.7 (42.2–45.1)	22.1 (17.7–26.6)	Yes	No	Combined		(–)	(–)
97/28-09	02-12-97	12:15	1:30	Yes	No	37.4 (36.4–38.3)	10.1 (8.8–11.5)	Yes	No	Combined		(–)	(–)
97/28-10	02-12-97	14:00	1:30	Yes	No	43.8 (41.9–45.7)	18.4 (13.8–23.0)	Yes	No	Combined		(–)	(–)
97/28-11	02-12-97	17:08	1:32	Yes	No	45.9 (45.0–46.7)	9.8 (8.4–11.2)	Yes	No	Combined		(–)	(–)
97/28-13	03-12-97	7:00	1:30	Yes	No	47.8 (47.1–48.5)	9.2 (8.1–10.3)	Yes	No	4.8 (–)	0.4 (–)	(–)	(–)
97/28-15	03-12-97	10:50	1:55	Yes	No	44.0 (43.0–45.0)	11.7 (9.7–13.7)	Yes	No	Combined		(–)	(–)
97/28-16	03-12-97	13:00	1:15	Yes	No	35.3 (32.5–38.1)	23.0 (17.6–28.4)	Yes	No	Combined		(–)	(–)
97/28-17	03-12-97	14:40	1:35	Yes	No	44.0 (42.8–45.2)	13.6 (11.1–16.1)	Yes	No	Combined		(–)	(–)
97/28-18	03-12-97	17:05	1:40	Yes	No	41.6 (40.3–42.8)	14.5 (11.7–17.3)	Yes	No	4.6 (–)	1.5 (–)	(–)	(–)
97/28-19	03-12-97	19:00	1:30	Yes	No	46.8 (46.1–47.4)	8.6 (7.7–9.5)	Yes	No	Combined		(–)	(–)
Combined hauls[a]										4.8 (–)	0.3 (–)		

[a] The selectivity data for the combined hauls marked as combined in the table.

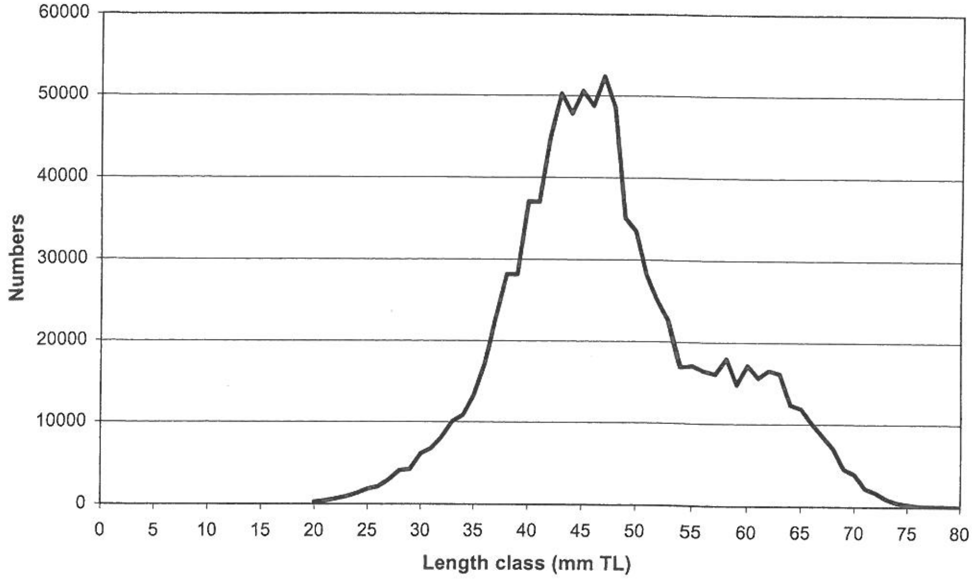


Fig. 5. The length distribution of all shrimps in the trawl path of the 39 hauls used in the whole trawl selectivity calculations.

cover sufficiently high to establish reliable confidence limits. No plaice were found in the codend cover. For sole 7 hauls were used for selectivity calculations of which one contained not enough fish in the cover to calculate confidence limits.

For 39 hauls, the small mesh pockets on the net were analysed for the presence of fish in order to determine the whole trawl selectivity (Table 1). Fish escaping through the meshes of the net body, however, were very rarely observed and negligible compared to the total catch.

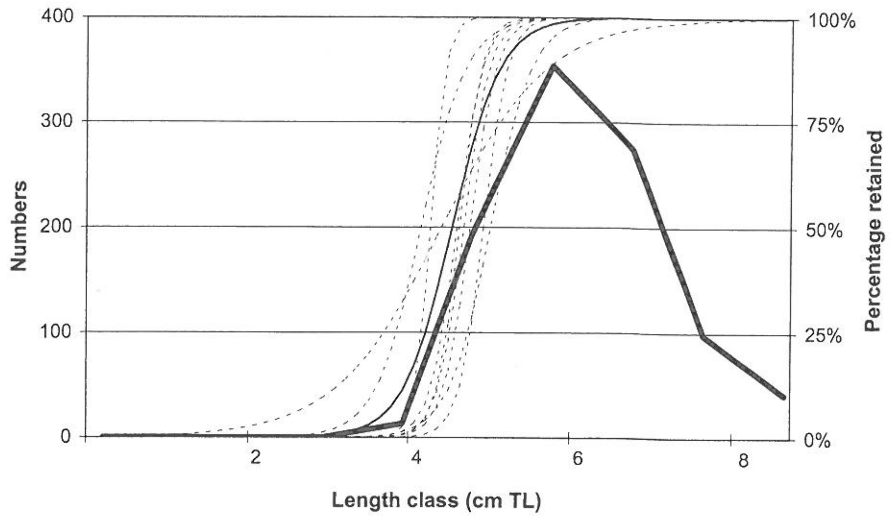


Fig. 6. The estimated selectivity ogives for dab together with the length distribution of the codend+codend cover catch (the overall selectivity ogive is drawn bold).

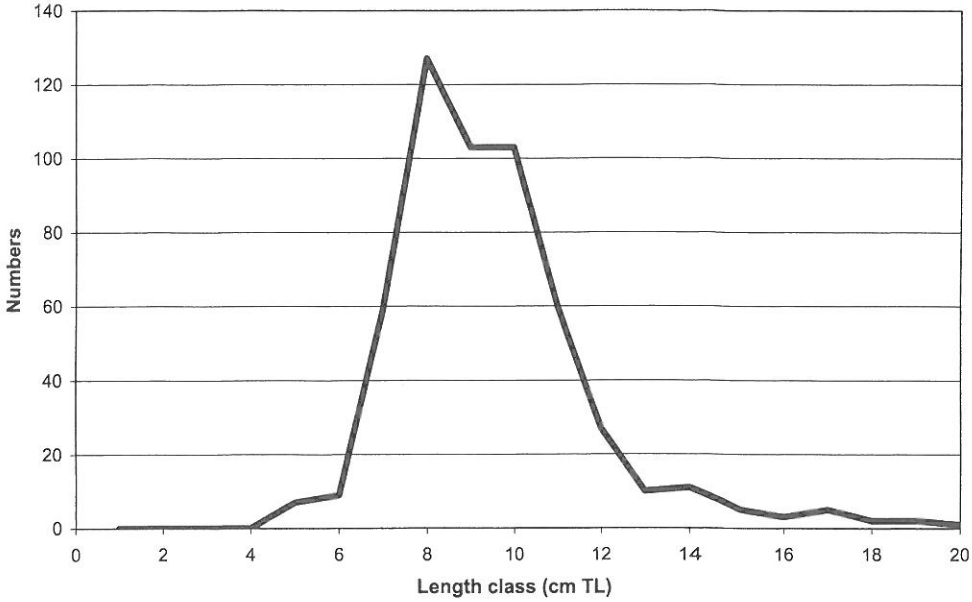


Fig. 7. The length distribution of the codend+codend cover catch for plaice.

3.2. Codend selectivity

The L50 for shrimp for all hauls combined was 39.4 mm (37.0–41.4) and the SF 1.82 (1.71–1.91). The SR was 11.6 mm (10.2–13.0). The selection ogive is shown in bold in Fig. 4. The selection ogives for the individual hauls are shown in dotted lines in Fig. 4 and the L50's and SR's are given in Table 1. Most of the L50's lay within the 35–45 mm range. Nine hauls had an extremely low L50, i.e. below 30 mm. Most of the

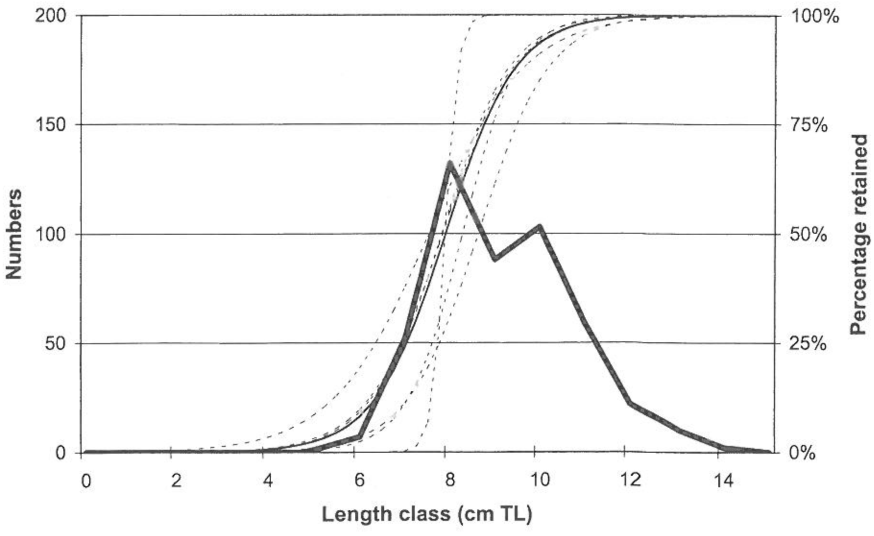


Fig. 8. The estimated selectivity ogives for sole together with the length distribution of the codend+codend cover catch (the overall selectivity ogive is drawn bold).

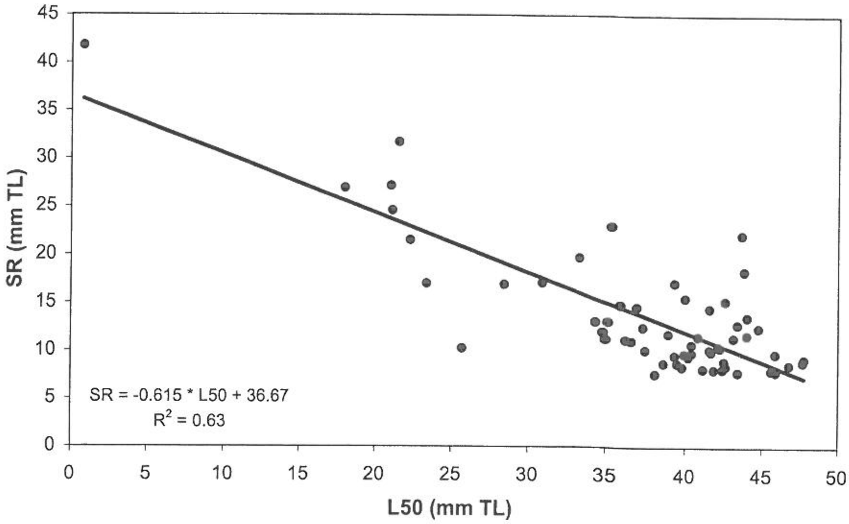


Fig. 9. Scatterplot and linear regression of L50 versus SR.

SR's lay within the 5–15 mm range. Eight hauls had an extremely high SR, i.e. above 20 mm. Six of these hauls also had a very low L50 which pointed at a possible high association between L50 and SR. The correlation coefficient ($R=-0.79$) was highly significant ($p<0.001$) and denoted a negative association between L50 and SR. The linear regression between L50 and SR shown in Fig. 9 indicated a slope significantly different from 0 ($p<0.001$), also without the outlier (0.8, 41.8) and an $R^2_{adj}=0.63$. Inspection of Fig. 9, however, showed a quite strong scatter around the regression line and a limited number of observations in the lower L50 range which weakened the conclusion of a clear relationship.

The correlation coefficients of L50 and SR with the covariates are given in Table 2. Light was neither significantly correlated with L50 nor wit SR. Catch volume and clogging were not significantl correlated with SR. All other covariates were asso ciated with L50 or SR at $p<0.05$ (Table 2). A multipl regression model was calculated for the dependen variable L50 and the significant covariates. Th regression summary is given in Table 3. Only clog ging, catch volume and state of the sea were retaine as significant variables. The expression for the L5 prediction was

$$L50 = 40.56 - 3.68c - 1.44v + 0.11s$$

where the parameters c, v and s were clogging, catcl volume and state of the sea, respectively. The F-valu is 46.4 with 3 and 55 degrees of freedom and th corresponding p-value <0.0001 indicated a highl significant relationship between the dependent vari able and the set of three independent variables. Th

Table 2
The correlation coefficients of L50 and SR with the possible explanatory variables

	L50	p-level	SR	p-level
Haul duration	0.41[a]	0.001	−0.31[a]	0.016
Speed through the water	0.32[a]	0.013	−0.38[a]	0.003
State of the sea	0.47[a]	0.000	−0.38[a]	0.003
Catch volume	−0.49[a]	0.000	0.16	0.220
Clogging of the meshes	−0.78[a]	0.000	0.79	0.101
Water temperature	−0.46[a]	0.000	0.34[a]	0.008
Light conditions	0.10	0.436	−0.19	0.151

[a] Correlation coefficients were significant.

Table 3
The multiple regression summary for independent variable L5 with state of the sea, catch volume and clogging (R=0.85 $R^2_{adj}=0.70$; $F(3.55)$=46.4; p<0.0001)

	B	S.E. of B	$t(55)$	p-leve
Intercept	40.56	1.955	20.75	0.000
Clogging	−3.68	0.438	−8.40	0.000
Catch volume	−1.44	0.442	−3.25	0.002
State of the sea	0.11	0.049	2.22	0.030

Table 4
The multiple regression summary for independent variable SR with clogging (R=0.79; $R^2_{adj}=0.61$; F(1.57)=92.9; p<0.0001)

	B	S.E. of B	t(57)	p-level
Intercept	11.32	0.555	20.40	0.000
Clogging	3.45	0.358	9.64	0.000

amount of variability in L50 explained by the model was 70%.

A multiple regression model was also calculated for the dependent variable SR and the significant covariates. The regression summary is given in Table 4. Only clogging was retained as a significant variable. The expression for the SR prediction was

$$SR = 11.32 - 3.45c$$

The F-value is 92.9 with 1 and 57 degrees of freedom and the corresponding p-value <0.0000 indicated a highly significant relationship between the dependent and the independent variable. The amount of variability in SR explained by the model was 61%.

For dab the L50 for all hauls pooled was 4.5 cm and the SF was 2.1. The SR was 0.7 cm. The selection ogive is shown in bold in Fig. 6. The selection parameters for the 8 single hauls and the 15 combined hauls are given in Table 1. The selection ogives are given in Fig. 6. The variability in the selectivity parameters was too low to find any relation with the covariates.

Plaice with lengths down to 5 cm were caught but no codend selection was observed.

For sole the L50 for all hauls pooled was 7.9 cm and the SF was 3.6. The SR was 1.7 cm. The selection ogive is shown in bold in Fig. 8. The selection parameters for the 7 single hauls are given in Table 1. The selection ogives are given in Fig. 8. As for dab the variability was too low to find any relation with the covariates.

3.3. Whole trawl selectivity

In Fig. 10a and b the percentages of shrimps escaping from the different net sections are shown based on the vertical and horizontal subdivision of the net, respectively. The areas indicate the relative amounts of shrimps escaping from each section. A moving average of three values has been applied to smooth the charts. The bar charts in Fig. 11 show each net section separately based on 3 mm length classes. Table 5 shows the percentages of shrimps <45 mm TL, >45 mm TL and all length classes combined escaping from the different net sections.

It is clear from Fig. 10 that most of the larger shrimps finish up in the codend. It is striking, however, that for the smaller shrimps the net selectivity is far more important than the codend selectivity. Of all shrimps <45 mm TL, 45% escape through the net meshes and only 26% escape through the codend meshes (Table 5). The selection through the meshes of the net is very length dependent (Fig. 11b). For the smallest shrimps measured, over 60% escape through the net meshes. This steadily decreases to reach a very low selection for the highest length classes. About 8% of all shrimps escape underneath the ground rope (Table 5), without a clear length dependence (Fig. 11a).

The data for the vertical subdivision of the net (Fig. 10a) indicate that for the net selectivity section C, which is the rounded sideway part of the belly, shows the highest escapes (24%). Section A, B and D, which are the upper parts of the net and the flat section of the belly of the net, are of very low importance for the selection of shrimps, especially when they are compared to section C (Fig. 11c–f). Less than 6% of the escapes occur through these three sections together. Except for section A it is evident that small shrimps can escape more easily than larger ones.

Based on the longitudinal subdivision (Fig. 10b) the differences in selectivity between sections are less evident than between the vertical sections. Fig. 11g–j, however, indicate that escape opportunities for shrimps decrease gradually from the anterior part to the posterior part of the net, especially for the larger animals. This is because the mesh size decreases and because meshes tend to close more towards the aft end of the net. Section 1 accounts for 14% of the escapes (Table 5). Contrary to the other sections, the smallest shrimps do not escape as easily as the mid length range from this anterior section. Sections 2, 3 and 4 account for 7, 8 and 1%, respectively (Table 5). This very low selectivity in Section 4 is probably due to the fact that this is the section with virtually closed meshes due to the tension in the net.

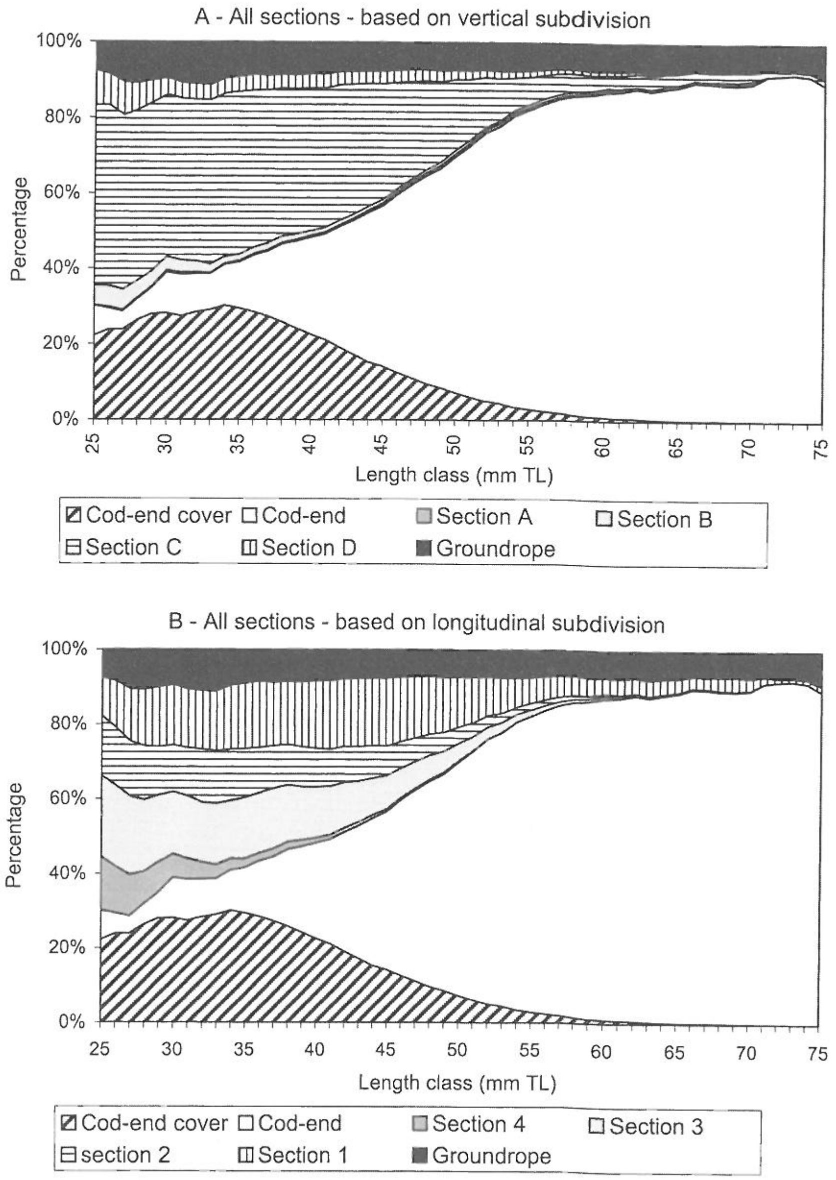


Fig. 10. Percentage of the total number of shrimps in the trawl path escaping from the different net sections.

The bulk of the larger shrimps (70%) finish up in the codend (Fig. 11k) (Table 5), and a substantial amount (26%) of non-marketable shrimps (<45 mm) are caught in the codend. About 30% of the marketable shrimps do not end up in the commercial catch and escape underneath the ground rope (7%), through the meshes of the net (19%) or through the codend meshes (6%) (Table 5).

No significant correlation was found between whole trawl selectivity and the covariates recorded.

4. Discussion

Reported selectivity parameters for *C. crangon* are rare. Selection factors obtained by Bohl and Koura

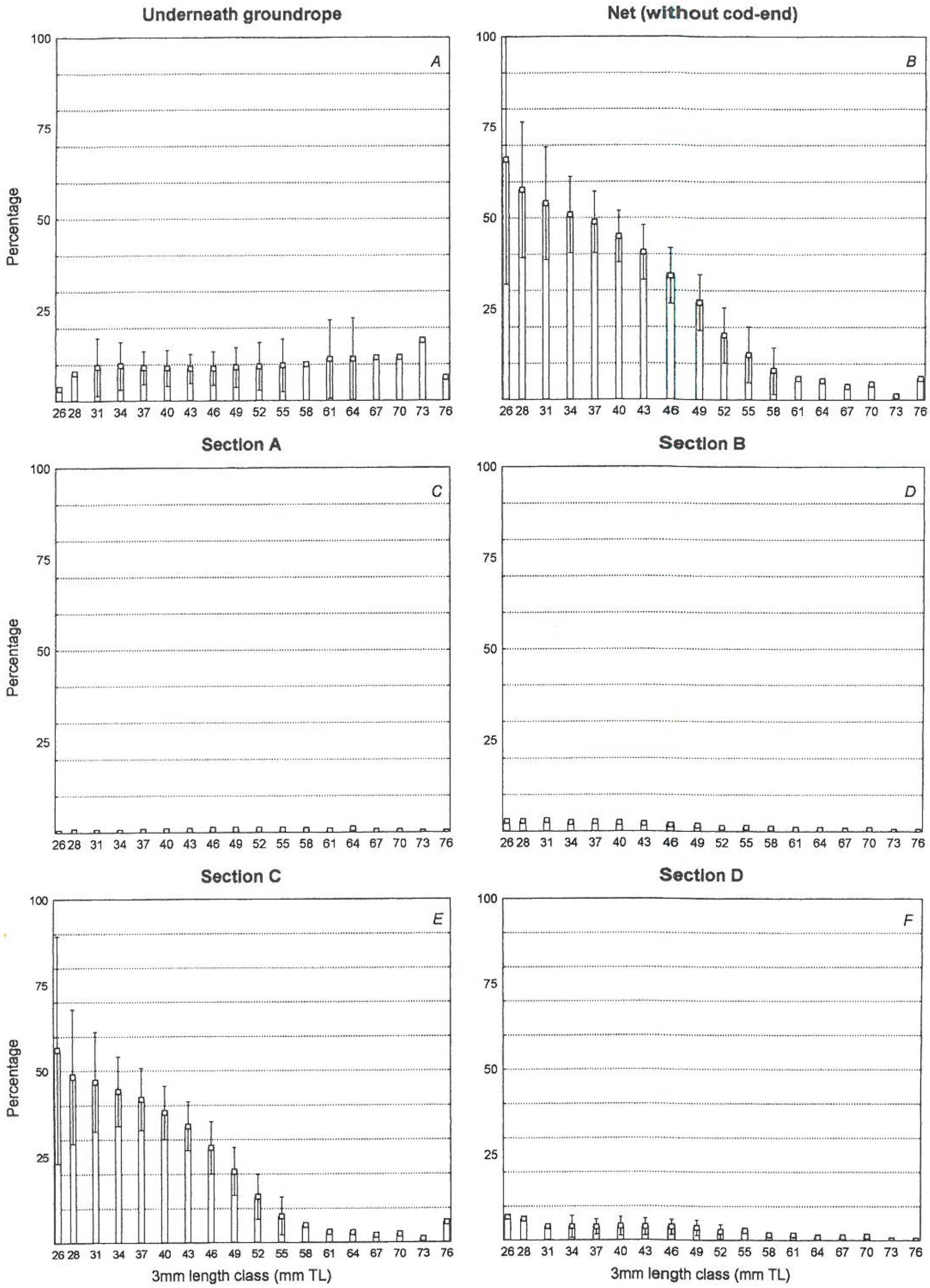


Fig. 11. Percentages of the total number of shrimps in the trawl path escaping from each net section separately.

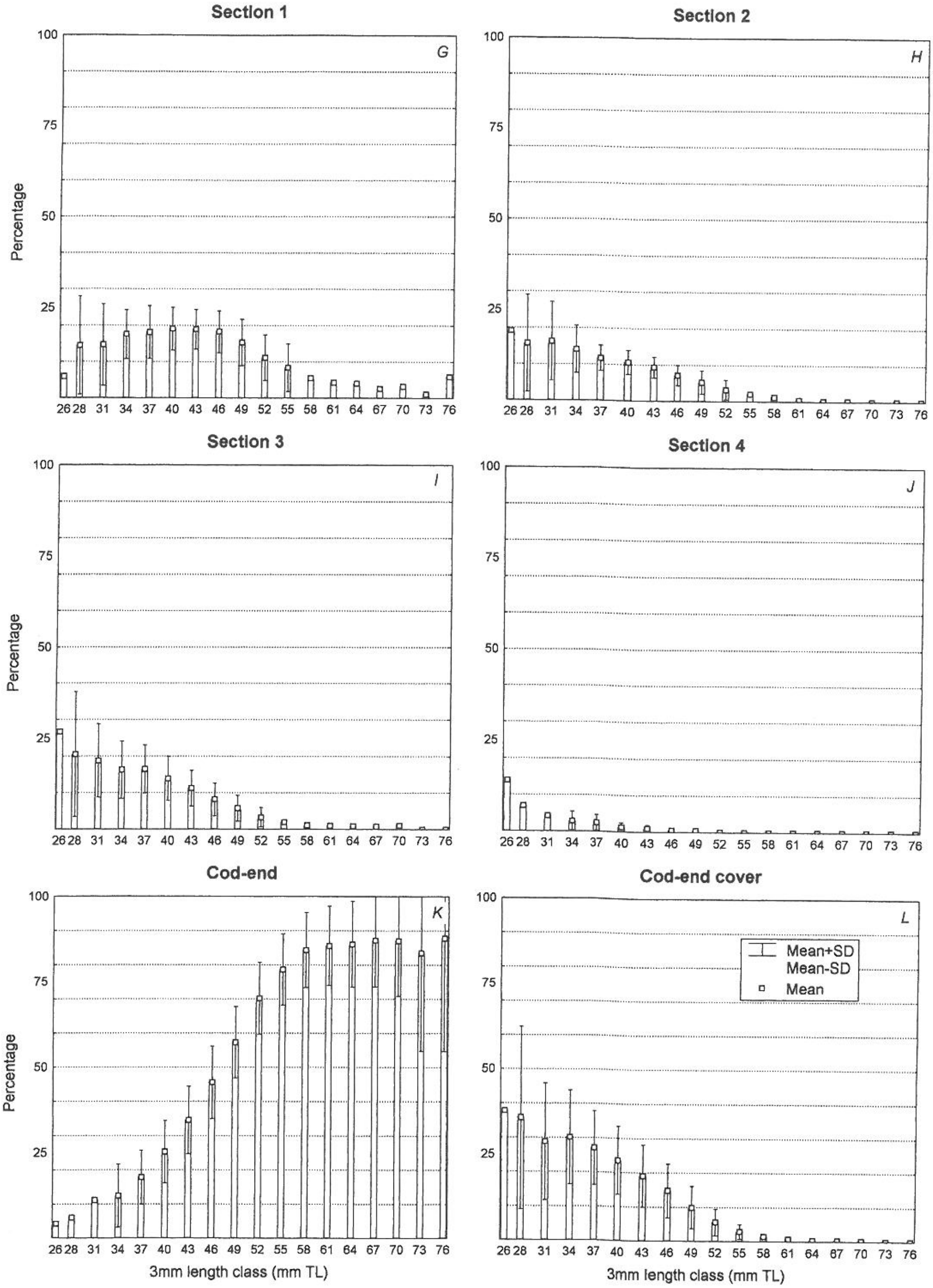


Fig. 11. (*Continued*).

Table 5
Percentages of shrimps, <45 mm TL, >45 mm TL and all length classes, escaping from the different net sections (standard deviation valuse are given between the brackets)

	<45 mm TL (%)	>45 mm TL (%)	All (%)
Codend cover	22 (10)	5 (4)	12 (7)
Codend	25 (9)	69 (11)	51 (12)
Net (without codend)	44 (6)	19 (6)	29 (7)
Section 1	18 (5)	11 (5)	14 (4)
Section 2	11 (3)	4 (2)	7 (2)
Section 3	14 (5)	4 (3)	8 (4)
Section 4	2 (2)	0 (0)	1 (1)
Section A	0 (1)	1 (1)	1 (1)
Section B	2 (3)	1 (1)	2 (2)
Section C	38 (6)	15 (5)	24 (5)
Section D	4 (2)	2 (2)	3 (2)
Underneath ground rope	9 (4)	7 (6)	8 (5)

(1962) for polyamide codends lay in the range 2.0–2.8. Recent experiments carried out by Graham (1997) with codends similar to the ones used in this study gave an SF of 1.6. The SF obtained in the present study lay in between the results of these two authors. The results on the whole trawl selectivity of the present study confirm the conclusion reported by Bohl (1963) that some part of the shrimps escaped through the net meshes. The present results not only demonstrate the existence of these escapes but also stress the relative higher importance of net selectivity compared with codend selectivity.

Graham (1997) reported an L50 of 4.6 cm and an SR of 0.6 cm for dab in a comparable shrimp trawl, which is very close to the results of the present study. The SF for dab of 2.1 found in this study is identical to the summary SF for dab in beam trawls reported in a review by Wileman for the European Commission (EU-study No. 1991/15). The SF for sole, however, was 3.6, which is higher than 3.2 mentioned in this review.

The high variability observed in the L50 values of the codend could for a large part be explained by the clogging of the meshes by hydroids, the catch volume and the state of the sea. L50 was negatively correlated with clogging, which is logical. The more hydroid threads that stick to the meshes, the smaller the opening will become that can be used by the animals to escape, thus reducing selectivity. Also total catch volume was negatively correlated with the L50. Higher catch volumes are often due to higher amounts of benthic animals in the catch, like crabs and starfish. Shrimps that end up in between high amounts of benthic animals in the codend do not always have the opportunity or force to find their way towards the open meshes. In a clean, low volume catch the encounters with the codend meshes will be much higher, thus increasing escape opportunities and selectivity. A consequence of this could be that in trawls with selective devices, like sorting grids or sieve nets that have cleaner catches of less volume, codend selectivity for shrimps will be higher. Sea state was positively correlated with the L50. Vessel motion, which depends on sea state, creates a pumping movement of the net, during trawling or during the hauling operation, when the trawl is heaving up and down alongside the vessel. These movements of the net may provoke the opening and closing of the meshes, which can induce a higher escapement of shrimps from the codend. A similar correlation between the sea state and codend selectivity was described for *Nephrops norvegicus* by Polet and Redant (1994) on a commercial vessel. It could be expected that the same three covariates would also affect SR, but only clogging was found to be significantly related with SR.

There is no legal minimum landing size for brown shrimps in the EU. There is however a minimum market size. According to EU-regulation 2406 shrimps should be graded in marketable and non-marketable shrimps on a sieve with 6.5 mm bar spacing. The minimum carapax width of 6.5 mm compares to a total length of 45 mm. This length lies very close to the mean L75 (45.2 mm TL) of the 20 mm shrimp codend and consequently quite a lot of non-marketable shrimps can be caught by this type of codend.

For the whole trawl selectivity study it was assumed that the total number of shrimps in the trawl path were known. The reliability of this number, however, depends upon the catching efficiency of the collecting bags underneath the ground rope. These were constructed to have a very good bottom contact but it was not possible to estimate their catching efficiency. Therefore the estimated number of shrimps escaping underneath the ground rope and consequently the total number of shrimps encountering the gear could be slightly underestimated.

5. Conclusions

The codend selectivity of a beam trawl for shrimps was very variable. Clogging of the meshes, catch volume and the state of the sea contributed significantly to this variability. On an average, the selectivity was rather poor for shrimp allowing relatively high amounts of non-marketable shrimps to be retained. The selectivity of the net body, however, was quite important and allowed more shrimps to escape than the codend. It was mainly the rounded lateral part of the netbelly that contributed to this selectivity.

Due to the small mesh size, codend selectivity for fish was very low. Only a small part of even the 0-age group fish could escape through the meshes. An increase in mesh size to improve this situation would shift the selection curve for shrimp to the right, which means that more marketable shrimps would be lost. Selective devices, like sorting grids or sieve nets, to separate the shrimps from the fish and/or benthos by-catch are therefore probably a better way to improve species selectivity of shrimp beam trawls.

The design of the fishing gear studied was comparable to most shrimp beam trawls used in the North Sea (van Marlen et al., report to the European Commission, EU-study 1994/044) and hence the results in this report have a wider applicability.

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