ICES Journal of Marine Science, 55: 835–845. 1998
Article No. jm980352

A species-selective trawl for demersal gadoid fisheries

A. Engås, T. Jørgensen, and C. W. West*

Engås, A., Jørgensen, T., and West, C. W. 1998. A species-selective trawl for demersal gadoid fisheries. – ICES Journal of Marine Science, 55: 835–845.

Experiments were carried out during two cruises in 1995 to test a prototype species-selective bottom trawl for separating cod from haddock and saithe, in the Norwegian bottom trawl fisheries in the Barents Sea. A sorting system incorporating a horizontal square mesh panel (150 mm bar length) dividing the trawl's body and extension sections into upper and lower compartments, leading aft to vertically-oriented trouser codends, was installed in a commercial roundfish trawl. During the first cruise approximately 90% of the haddock and 70% of the saithe were caught in the upper codend, with 70% of the cod in the lower codend. During the second cruise 90% of the haddock and 60% of the saithe were caught in the upper codend, with 65% of the cod caught in the lower codend. *In situ* video observations showed that fish, apparently haddock, entered the trawl at all levels, but subsequently many of those in the lower half attacked upwards and through the separating panel along its length as they passed towards the trouser codends. The differences in the results by species and season are discussed, along with the applicability of the sorting system to commercial fisheries.

Key words: species-selection, bottom trawls, commercial fisheries, gadoids.

Received 3 June 1996; accepted 16 November 1997.

A. Engås, T. Jørgensen: Department of Marine Resources, Fish Capture Division, Institute of Marine Research, PO Box 1870 Nordnes, 5024 Bergen, Norway. C. W. West: Fisheries Research Institute, Box 357980, University of Washington, Seattle, Washington 98195, USA. Correspondence to T. Jørgensen: tel: +47 55 236825; fax: +47 55 236830; email: terjej@imr.no

Introduction

Quotas are an important tool for regulating the exploitation of individual species in many multispecies fisheries. In the Norwegian groundfish trawl fisheries in the Barents Sea the principal target species are cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*), but saithe (*Pollachius virens*) are also commonly taken. Exploitation of cod and haddock is presently regulated by individual vessel quotas in this fishery, while licensed vessels can fish freely for saithe within the total allowable catch quotas allocated to the various components of the fleet.

Under these circumstances, trawl gear that permits species-selective harvesting offers real benefits to commercial fishermen. In situations where a vessel's annual quota for cod or haddock is low relative to the other species, or if early in the season it has caught a disproportionately large proportion of its quota for one of them but not the other, practical difficulties can arise in terms of catching the balance of its quotas for the other species since they often occur together and discarding is prohibited and strictly enforced. Market considerations may also motivate fishermen to fish selectively for one species or the other, and to shift their exploitation pattern on short notice.

Main and Sangster (1981) presented a classic description of species-related behavioural differences in the reactions of fish to trawls, focusing on several roundfish species including cod, haddock, and saithe. As a result of these findings, many studies have been carried out world-wide attempting to utilize behavioural differences in designing trawls that can separate species (e.g. Main and Sangster, 1982, 1985; Valdemarsen *et al.*, 1985; Boudreau and Tait, 1991; Moth-Poulsen, 1994; Wileman and Main, 1994; Arkley and MacMullen, 1996). Main and Sangster (1982) tested a three-level trawl to determine in which level various species entered the trawl. They found that cod primarily entered the lower compartment of the trawl, while the majority of

*Authorship equal.

1054–3139/98/050835+11 $30.00/0

haddock in the mouth of the trawl consistently rose from the seabed to enter the trawl in its uppermost level. A similar experiment with a two-level trawl in the Barents Sea (Valdemarsen *et al.*, 1985) confirmed the observations of Main and Sangster (1982) with respect to the catch composition of cod and haddock in the two levels, but haul-to-haul variation was large. However, in tests of similar separator designs in the Gulf of St Lawrence, the majority of cod were caught in the upper compartment (Boudreau and Tait, 1991). All the above studies were carried out with one or more relatively small-meshed horizontal dividing panels mounted above and parallel to the fishing line, thus dividing the trawl into different compartments from the mouth to the codend(s).

Preliminary Norwegian studies of the distribution and behaviour of cod and haddock in the extension section of a bottom trawl were carried out by the use of underwater video cameras, with horizontal ropes as reference marks to indicate the upper and lower regions of the extension sections (unpubl. data). While few cod and saithe were observed during these studies, the observations showed that haddock passing aftwards towards the codend tended to rise upwards within the extension. These observations led to the hypothesis that it might also be possible to separate cod and haddock within the body and extension of the trawl and not only in the trawl mouth area, as was attempted in the earlier studies mentioned above. Our approach was to use a horizontal separating panel of a mesh size large enough that fish could easily penetrate it. Assuming fish to perform their characteristic escape behaviour also inside the trawl, we expected haddock in the lower compartment to penetrate the panel and enter the upper compartment, while cod from to upper panel would show the opposite behaviour, i.e. move from the upper to the lower compartment.

Initial fishing trials conducted in the Barents Sea in 1993 and 1994 using a dividing panel made of 300 mm square mesh (or 150 mm bar length) netting in the extension section of an experimental trawl gave promising results with respect to separating cod and haddock. Approximately 70% of the haddock captured were found in the upper codend (unpubl. data) while around 70% of the cod were caught in the lower codend. Moreover, Moth-Poulsen (1994) also found that whiting (*Merlangius merlangus*) and haddock to a lesser extent would swim upwards through a square mesh separating panel. We therefore decided to carry out more comprehensive tests of the separating power of a large-meshed dividing panel. Because of practical problems experienced with the trawl used in the 1993 and 1994 experiments, the sorting device was redesigned and incorporated into a trawl in common use by commerical vessels.

Materials and methods

Cruise and vessel information

Two experimental cruises were carried out in the Barents Sea onboard the 2400 Hp Norwegian stern trawler "Anny Kræmer". The first cruise took place between 19 April and 3 May 1995 and the second took place between 17 and 26 October 1995. Experimental tows were made on various commercial fishing grounds (Fig. 1), at depths ranging from 90 to 280 m. The vessel was equipped with dual slipways so that two trawls could be rigged and ready for use at all times.

Experimental gear and operations

The experimental trawls were modified "Maxi" two-panel commercial groundfish trawls sized to suit the vessel's horsepower. The trawls were identical except for details that will be described below. The experimental modification to the trawls (Fig. 2) comprised a replacement for the back body and extension sections. The primary purpose of this modification was to adapt the trawl from its original single-codend configuration to a vertically-oriented trouser trawl configuration, with two codends arranged one above the other. A horizontally-oriented large-meshed (150 mm bar length) square mesh separating panel was installed between the selvedges joining the upper and lower panels, extending from the front of the trouser junction forwards to the aft section of the first belly behind the fishing circle (Figs 2 and 3). The separating panel was tailored to be stretched tight when the trawl was spread into its fishing configuration, dividing the trawl into upper and lower compartments leading to the two codends. Otherwise, mesh sizes, twine diameters etc. followed normal commercial practice.

All codends were made of nominal 136 mm regulated (inside measurement) mesh size and were full-sized commercial codends as used in the Norwegian groundfish fisheries. The upper codends on each of the two experimental trawls were made of 6 mm double-twine polyethylene (PE) netting to make them buoyant thus keeping them from fouling the lower codends, which were made of double polyamide (PA) twine, 90 m kg^{-1} runnage. Previous experiments (Valdemarsen, 1987) have not shown any differences in selectivity for otherwise identical codends made of these two netting materials. At the end of the first cruise, measurements were made of a sample of the meshes in the four experimental codends using a hand-held wedge-type gauge thrust into the netting. Twenty meshes were measured on each codend, working forward from a point five meshes above the codend closure and approximately one-half of the way across the upper panel of the codend. Average measured mesh sizes (inside measure) are given in Table 1.

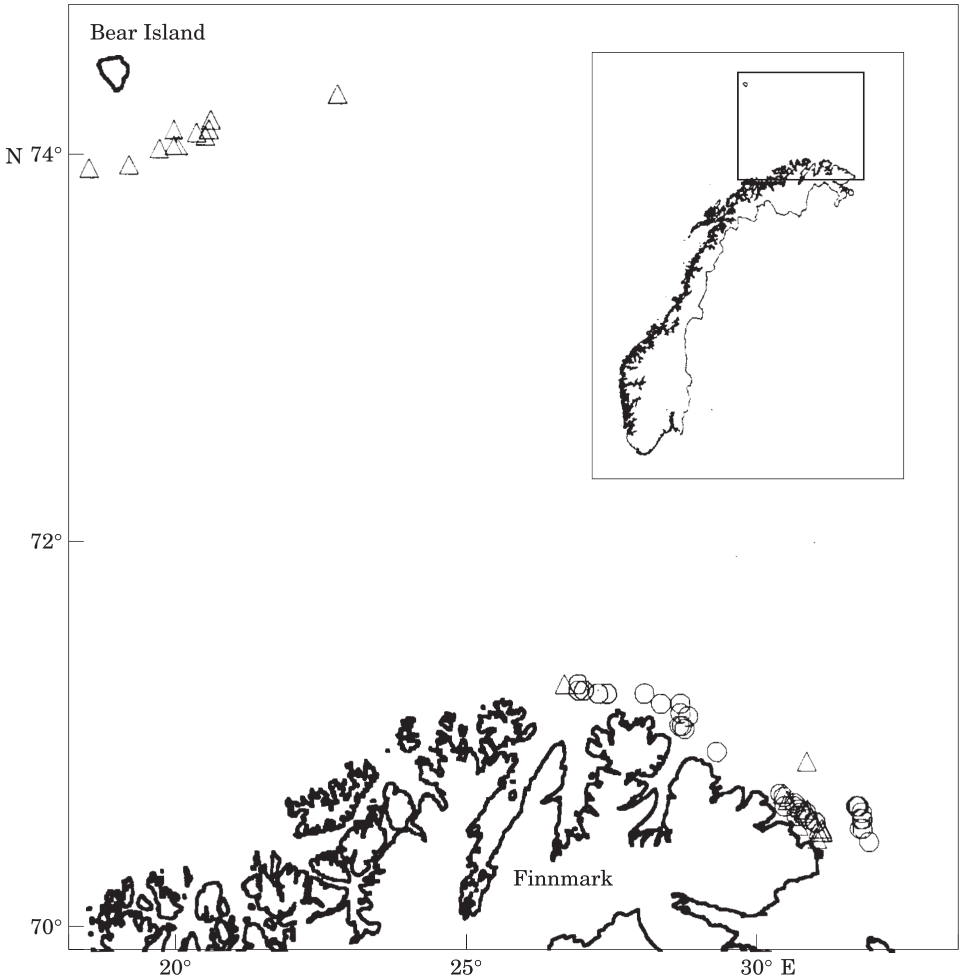

Figure 1. The fishing areas and the geographic location where the hauls were made. Cruise 1 (○); Cruise 2 (△).

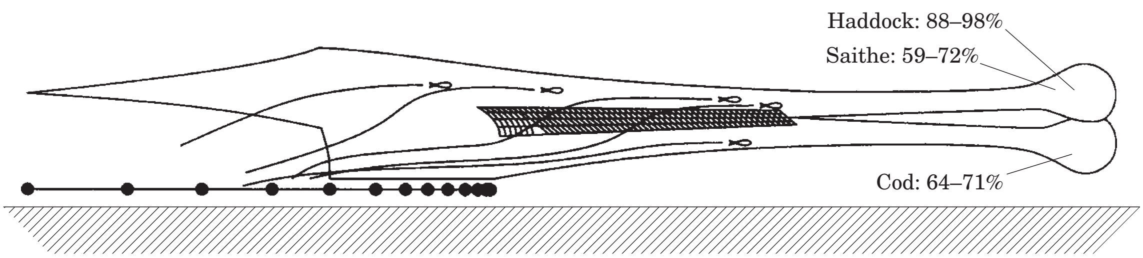

Figure 2. Schematic of sorting trawl configuration and typical fish responses.

The trawls were rigged with conventional rockhopper footropes (50 cm diameter) and a two-bridle rigging system, 174.5 m in overall length. The vessel used steel V-doors of roughly 9 m^2 surface area, weighing 2000 kg each.

During the early stages of the first cruise, the portside experimental trawl was additionally fitted with a small-mesh funnel (see Fig. 3 for details) in the lower extension section, approximately 1 m behind the aft end of the separating panel. The purpose of this funnel was to provide an artificial constriction in the lumen of the lower extension in order to interrupt the free passage of fish towards the codend and offer them an incentive and opportunity to make additional escape attempts into the upper extension. After 15 tows with the trawl in this configuration the funnel was removed, and for the

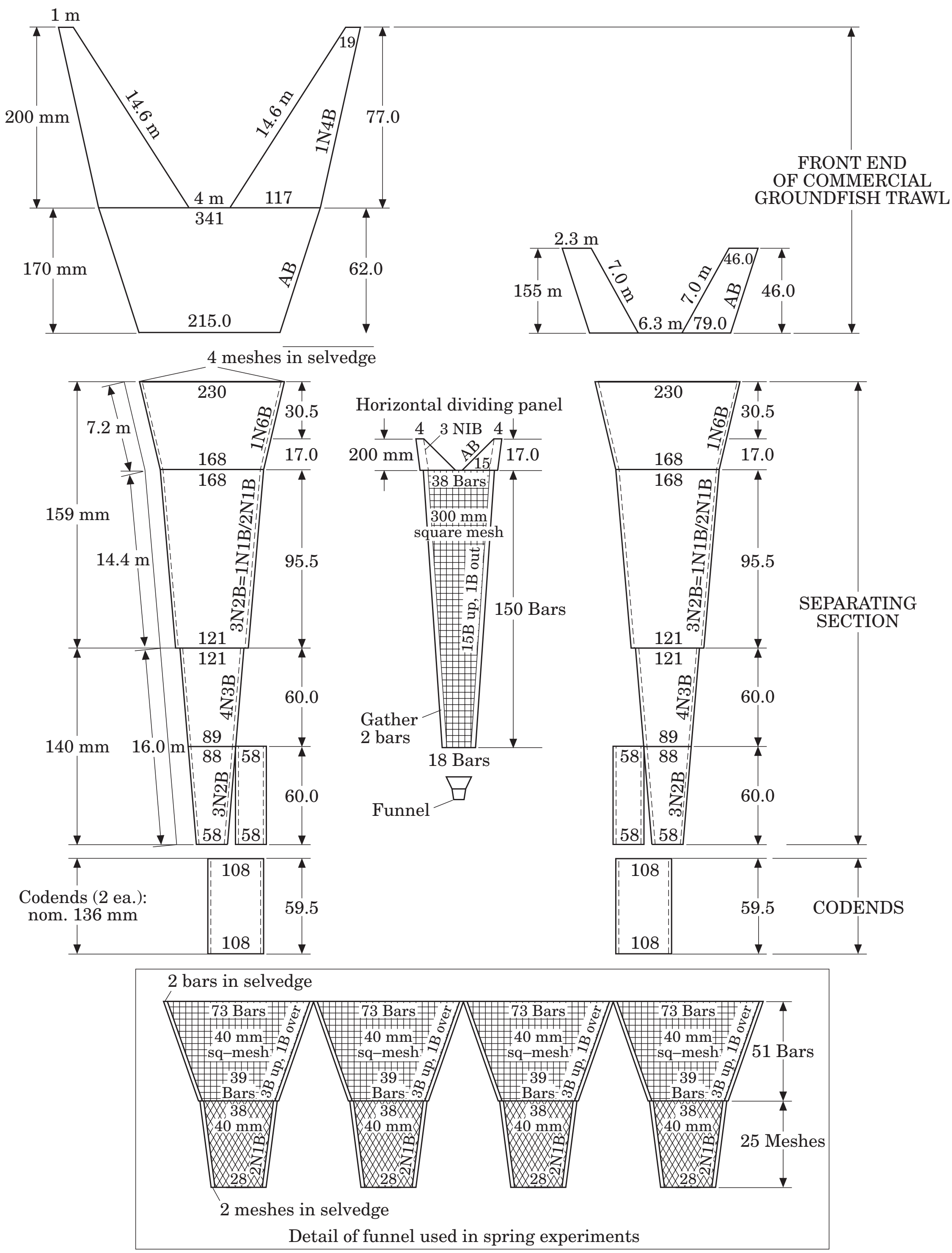

Figure 3. Construction and installation plan for the experimental separating section.

Table 1. Average measured mesh sizes.

Codend	Mean (mm)	s.d.
Starboard lower (PA)	141.1	2.7
Starboard upper (PE)	144.4	2.7
Port lower (PA)	147.8	2.6
Port upper (PE)	142.1	3.3

remainder of the first cruise and for all tows conducted during the second cruise the port and starboard trawls were configured identically.

In order to qualitatively verify that the experimental trawls performed in a manner comparable to standard commercial gear, four tows were made with the ship's conventional groundfish trawl during the first 3 days of the first cruise, interspersed among the experimental tows. We found that there was comparable catching performance between the experimental and the conventional trawls (see also Engås and West, 1995). The port and starboard experimental trawls were fished in an alternating pattern except for occasional interruptions due to gear damage.

Fishing operations took place around the clock. Due to the high latitudes at which the tows were conducted, full darkness was not encountered during the first cruise; conversely most of the tows conducted during the second cruise could be considered night-time hauls. Tow durations varied between 1 and 4 hours (with most tows either 1 or 2 hours in length) depending on fish densities. In an effort to maintain commercial fishing practices as much as possible other operational decisions such as the ratio of warp length to depth, vessel speed, and vessel course were left to the captain's discretion.

Data recording procedures

Catches from the two codends were kept separate throughout the entire dumping and sampling process. Estimates of total catch weight and species composition were recorded for each codend, based on the processed weight of each species component in the catch multiplied by the species-specific scaling factors used by the Norwegian fisheries authorities for converting processed weight to round weight (1.50, 1.40, 1.35 for cod, haddock, and saithe, respectively).

Catches from selected tows were sampled for length composition, using total length rounded down to the next lowest whole centimetre. Efforts were made to measure all individuals of the target species (cod, haddock, and saithe) but often catches were so large that it was necessary to take subsamples. Whenever such subsampling was necessary, all non-measured individuals were counted in order to determine the proportion sampled.

Analytical methodology

The proportion $\hat{r}_k$ of each of the three species retained in codend k (k={upper, lower}) was calculated using the ratio estimator:

$$\hat{r}_k = \frac{\sum_{i=1}^{n} w_k(i)}{\sum_{i=1}^{n} w_T(i)} \tag{1}$$

where w_k (i) is the catch weight of the chosen species in codend k for haul i, w_T (i) is the total catch weight (both codends) of the species for haul i, and n is the number of hauls with non-zero catches for the species. For purposes of convenience, the upper codend was designated as the "target" codend (codend k) for haddock and saithe while the lower codend was chosen for cod, these being the codends where the highest proportions of these species were expected to be found, respectively. Confidence intervals for the estimated proportions were based on bootstrap percentiles (Efron and Tibshirani, 1993). The percentiles used were BC_a estimates (bias and acceleration corrected (Efron and Tibshirani, 1993). Each bootstrap sample was the size of the original number of hauls sampled with replacement and 2000 bootstrapping iterations were performed.

Randomization tests (Edgington, 1987) were used to test the null hypothesis of no difference in the separation proportions obtained with the port and starboard trawls, or the port trawl with and without the funnel as tested on the first cruise. The calculated p-values were based on 5000 random permutations, and the test statistic was the difference (d) between the proportions as calculated from Equation (1):

$$d = \frac{\sum_{i=1}^{n} w_k(i)}{\sum_{i=1}^{n} w_T(i)} - \frac{\sum_{j=1}^{m} w_k(j)}{\sum_{j=1}^{m} w_T(j)} \tag{2}$$

where i and j index the n and m hauls for the two designs to be compared. Two-tailed tests were used. A similar test was used to test the null hypothesis of no difference in separation proportions between cruises.

The null hypothesis of no difference in length frequency distributions of fish caught in the upper and lower codends of individual hauls was also tested using randomization tests. The tests were performed on the actual (non-scaled) within-haul length measurements. Probabilities were based on 5000 random permutations using the largest absolute difference between the two

Table 2. Estimated separation efficiency ($\hat{r}$) for the various experimental trawl designs and p-value for the null hypothesis of no difference in separation efficiency between the designs.

Species	No. hauls	$\hat{r}$ (%)	No. hauls	$\hat{r}$ (%)	p-value
Cruise I	Starboard		Port		
Haddock	17	88.79	10	86.19	0.557
Cod	17	69.70	10	69.13	0.890
Saithe	9	66.23	6	77.06	0.454
	Funnel		No funnel		
Haddock	14	92.70	27	87.68	0.100
Cod	15	73.84	27	69.48	0.246
Saithe	8	74.65	15	71.72	0.817
Cruise II	Starboard		Port		
Haddock	17	88.79	10	86.19	0.557
Cod	17	69.70	10	69.13	0.890
Saithe	9	66.23	6	77.06	0.454

cumulative frequency distributions as the test statistic, i.e. the Kolmogorov-Smirnov test statistic (Zar, 1984). When estimating the overall length frequency distribution of the catches, numbers at each length were raised to the catch size before pooling.

Observations of fish behaviour and trawl performance

One haul during each cruise was conducted in order to obtain observations of the physical configuration of the experimental gear and the behaviour of fish within it. These underwater observations were made by means of an "Ocean Rover" towed underwater vehicle fitted with a high-frequency scanning sonar system and a low-light (10^{-3} lux) Silicon Intensified Target (SIT) camera permitting video observations without artificial illumination.

Results

A total of 43 valid experimental hauls was carried out during the first cruise and 23 during the second cruise. There was neither evidence for a difference in separation efficiency between the port and starboard trawls for any of the three species, nor for an effect of the funnel on separation efficiency (Table 2). Accordingly, all subsequent analyses were performed on combined data from all hauls. Separation efficiency for each of the three species was found to be independent of catch size, both with respect to the total catch of the particular species and the total catch weight for all species combined (Fig. 4, Table 3).

The results from the first cruise showed 89% separation of haddock and 72% separation of saithe into the upper codend (Table 4). Cod were primarily caught in the lower codend with an average separation efficiency of 72%. Haul-to-haul variation was considerably larger for saithe than for cod and haddock as illustrated by the wider confidence intervals of the estimated proportions. The separation results for haddock (88%) obtained in the second cruise were similar to those found in the first cruise, but were lower for cod and saithe (64 and 59%, respectively) (Table 4). Again haul-to-haul variation was relatively higher for saithe than for cod and haddock. Only for cod were the separation efficiencies significantly different between the two cruises ($p=0.02$).

Examination of the catch data showed that the hauls taken near Bear Island (during the second half of the second cruise) consisted primarily of cod, while in the hauls taken near the coast of Finnmark haddock and saithe were also well represented in the catches. However, separation efficiencies in the two areas were similar (Table 5).

Analysis of the length measurements for cod showed a significant ($p<0.001$) difference in the size of the cod caught in the upper and lower codends in 9 out of 15 hauls tested during the first cruise and in 3 out of the 6 hauls for which length measurements were taken during the second cruise. Whenever a significant difference was found, the larger cod were caught in the lower codend. For the overall catch, comparatively more of the cod in the size range 70–90 cm were caught in the lower codend (Fig. 5). With two exceptions in the case of haddock, there were no significant differences in the length frequencies of haddock and saithe in the upper and lower codends (Table 6b, 6c; Fig. 5).

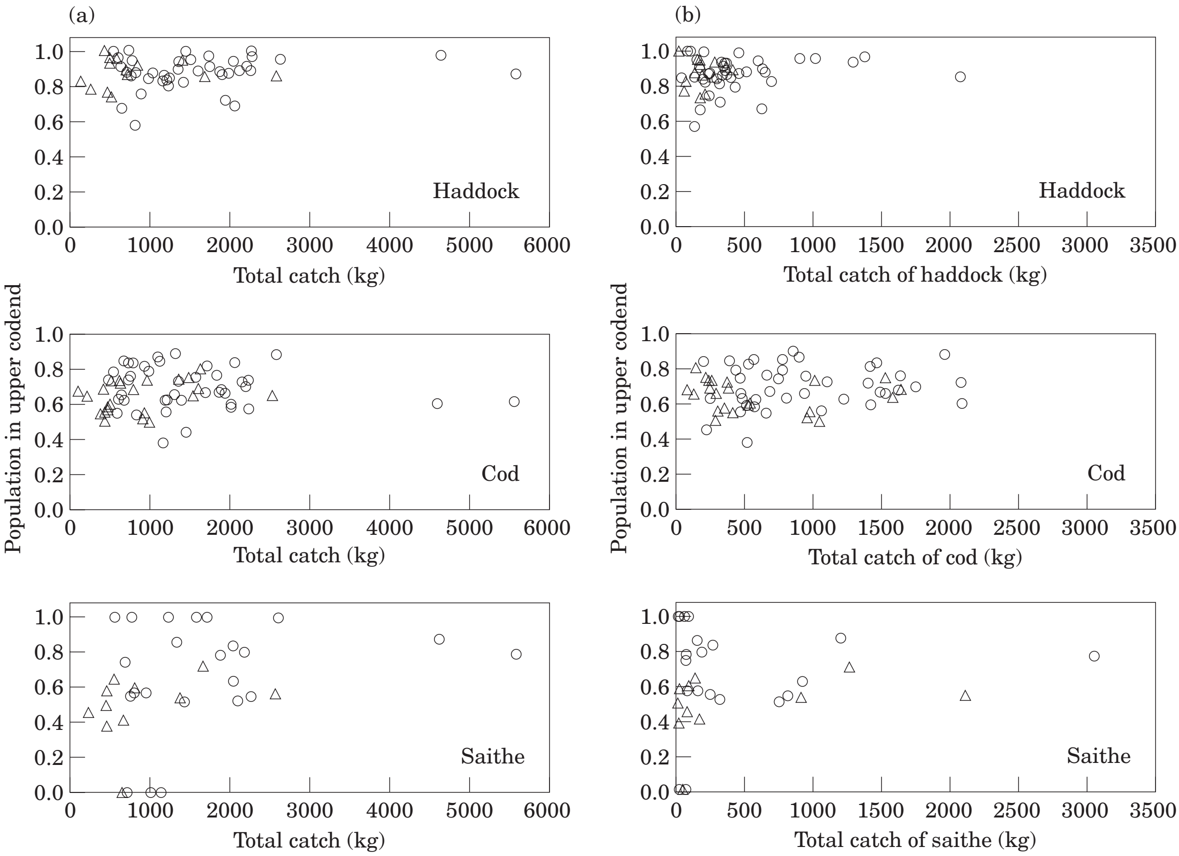

Figure 4. Separation efficiency for the three species, haddock, cod, and saithe, as a function of catch weight. (a) total catch weight, all species, (b) catch weight for that species only, upper and lower codends combined. Cruise 1 (○); Cruise 2 (△).

Table 3. Kendall's coefficient of rank correlation between separation efficiency for a species and the total catch of that species in a haul and between separation efficiency for a species and the overall catch in a haul. The p-value is for the null hypothesis of no correlation between the two variables.

			Separation efficiency vs.			
			Catch species		Overall catch	
Cruise	Species	No. of hauls	τ	p	τ	p
Spring	Haddock	41	0.156	0.151	0.151	0.164
	Cod	42	− 0.116	0.278	0.053	0.618
	Saithe	23	− 0.162	0.278	0.115	0.443
Autumn	Haddock	14	− 0.077	0.702	− 0.011	0.956
	Cod	23	0.202	0.178	− 0.269	0.073
	Saithe	11	0.345	0.139	0.309	0.186

Trawl performance and fish behaviour observations

The video and sonar observations confirmed that the physical configuration of the experimental trawls conformed to design expectations. The separating panel was stretched tight across the width of the trawl and roughly divided the trawl into equal upper and lower compartments. At its aft end, there was adequate room (1.5–2.0 m diameter estimated from scanning sonar measurements) at the beginning of the trouser extension section for passage into each leg of the extension.

Fish behaviour within the trawl could not be quantitatively assessed, but some overall observations were consistent. Fish entered the trawl at all levels, although the majority were observed entering at a relatively low

Table 4. Estimated separation efficiency (r̂) by species and cruise. The corresponding 95% confidence intervals were calculated by bootstrapping. "z_0" is the bias correction and "acc" the acceleration factor used to correct the percentiles. "U" designates upper codend and "L" lower codend.

Species	No. hauls	Codend	r̂ (%)	95% C.I.	z_0	acc
Cruise I						
Haddock	41	U	89.38	86.72–92.23	0.038	0.001
Cod	42	L	71.03	67.47–74.30	0.011	0.024
Saithe	23	U	71.94	60.99–80.05	− 0.014	0.064
Cruise 2						
Haddock	14	U	88.11	83.33–90.92	0.038	0.001
Cod	23	L	63.86	59.28–68.28	− 0.010	0.024
Saithe	11	U	59.16	53.56–69.94	− 0.099	0.064

Table 5. Estimated separation ratiois for cod, second cruise, broken down by area.

Area	No. hauls	r̂ (%)	95% C.I.	z_0	acc
Bear Island	12	63.73	58.25–67.90	0.025	0.031
Finnmark	11	63.97	56.75–71.13	0.074	0.029

level just clearing the fishing line and bottom belly panel. As fish passed aftwards through the lower compartment of the trawl towards the codend many attempted, often successfully, to swim upwards and penetrate the separating panel. Such attempts appeared to increase in frequency and vigour as fish came closer to the beginning of the trouser extension and as the cross-section of the trawl decreased. In no case were fish in the upper compartment ever seen attacking downwards towards the separating panel although it is possible that unobserved attempts occurred. Haddock could in many cases be identified from the black mark on the side of the fish, but otherwise our ability to identify the species of the observed fish was limited.

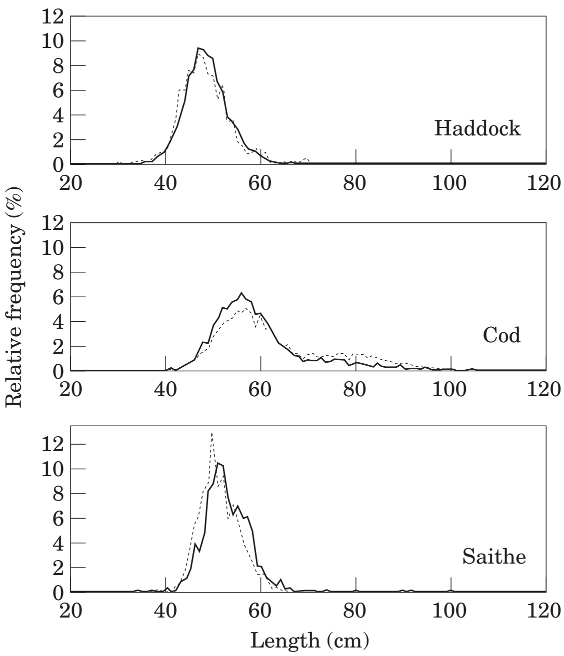

Figure 5. Relative length frequency of haddock, cod, and saithe in upper (——) and lower (– – –) codends, all hauls combined.

Discussion

The present experiments differ from similar trials with separator panels in trawls in that an attempt is made to use a large-mesh panel to exploit species-specific behavioural responses within the trawl to improve upon the initial vertical species separation present at the trawl opening. This was necessary because earlier experiments had shown that haddock, at least in Norwegian waters, often entered the trawl at a low level together with the cod. A further distinction is that we used a separator panel that did not extend all the way forwards to the trawl mouth as has been tried in other reported studies. When such panels extend all the way to the trawl mouth, the operating height of the front part of the panel becomes sensitive to variations in the trawl's horizontal spread caused by such factors as towing speed, the ratio of warp length to depth, catch size, bottom type, etc. (Engås, 1994). Since previous experiments have shown separation efficiency strongly affected by the vertical height of the panel's leading edge (Main and Sangster, 1982, 1985; Valdemarsen *et al.*, 1985), this is likely to contribute to increased haul-to-haul variation in

Table 6a. Results of the comparison of the size distributions of cod caught in the upper and lower codends. "n" is the number of fish measured, "L_{mean}" the mean length of the n fish, "d" is the Kolmogorov-Smirnov test statistic, the maximum absolute difference between the two cumulative distribution functionsm, and the "p-value" is the proportion of values of d generated in the 5000 random permutations of the data that were larger than the observed d. Where p-values were significant, the word "upper" or "lower" given in the last column designates the codend in which the largest fish were found.

Haul No.	Lower codend		Upper codend		d	p-value	Larger fish in
	n	L_{mean}	n	L_{mean}			
Cruise I							
12	386	56.40	540	49.26	0.096	0.494	—
13		46.95	23	60.09	0.101	0.213	—
17	638	55.89	380	54.67	0.173	0.003	lower
18	461	54.82	177	53.54	0.206	0.003	lower
24	856	71.89	413	66.50	0.212	<0.001	lower
25	710	71.73	443	67.73	0.172	<0.001	lower
27	268	70.63	214	68.13	0.147	0.025	lower
35	744	67.84	317	64.08	0.222	<0.001	lower
40	385	62.38	186	65.61	0.185	0.002	upper
43	424	59.27	264	59.71	0.149	0.049	lower
45	401	57.90	253	57.94	0.105	0.453	—
51	774	62.21	744	57.92	0.232	<0.001	lower
52	363	56.99	214	58.00	0.121	0.192	—
55	624	62.49	370	61.06	0.101	0.213	—
56	347	66.49	77	64.75	0.125	0.334	—
Cruise II							
2	344	61.74	197	58.86	0.263	<0.001	lower
4	487	60.90	230	58.11	0.256	<0.001	lower
12	373	57.37	123	58.70	0.112	0.391	—
13	522	58.02	423	59.75	0.100	0.247	—
16	531	62.48	470	59.88	0.250	<0.001	lower
18	357	54.57	465	59.86	0.289	0.529	—

separation efficiency. Because of its location further aft in the trawl, the height of the panel used in the present experiments is relatively less sensitive to variations in trawl geometry.

Fishing trials with separator panels have shown that even within a single species, the optimal height for a separating panel in one region may not be the best placement in other regions. In the North Sea, a panel height of 3 feet [Scottish waters, Main and Sangster (1985)] and 1 metre [English coast, Arkley and MacMullen (1996)] yielded approximately 80% of the cod in the lower codend, but when a similar panel height was used in the Gulf of St Lawrence, between 80 and 100% of the cod were captured in the upper codend (Boudreau and Tait, 1991). In previous Barents Sea experiments (Valdemarsen *et al.*, 1985), average cod proportions in the lower codend varied between 50 and 75%, depending on the panel height.

One possible explanation is that there may be differences in the vertical distribution of the various fish species from one area to another. Attempting to separate Norway pout and haddock/whiting, Wileman and Main (1994) observed no systematic overall effect of a separator panel but did observe a large variation between fishing grounds. This makes it difficult to determine an optimal panel placement that will be valid over a large geographic area. In addition, there may even be a seasonal effect as indicated by the differences in cod separation efficiencies between the spring and autumn cruises reported in this study.

Using the 150 mm square-mesh panel we observed higher and less variable separation ratios for haddock than those reported by Valdemarsen *et al.* (1985) in their earlier Barents Sea experiments. We attribute this partly to the separator's design offering haddock that have entered the trawl at a low level an opportunity to perform their characteristic upward escape reaction (Main and Sangster, 1981) later within the body of the trawl, i.e. swim from the lower compartment through the panel and into the upper compartment. The separating system for haddock thereby becomes more robust and less sensitive to the distribution and behaviour in the trawl mouth. The *in situ* video observations showed fish penetrating the panel from the lower to the upper compartment, and in the few instances that the fish's species could be identified they were haddock.

There is other circumstantial evidence that the fish seen penetrating the panel were haddock. The separation

Table 6b. Results of the comparison of the size distributions of haddock caught in the upper and lower codends.

Haul No.	Lower codend n	Lower codend L_{mean}	Upper codend n	Upper codend L_{mean}	d	p-value	Larger fish in
Cruise I							
12	47	48.81	290	49.26	0.146	0.654	—
13	22	46.95	351	49.08	0.125	0.945	—
18	4	45.00	23	46.30	0.304	0.820	—
24	236	47.72	356	46.94	0.173	0.085	—
25	82	51.71	313	49.34	0.421	<0.001	lower
27	114	48.00	379	48.30	0.080	0.931	—
35	161	48.48	388	48.49	0.130	0.342	—
40	160	45.14	296	46.10	0.121	0.444	—
43	37	48.49	361	49.42	0.125	0.854	—
45	52	48.67	264	49.73	0.241	0.127	—
51	52	47.02	334	49.68	0.210	0.109	—
52	46	46.35	217	47.54	0.137	0.623	—
55	61	47.79	367	49.40	0.159	0.402	—
56	42	47.79	202	48.74	0.427	0.481	—
Cruise II							
2	31	48.61	69	48.11	0.217	0.273	—
4	46	50.50	373	49.50	0.140	0.581	—
12	47	48.96	239	49.82	0.127	0.735	—
16	167	54.57	465	52.92	0.289	<0.001	lower

Table 6c. Results of the comparison of the size distributions of saithe caught in the upper and lower codends.

Haul No.	Lower codend n	Lower codend L_{mean}	Upper codend n	Upper codend L_{mean}	d	p-value	Larger fish in
Cruise I							
12	157	49.88	269	49.57	0.171	0.329	—
13	122	48.64	168	49.64	0.127	0.708	—
17	5	49.40	28	50.79	0.386	0.415	—
43	274	50.57	268	51.18	0.110	0.690	
45	311	51.38	259	52.73	0.173	0.104	
51	82	55.68	276	59.96	0.180	0.242	—
55	16	59.19	16	58.00	0.313	0.300	—
56	40	58.08	23	55.70	0.333	0.079	—

efficiencies for cod and saithe obtained in this study are comparable to those reported by Valdemarsen *et al.* (1985), where a small-meshed separator panel which blocked fish passage from one level to the other was used. In an attempt to develop a species-specific whiting trawl, Moth-Poulsen (1994) tested two designs in which fish could only enter the upper codend by penetrating a separating panel. About 50% of the whiting and 20% of the haddock were caught in the upper codend, but very few cod. The findings from these studies taken together suggest that the separation efficiencies we obtained for cod and saithe reflect the actual vertical distribution of fish in the mouth of the trawl, but that haddock will often try to swim upwards through such panels. The larger haul-to-haul variation in separation efficiency for saithe than for cod and haddock may partially be a result of several small catches of saithe. Initially we expected cod to penetrate the panel from the upper to the lower compartment, but the video observations showed only movements from the lower to the upper compartment.

Main and Sangster (1985) observed that fish were frequently meshed when a separating panel of 80 mm mesh size was used and recommended the use of a panel with the minimum legal mesh size. No meshing in the 150 mm square mesh panel was observed during the fishing trials in the Barents Sea, nor did the panel and trouser codends present any other handling problems during these commercial style fishing operations.

Cod was the only species showing a trend for size differences between the lower and upper codends. Such size differences were not seen on every haul, but when detected there was a strong tendency for larger fish to be found in the lower codend, especially the very largest individuals. The reason for this is not clear. The practical significance of the size difference is debatable as the difference in mean length never exceeded 5 cm or so, and was at least partially due to the presence of a few large fish caught in the lower codend rather than any marked differences in overall size composition.

The present design gives very promising results in terms of sorting haddock into the upper codend. Fishermen targeting haddock using the present system, and with the lower codend open in order to avoid catching cod, risk losing only approximately 10% of their landed weight of haddock. However, sizeable proportions (up to 40%) of the cod are still caught in the uper codend. Another potential application might be for fishermen to use a relatively large mesh size in the lower codend so that their cod catches are both reduced and shifted towards larger fish, which presently command a 40% higher price per kilogram.

References

Arkley, K., and MacMullen, P. 1996. Commercial evaluation of a separator trawl in a North Sea fishery. ICES Fishing Technology and Fish Behaviour (FTFB) Working Group Meeting, Woods Hole, USA 15–18 April 1996.

Boudreau, M., and Tait, D. 1991. The performance of a horizontal split level trawl in the Gulf of St. Lawrence segregating cod from flatfish. ICES Fishing Technology and Fish Behaviour (FTFB) Working Group Meeting, Ancona, Italy 22–24 April 1991.

Edgington, E. S. 1987. Randomization tests. Second edition. Statistics: textbooks and monographs, volume 77. Marcel Dekker, Inc., New York. 341 pp.

Efron, B., and Tibshirani, R. J. 1993. An introduction to the bootstrap. Chapman and Hall, New York. 436 pp.

Engås, A. 1994. The effects of trawl performance and fish behaviour on the catching efficiency of demersal sampling trawls. *In* Marine fish behaviour in capture and abundance estimation, pp. 45–68. Ed. by A. Fernö, and S. Olsen. Fishing News Books, Blackwell Science Ltd, Oxford. 221 pp.

Engås, A., and West, C. W. 1995. Development of a species-selective trawl for demersal gadoid fisheries. ICES CM 1995/B+G+H+J+K: 1.

Main, J., and Sangster, G. I. 1981. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. Scottish Fisheries Research Report No. 23. 23 pp.

Main, J., and Sangster, G. I. 1982. A study of a multi-level bottom trawl for species separation using direct observation techniques. Scottish Fisheries Research Report No. 26. 16 pp.

Main, J., and Sangster, G. I. 1985. Trawling experiments with a two-level net to minimise the undersized gadoid by-catch in a Nephrops fishery. Fish Research, 3: 131–145.

Moth-Poulsen, T. 1994. Development of a species selective whiting trawl. ICES CM 1994/B: 22 Ref. G.

Valdemarsen, J. W. 1987. Sammenligning av selektiviteten til polyetylen og polyamid trålposer. Rapport no. 6121. Fiskeriteknologisk forskningsinstitutt, Bergen, Norway [In Norwegian].

Valdemarsen, J. W., Engås, A., and Isaksen, B. 1985. Vertical entrance into a trawl of Barents Sea gadoids as studied with a two-level fish trawl. ICES CM 1985/B: 46.

Wileman, D. A., and Main, J. 1994. Attempts to develop a species selective trawl for fishing pout. ICES CM 1995/B: 10 Ref. G.

Zar, J. H. 1984. Biostatistical analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 620 pp.