Available online at www.sciencedirect.com
SCIENCE DIRECT®

Fisheries Research 79 (2006) 303–312

FISHERIES RESEARCH

www.elsevier.com/locate/fishres

Escapement of gadoid fish beneath a commercial bottom trawl: Relevance to the overall trawl selectivity

Ólafur Arnar Ingólfsson *, Terje Jørgensen

Research Group of Responsible Fish Capture, Institute of Marine Research, PO Box 1870 Nordnes, N-5817 Bergen, Norway

Received 10 May 2005; received in revised form 14 November 2005; accepted 6 December 2005

Abstract

Escapement of Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and saithe (*Pollachius virens*) beneath a commercial bottom trawl, rigged with a 60 cm diameter rockhopper gear, was studied in the Barents Sea. The study was performed off the coast of north Norway in March/April 2003. In order to collect the escapees, three sampling bags were attached behind the rockhopper gear. Approximately one third of the cod and a quarter of the haddock available to the trawl escaped. Cod escape rates were highly length-dependent, following a sigmoid curve with an estimated length at 50% escape of 38.5 cm and interquartile width of 34.1 cm. Length dependence was less pronounced in haddock. The escape rate of saithe was not length-dependent, and on average 7% passed under the trawl's fishing line. Fish abundance had no observable effects on escape rates. Both video observations and scale abrasions on the fish caught in the collecting bags showed that some of the escaped fish had been overrun by the gear.

Keywords: Cod; Escapement; Haddock; Rockhopper; Selectivity; Trawl

1. Introduction

The rockhopper ground gear was introduced into the trawl fisheries in the mid-1980s, and is now widely used by commercial groundfish trawlers. Compared to trawls using traditional steel bobbins, trawls fitted with rockhopper gear can fish on rougher bottoms and net damage has been reduced. There are also indications that rockhopper ground gear is more efficient than bobbins gear in catching fish close to the bottom (Main and Sangster, 1985; Engås and Godø, 1989). The efficiency of the rockhopper gear in commercial fisheries, i.e. to what extent fish go under the gear, however, has not been investigated. Studies of escapement beneath survey trawls with rubber rollers and steel and rubber bobbins, using collecting bags behind the gear for collecting escapees, have shown escapement of Pacific cod (*Gadus macrocephalus*) (Munro et al., 1997) and Atlantic cod (Engås and Godø, 1989; Walsh, 1992) to be inversely proportional to fish length. Engås and Godø (1989) also reported a high degree of length-dependent escapement of haddock beneath the survey trawl though Ehrich (1987) registered no escapement of young haddock. If escapement is length- and/or species-dependent, it is part of the overall selectivity of the trawl, and is thus of importance to both managers and the fishing industry.

Comparative experiments showed that rockhopper ground gear rigged on a survey trawl (Engås et al., 1988; Engås and Godø, 1989) demonstrated higher efficiency than gear fitted with bobbins, particularly for small cod. It would nevertheless be an over-simplification to generalize the results as a difference between rockhopper and roller gear since the gears differed in weight and dimensions. In addition, although similar escape patterns beneath commercial and survey trawls may be assumed, the difference between the gear types cannot be ignored. In general, large commercial trawlers use gear with 45–60 cm disc diameters compared to 35.6 cm for the Norwegian bottom survey trawl.

Main and Sangster (1983) noted during direct diving observations of a demersal otter trawl that a number of saithe were hit by the ground gear and subsequently run over by the trawl. The authors noted that some degree of body damage was inevitable, but no data were available regarding the fate of

* Corresponding author. Tel.: +47 55236813; fax: +47 55236830.
E-mail address: olafur.ingolfsson@imr.no (Ó.A. Ingólfsson).

0165-7836/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.fishres.2005.12.017

the escaping fish. During a study of fish orientation and swimming behaviour in response to a bottom trawl, Walsh and Hickey (2003) made photographic and video observations of fish, amongst them cod, colliding with and being overrun by the rockhopper gear. Recent underwater video recordings of a survey bottom trawl made by Institute of Marine Research, Bergen (unpublished observations) also showed that the rockhopper ground gear clearly struck a large numbers of cod and saithe. Some of the run-over fish may be injured and even moribund. In view of the apparently large number of fish that escape below the ground gear, fish injured this way may be an important source of unaccounted mortality.

The Norwegian video observations were made at a depth of approximately 300 m and required the use of artificial lighting. Although some studies have indicated that lighting has no significant effect on the swimming behaviour of fish (Weinberg and Munro, 1999), doubt exists as to the validity of these observations due to the presence of video lights. Quantitative data without using lights would determine whether escapement under commercial fishing conditions are comparable to those seen on the video recording.

The objective of this paper is to quantify escapement of cod, haddock and saithe beneath the fishing line of a commercial bottom trawl under realistic conditions, by the use of netting bags to collect the escapees. The study is a part of an ongoing project to assess the potential unaccounted mortality resulting from commercial trawling activities.

2. Materials and methods

The fishing trials were conducted on board the chartered commercial stern trawler “Ståltor” (47.6 m, 2280 kW) from 25 March to 4 April 2003. The fishing grounds were off the coast of Finnmark, north Norway at depths ranging from 230 to 290 m. The trawl used was a “Cotesi” no. 3 (Fig. 1), a design used by many Norwegian stern trawlers. In order to prevent fish from escaping through meshes of the trawl belly or extension sections, these sections were made of netting of smaller mesh size than the ∼150 mm normally used in commercial trawls of this design. In order to compensate for the changes, the experimental trawl was made of thinner twine than generally used in commercial trawls in order to keep the flow of water in the experimental trawl similar to that in a commercial trawl. The exact twine thickness for each section was chosen in such a way that overall twine area of the two layouts was identical. Mesh size was measured with an ICES spring-loaded mesh gauge set at 4 kg. Measurements were made while the netting was wet and 20 meshes in a row were measured in each panel of the trawl and the bags. Mean mesh sizes with standard errors are shown in Table 1. The vessel’s own commercial rockhopper gear with 60 cm diameter discs and a weight in seawater of approximately 10 kg m^{-1} was used (Fig. 1).

In order to collect fish escaping beneath the trawl, three collecting bags were placed behind the footgear underneath the trawl (Figs. 2 and 3). The headline of the bags was connected to the fishing line of the trawl. The fishing line of the bags was rigged on a ground gear made of 10 cm rubber discs with 30 cm disc spacing, threaded on a 19.8 m long 14 mm diameter steel wire (Fig. 4). A 1.0 m long, 19 mm steel chain extension was used to connect the front ends of the gear to the front ends of the fishing line. A 20.0 m long, 16 mm (5.7 kg m^{-1}) chain was connected to the fishing line of the bags along with the ground gear to ensure bottom contact. There were no gaps between the bags.

Table 1
Mesh size measurements with standard error (S.E.)

Gear	Panel measured	Drawing ref.	Mesh size	
			Mean	S.E.
Main trawl	Top wing	A	76.35	0.39
	Square	B	74.10	0.29
	Lower wing	C	43.15	0.20
	Belly	D	44.55	0.15
	Extension	E	43.70	0.23
	Codend	F	21.60	0.11
Collecting bags	Panels		40.55	0.54
	Codend		23.75	0.14

Twenty meshes in a row were measured. The characters A–F refer to panels in Fig. 1.

All hauls were taken during the day. Haul duration was defined as the time from when the gear was on the bottom (as estimated by echograph from the trawl eye) until heaving started. In order to reduce the risk of net damage, towing time was reduced to the minimum needed to obtain commercial catch levels. A sample of cod was taken from a collecting bag and bruises (subcutaneous bleeding) and abrasions (scrape marks on the skin, epidermis ruptured) were assessed on a binary basis (injury/no injury). Differences in the length distributions of injured and uninjured fish were tested by a Kolmorogov–Smirnov test.

During one haul an underwater video camera system consisting of a SIT camera, an aluminium pressure-resistant casing containing a video recorder and a battery, and a 9 W fluorescent light tube, was used to observe the behaviour of fish around the ground gear. The camera was attached to the trawl roof, 5.4 m behind the centre of the headline. During another haul a digital still-photography camera system was used. This consisted of three cylindrical containers, each with a Plexiglas window, one containing a digital camera and two containing a flashlight. Photos were taken every 30 s by the use of a time-lapse controller.

2.1. Data analysis

Fish from the codend and the three collecting bags were kept separate and cod, haddock and saithe were measured to the nearest cm below. Large catches of cod (more than approximately 1000 fish in the main codend) were subsampled. The proportion of fish retained by the trawl was calcu-

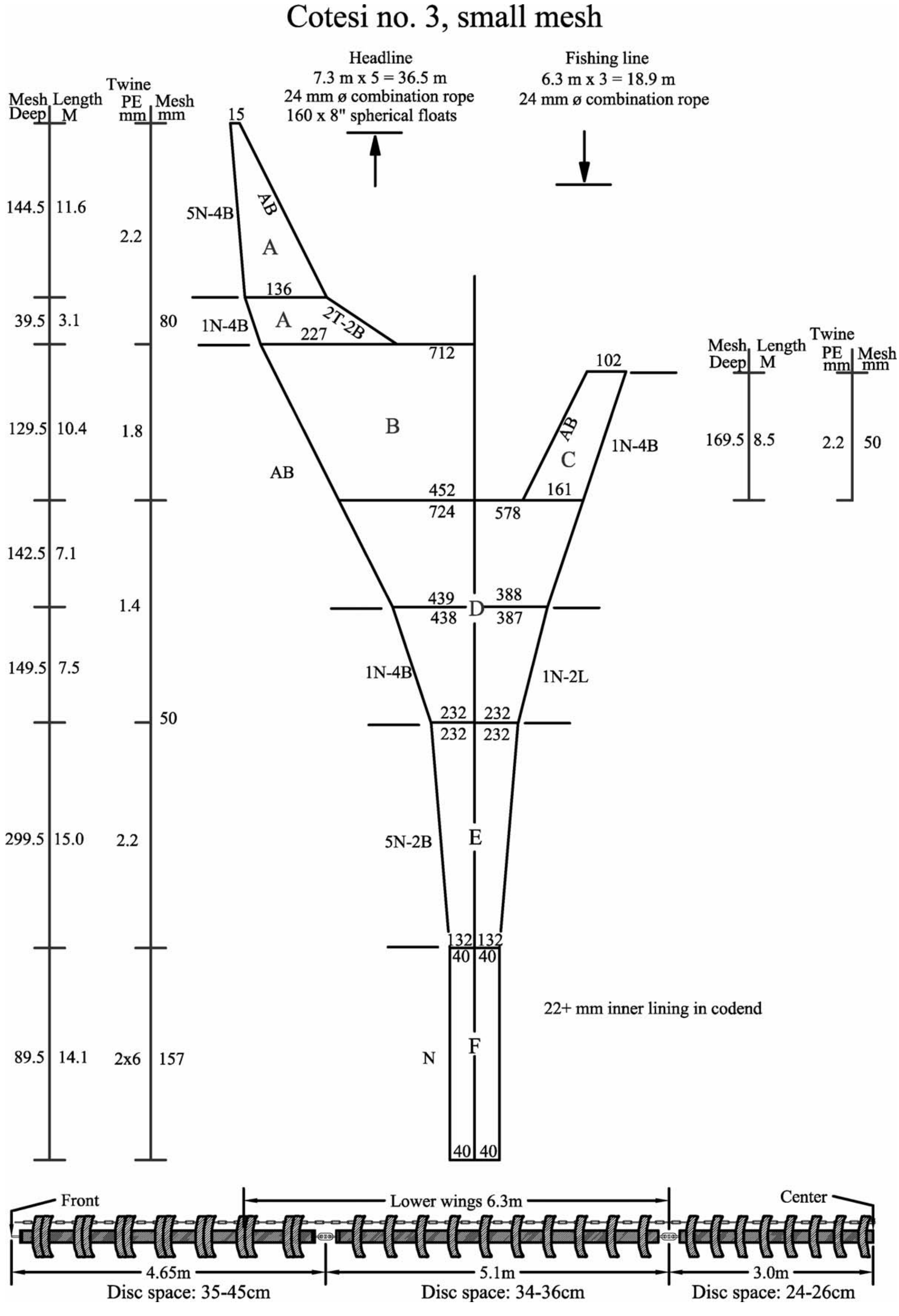

Fig. 1. Cotesi no. 3, the trawl used in the experiment. Half of the symmetrical rockhopper gear is shown.

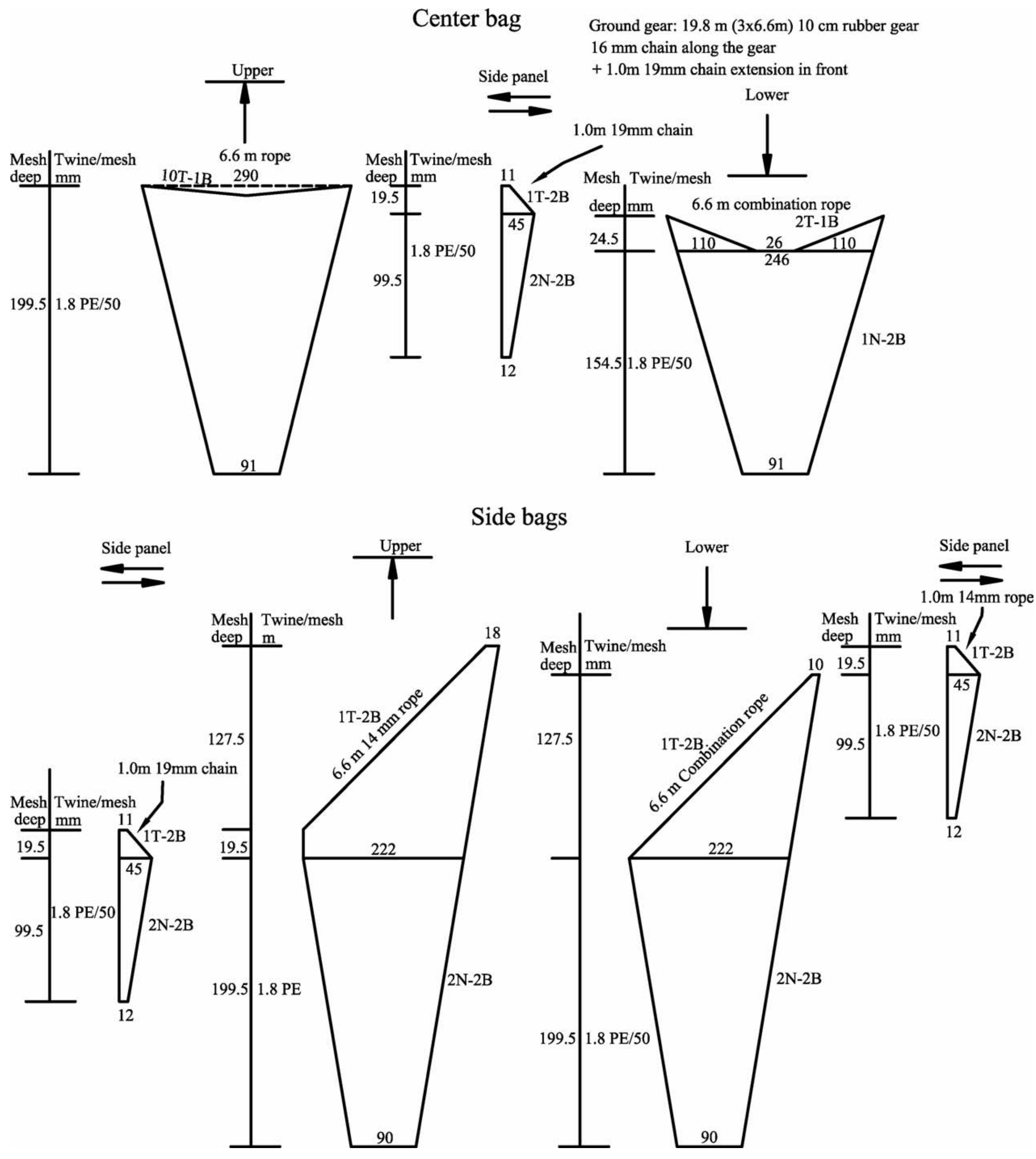

Fig. 2. The collecting bags. Starboard and port bags are symmetrical. The codends of the collecting bags are not drawn (length: 3.0 m, mesh size: 24 mm+).

lated as the number of fish in the codend divided by the total number of fish in the codend and bags for each length.

Four models were fitted to the cod data; logit, probit, complementary log–log (c log–log) and Richard's curve (Wileman et al., 1996). The first three models are members of the Generalized Linear Models (GLM) family (McCullagh and Nelder, 1989). The model with the lowest AIC (Akaike's Information Criterion, see e.g. Venables and Ripley, 2002) was chosen. In cases of subsampling, the models were fitted to unraised data, and the subsampling fractions included in the model (Millar, 1994). For the logistic model, this simplifies to setting log(proportion measured in codend/proportion measured in bags) as an offset variable. Restricted maximum likelihood (REML), commonly used for selectivity analysis (Fryer, 1991), was used to calculate the joint selection curve and for testing density dependence. To test density dependence the hauls were classified in two groups; high (>6000 fish h^{-1}) and low density (<700 fish h^{-1}), the bound-

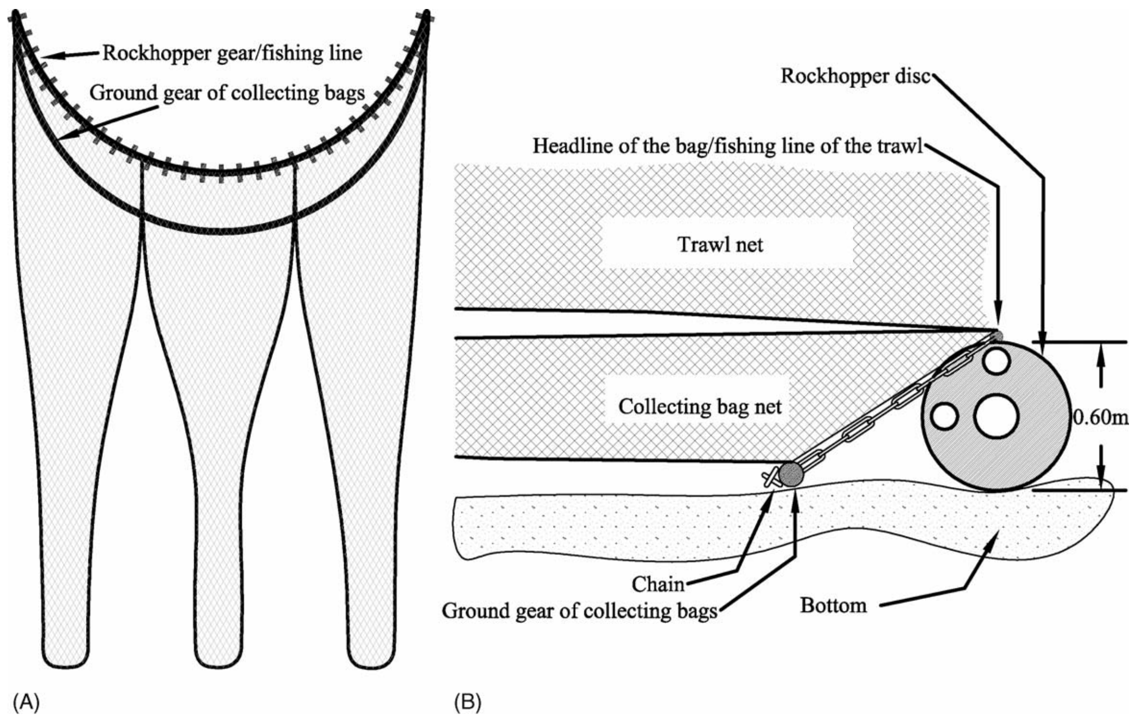

Fig. 3. Schematic presentation of the bags: (A) top view; (B) side view.

aries chosen by the nature of the catches, i.e. there were no intermediate catch levels. For informational purpose, points with ≤2 measured fish of each length are shown as open dots on plots. For statistical analysis, we used the R statistical program (R Development Core Team, 2004).

3. Results

The recorded headline height varied between 2.5 and 5 m, mostly 3.2–3.4 m. Five instantaneous measurements of wing-end spread were obtained (27.2, 27.9, 28.9, 32.6, 34.1 m). Door spreads ranged from 145 to 165 m. The state of polish of the chain along the footgear of the collecting bag confirmed that there had been bottom contact. Haul duration was 7 min for hauls 9, 11, 28 and 29, 12 min for hauls 13–16 and 20 min for haul 19.

The bags frequently caught stones of various sizes, leading to bag damage in 14 out of 22 hauls. The results from the remaining eight valid hauls are shown in Table 2 and Figs. 4–6. The cod catches varied from 53 to 5432 individuals per haul, and the lengths ranged from 10 to 100 cm. The ground gear was found to be size-selective for cod ($p \leq 0.01$, Fig. 5), with an estimated L_{50} of 38.5 and a SR of 34.1 cm. During the experiments, we observed on average 57% escapement of cod below, and 28% of cod above the minimum legal catch size (47 cm). Note that these rates will vary with the population size distribution. No density dependence in escapement could be detected. Of the GLM models tested, the logit model gave the best or an equally good fit in six out of eight cases (Table 3). When the logit and Richard's models were compared, the differences were marginal and the simpler logit model was therefore chosen as representative. Generic parameter estimates, with estimates of 50% escape (L_{50}) and selection range (SR), are shown in Table 4.

Fish from the collecting bags were frequently injured, with scrape marks across the body. Samples of 108 cod were taken from one bag. Of those, 51 fish were classified as injured, with no differences in the length distributions of injured and uninjured fish (Kolmorogov–Smirnov test, $p > 0.05$). Dissection

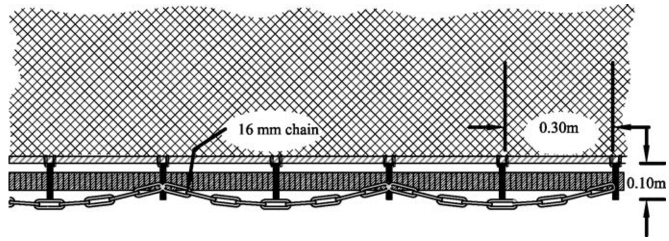

Fig. 4. The footrope of the collecting bags. The chain shown in the figure was mounted behind the rubber gear.

Table 2
Number of fish by bags and escape rates in each haul

Species	Haul	Collecting bags			Main codend	Escape rate (%)
		Port	Middle	Starboard		
Cod	9	58	151	123	383	46.4
	11	193	944	458	2997	34.7
	13	10	29	9	183	20.8
	14	8	28	22	117	33.1
	16	10	36	9	96	36.4
	19	4	15	13	21	60.4
	28	75	180	106	918	28.2
	29	275	1049	444	3664	32.5
Weighted mean						33.6
Haddock	9	4	28	15	203	18.8
	11	7	23	6	140	20.5
	13	8	17	10	108	24.5
	14	8	44	26	213	26.8
	16	20	54	10	345	19.6
	19	9	17	11	111	25.0
	28	4	26	9	122	24.2
	29	14	31	9	124	30.3
Weighted mean						23.1
Saithe	9	0	12	4	337	4.5
	11	2	14	8	177	11.9
	13	4	1	3	51	13.6
	14	1	0	1	83	2.4
	16	0	0	0	19	0.0
	19	0	0	0	1	0.0
	28	0	1	0	25	3.8
	29	2	4	1	59	10.6
Weighted mean						7.2

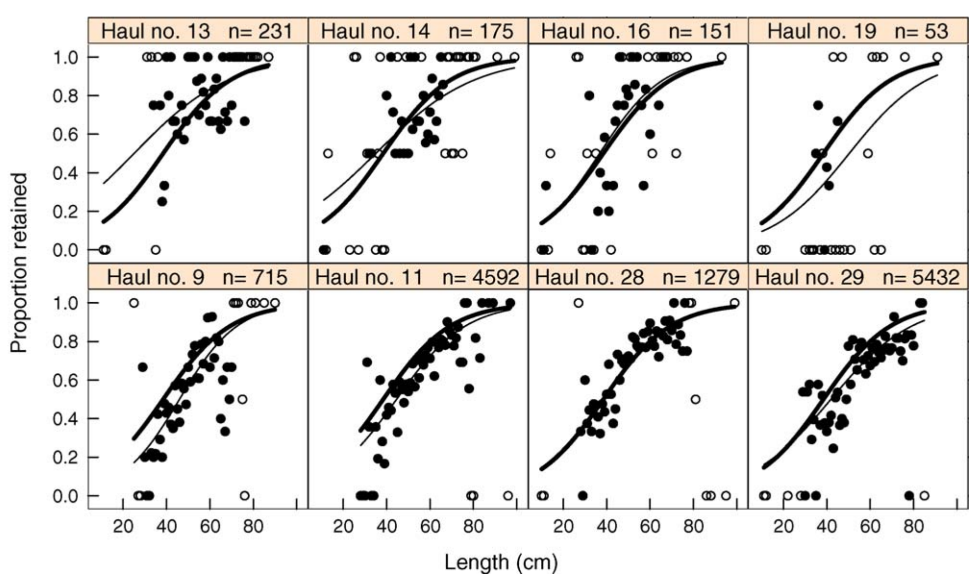

Fig. 5. Curves showing length-dependent escapement of cod beneath the trawl's fishing line. The joint selection curve is shown in bold. Open dots show ≤2 fish of same length measured. Total numbers of cod in codend and bags for each haul are indicated in the figure. The arrangement of the plots is such that the four hauls with smaller catches are on top.

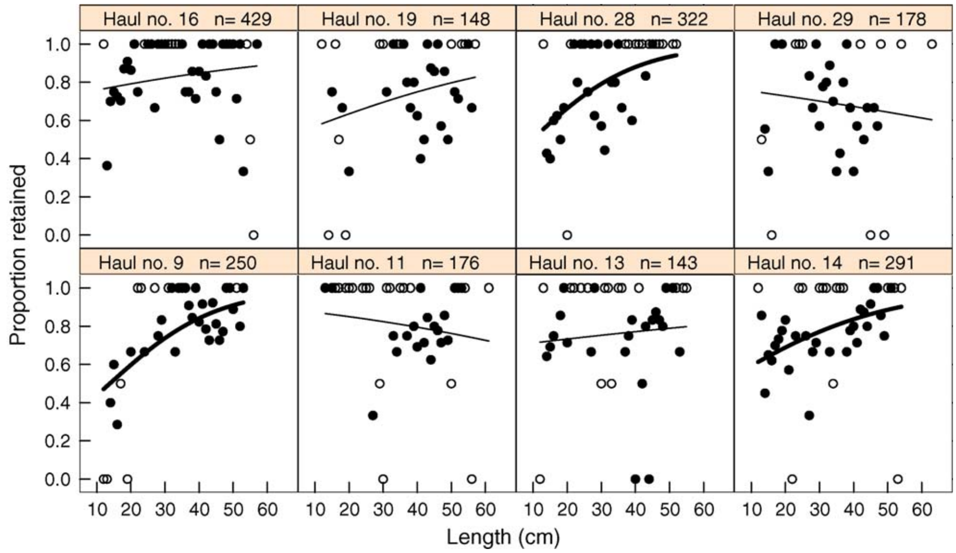

Fig. 6. Escapement of haddock beneath the trawl's fishing line with regression curves. Cases with significant length dependence ($p < 0.05$) are shown with bold curves (hauls 9, 14 and 28). Open dots show ≤2 fish of same length measured. Total numbers of haddock in codend and bags are indicated in the figure.

Table 3
AIC values from tested model, the lowest values, representing best fit are bolded

Haul	AIC values			
	Logit	Probit	c log–log	Richard's
9	187.5	188.5	193.6	**187.2**
11	218.4	218.5	224.0	**218.1**
13	**107.2**	107.3	107.7	108.7
14	**105.8**	**105.8**	106.3	107.3
16	**99.1**	99.3	99.9	101.1
19	46.0	**45.8**	45.9	47.8
28	226.4	230.4	239.9	**224.8**
29	246.0	**244.7**	247.6	245.7

revealed muscle tissue bleeding in some fish, reaching to the spinal bone.

Of the haddock, 23.1% escaped beneath the trawl's fishing line (pooled data). The length of the haddock ranged from 10 to 60 cm, 140–430 individuals per haul. The length dependence of escape was not as clear as for the cod, with three of eight hauls showing length dependence ($p < 0.01$, Fig. 6).

From 1 to 353 saithe were caught per haul, with an observed mean escape rate of 7.2% (Table 2). The saithe, whose length ranged from 40 to 70 cm, showed no sign that escape rates were dependent on length (Fig. 7).

The video recordings, using artificial light, showed roundfish swimming in front of the trawl in the towing direction. Some of the fish were seen to escape actively beneath the rockhopper gear, but a large number of fish were observed being struck and run over by the gear. Estimated escape rates of cod were higher and less length-dependent than the hauls taken without artificial light (L_{50} = 71.2 cm, SR = 33.7 cm). The still photos also showed fish (mainly cod) swimming in front of the gear in the towing direction.

Table 4
Parameters from the logistic regression along with estimates of L_{50} and SR in cm for the cod

Haul no.	*a*		*b*		L_{50}		SR	
	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.
9	−3.444	0.420	0.075	0.009	46.0	1.1	29.3	3.4
11	−2.750	0.355	0.062	0.006	44.4	1.4	35.5	3.7
13	−1.150	0.717	0.046	0.013	25.0	8.7	47.9	13.9
14	−1.541	0.623	0.044	0.012	35.0	5.6	49.9	13.6
16	−2.508	0.689	0.068	0.015	36.7	3.2	32.2	7.1
19	−2.806	1 133	0.056	0.026	50.4	6.4	39.4	18.1
28	−2.389	0.307	0.063	0.006	37.8	1.6	34.9	3.2
29	−2.055	0.309	0.050	0.005	41.0	2.0	43.9	4.7
REML	−2.475	0.197	0.064	0.004	38.5	3.9	34.1	2.1

The REML estimation shows joint parameters for all hauls along with their standard errors.

4. Discussion

The study reported here demonstrated high rates of escape in fish below the fishing line of a commercial bottom trawl rigged with a rockhopper gear. While some fish may escape actively, other fish appear to be run over by the gear. The data were obtained by fitting collecting bags behind the rockhopper gear of a modified trawl. This methodology is based on several assumptions:

(1) The collecting bags retain all fish that pass beneath the trawl.

The collecting bags covered the entire length of the fishing line with no gaps between them. The ground gear of the bags was also attached to a chain spanning the entire ground gear length in order to ensure bottom contact. When rockhopper gear is operated on a rough bottom or when it climbs obstacles, part of the gear may

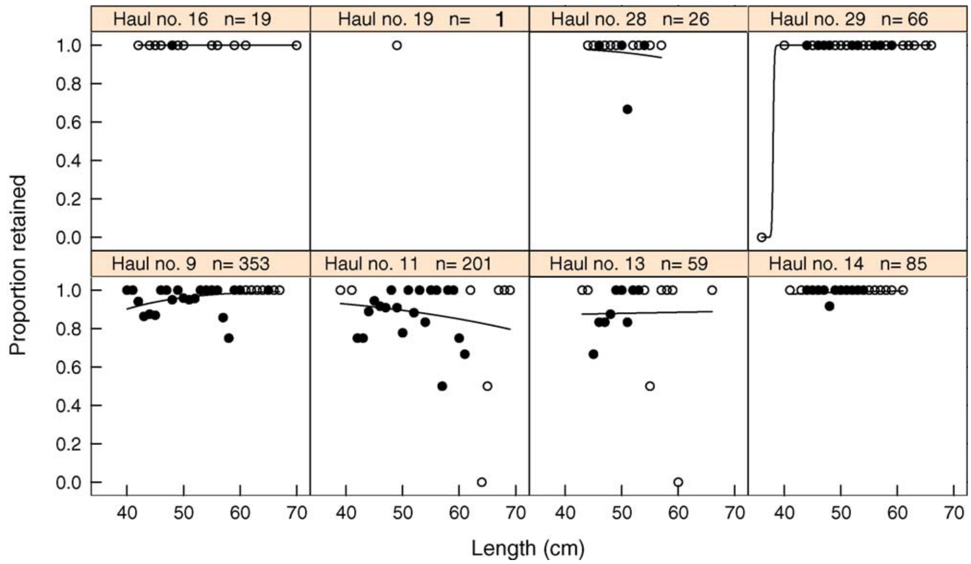

Fig. 7. Escapement of saithe beneath the trawl's fishing line with regression curves. Open dots show ≤2 fish measured. Total numbers of saithe in codend and bags are indicated in the figure.

at times lift off the bottom and form openings where fish may escape. Video recordings and still photography of the bottom in the area fished showed a flat sand/gravel substrate with occasional boulders. Since the ground gear of the collecting bags was small, in many hauls (14 of 22) the collecting bags were torn by boulders that had entered them. These hauls were excluded from the analysis. For the hauls included, obstacles were presumably not encountered, with the gear moving smoothly with good bottom contact throughout the tow. Cod catches in the portside collecting bag were usually smaller than in the starboard bag. No irregularities regarding rigging were detected and the difference in catches persisted after the bags had been replaced with new ones. This skewness in escape pattern was presumably due to some slight difference in warp length not detected by the autowinch system. Such a bias may have produced an asymmetric curvature of the fishing line and footrope, causing the rearmost point of the curvature to shift towards the wing gear on the side where the slack was. A similar skewness was also seen in the study by Walsh (1992), and in recent data on escapement beneath the Norwegian sampling trawl (unpublished data).

(2) The attachment of the collecting bags did not alter the geometry of the trawl.

No changes in door spread or headline height relative to standard commercial rigging were observed when the bags were attached to the trawl. The measurements also showed normal spreading for this type of trawl, i.e. more than half the headline length. Nor did video recordings taken with the bags mounted reveal any abnormality in geometry, and we therefore regard the effect of the collecting bags on trawl geometry as negligible.

(3) The main trawl gear and the gear of the collecting bags were in simultaneous contact with the bottom.

If the trawl gear and the gear of the collecting bags did not land and leave the bottom at the same time, the bags might have collected fish at times when the trawl was not fishing. The bags were rigged in such a way that they were approximately 1 m behind the gear, and the event of landing and leaving occurred in just a few seconds. We therefore regard the probability of this bias as negligible.

(4) The experimental trawl had same efficiency as a commercial trawl.

It is as important that all fish entering the trawl are accounted for, as that all fish escaping below the trawl are collected. Commercial trawls have comparatively large meshes in the wing, belly and extension sections. In order to prevent any escapement of fish from these regions, the trawl used was made of smaller-meshed netting than usually used in this trawl design. In order to minimize any effect of altered water flow due to the smaller meshes, the trawl was made of netting with thinner twine, so that the total area occupied by the twine in the experimental trawl was identical to that of a trawl with commercial mesh sizes and twine thickness. An unpublished comparative study using the twin trawl method, comparing our small-mesh trawl versus a trawl with same design but larger (150 mm) meshes, confirmed that the small-mesh trawl has the same catch efficiency.

Approximately one third of the cod, a quarter of the haddock and 7% of the saithe available to the trawl escaped. Escape rates of cod were highly length-dependent, following a sigmoid curve with an estimated length at 50% escape of 38.5 cm and an interquartile width of 34.1 cm. The length dependence for haddock was less pronounced and for saithe there were no indications of a length dependence. These results are in agreement with experiments carried out using research sampling trawls equipped with gear of considerably smaller dimensions. By recalculating the results from the study by Engås and Godø (1989), who used a survey trawl with bobbins gear, we get an estimated L_{50} and SR for cod of 39.7 and 35.8 cm, respectively. Walsh (1992), using a large-meshed trawl (decreasing from 180 mm in front to 130 mm in its rear part) and bobbin gear, obtained a similar L_{50} of 41.5 but a lower SR of 18 cm (recalculated). Different trawl types and ground gears make direct comparison of experiments impracticable, but a possible explanation of this difference in SR is that size selection through the trawl meshes in the belly and extension was not taken into account by Walsh (1992). This stresses the importance of using small-mesh trawls in experiments like this.

Marked between-species differences were found in the level and pattern of escapement, probably due to behavioural differences. Cod have been observed to swim very close to the bottom as they tire from swimming in front of an approaching trawl, while haddock display upward escape reactions (Main and Sangster, 1981). This difference has been utilized to design species-selective trawls by the use of horizontal separator panels (Main and Sangster, 1982, 1985; Engås et al., 1998). The length-dependent escapement may be due to size-related differences in swimming ability and greater tendency of smaller fish to make escape attempts through the narrow spaces between the rockhopper discs.

For the three studied species, it is apparent that more fish escaped at the bosom area than each of the wings. This is consistent with the results of Walsh (1992) and probably a result of the fish aggregating in front of the trawl gear at the centre part due to the herding process.

Our trials were done onboard a commercial stern trawler operated as during commercial fishing, and fishing was undertaken on commercial fishing grounds, at commercial catch rates and during the commercial fishing season. The trawl was of a design commonly used by the Norwegian fleet, and the vessel's own rockhopper ground gear and trawl doors were used. Rockhopper gear is widely used by larger groundfish trawlers in the N-Atlantic. The results obtained should therefore reflect the level of escapement of cod and haddock below trawls in these commercial fisheries. Our results were obtained on a fishing ground with sand and gravel. On softer substrates the gear may well penetrate deeper into the substrate, reducing the proportion of fish passing beneath the trawl.

Most trawling in the Barents Sea takes place at depths of between 200 and 350 m. The present study was carried out during the day at depths of 230–290 m without artificial light, and is thus representative of daytime fishing. Ambient light level has been shown to affect fish behaviour (Glass and Wardle, 1989) and the results from the haul taken with artificial light suggest that artificial light affects behavioural responses in gear-related studies.

Knowledge of the scale of escapement is essential for improvements in gear design. If the fish escaping below the trawl do not suffer any increased mortality, length-dependent escapement below the trawl will function as a size-selective device that increases the selective properties of the trawl. This is desirable from a management point of view, as more small fish will avoid capture. For the industry, however, escapement of fish of commercial size below the trawl represents a loss of revenue.

About half of the fish that escaped below the ground gear had scale abrasions or bruises caused by contact with gear. The extent to which these injuries per se cause mortality is unknown, but fish escaping from gear may, at least temporarily, run a higher risk of predation due to injuries and the physiological stress associated with the capture process (Ryer, 2003). The scale of escapement documented in this study accentuates the importance of survival studies on fish that have been run over by ground gear.

Acknowledgements

We would like to thank A. Fernö and A.V. Soldal for valuable comments on an earlier version of the manuscript. This project was partially funded by the Research Council of Norway (Project No. 147486/I10).

References

Ehrich, S., 1987. The proportion of young cod escaping under the G.O.V.-trawl rigged with a heavy bobbin footrope. ICES C.M. 1987/B: 28.

Engås, A., Godø, O.R., 1989. Escape of fish under the fishing line of a Norwegian sampling trawl and its influence on survey results. J. Cons. Int. Explor. Mer. 45, 269–276.

Engås, A., Jacobsen, J.A., Soldal, A.V., 1988. Catch comparison between rockhoppers and bobbins ground gear on the Norwegian bottom sampling trawl. ICES C.M. 1988/B: 31, 12 pp.

Engås, A., Jørgensen, T., West, C.W., 1998. A species-selective trawl for demersal gadoid fisheries. ICES J. Mar. Sci. 55, 835–845.

Fryer, R.J., 1991. A model of between-haul variation in selectivity. ICES J. Mar. Sci. 48, 281–290.

Glass, C., Wardle, C.S., 1989. Comparison of the reactions of fish to a trawl gear, at high and low light intensities. Fish. Res. 7, 249–266.

Main, J., 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., Sangster, G.I., 1982. A study of a multi-level bottom trawl for species separation using direct observation techniques. Scottish Fisheries Research Report vol. 26, 17 pp.

Main, J., Sangster, G.I., 1983. Fish reactions to trawl gear – a study comparing light and heavy ground gear. Scottish Fisheries Research Report No. 27, 17 pp.

Main, J., Sangster, G.I., 1985. Report on the direct observation experiments with the chalut 28.90/37.1 m JCB trawl during July 3–23, 1984. ICES C.M. 1985/B: 9/Ref K, 19 pp.

McCullagh, P., Nelder, J.A., 1989. Generalized Linear Models, 2nd ed. Chapman & Hall, London.

Millar, R.B., 1994. Sampling from trawl gears used in size-selectivity experiments. ICES J. Mar. Sci. 51, 293–298.

Munro, P.T., Weinberg, K.L., Somerton, D., 1997. Estimating size-dependent capture rates at the footrope of two different kinds of survey trawls. ICES C.M. 1997/W: 06, 18 pp.

R Development Core Team, 2004. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-00-3, URL: http://www.R-project.org.

Ryer, C.H., 2003. Trawl stress and escape vulnerability to predation in juvenile walleye pollock: Is there an unobserved bycatch of behaviourally impaired escapees? Mar. Ecol. Prog. Ser. 232, 269–279.

Venables, W.N., Ripley, B.D., 2002. Modern Applied Statistics with S, 4th ed. Springer-Verlag, New York.

Walsh, S.J., 1992. Size-dependent selection at the footgear of a groundfish survey trawl. N. Am. J. Fish. Man. 12, 625–633.

Walsh, S.J., Hickey, W.H., 2003. Behavioural reactions of demersal fish to bottom trawls at various light conditions. ICES Mar. Sci. Symp. 196, 68–76.

Weinberg, K.L., Munro, P.T., 1999. The effect of artificial light on escapement beneath a survey trawl. ICES J. Mar. Sci. 56, 266–274.

Wileman, D.A., Ferro, R.S.T., Fonteyne, R., Millar, R.B., 1996. Manual of methods of measuring the selectivity of towed fishing gears. ICES Cooperative Research Report No. 215.