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Selectivity in a trawl codend during haul-back operation—An overlooked phenomenon

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Abstract

The selectivity of a 99 mm trawl codend was assessed using a codend cover fitted with a MultiSampler, which was acoustically triggered to take separate samples at three different phases of the haul. The first sample was collected during towing, the second during haul-up and the third at the surface. A total of 18 hauls were conducted with a commercial fishing vessel west of Scotland. It was demonstrated that escapes take place not only during the tow but also in the short period when the trawl is hauled back from the seabed and when the codend is at the surface. For haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*) and Norway lobster (*Nephrops norvegicus*), respectively, the mean percentages escaping at the surface were 16, 12 and 38% of the total escape while 17, 8 and 28% escaped during the haul-up phase. Compared to towing, the escape rate (no./min) increased for haddock by a factor 2.7 during haul-up and by a factor 1.7 at the surface, whereas the escape rates of whiting were similar for the three phases. The escape rate of Norway lobster increased by a factor of approximately 7 for both the haul-up and surface phases, compared to the towing phase. The selectivity parameters $L50$ (50% retention length) and SR (selection range = $L75$–$L25$) were estimated and compared for the three different phases and for the whole haul for haddock, whiting and Norway lobster. For all three species there was no significant ($P > 0.05$) difference in $L50$ between the three phases of the haul. There was also no significant difference for whiting and Norway lobster when comparing the SR of the three phases, whereas the SR was significantly lower for haddock when comparing the surface phase with towing and haul-up. The estimate of $L50$ when towing was about 6 cm lower for haddock and whiting and 9 mm for Norway lobster compared to the selection curve estimated conventionally for the whole haul. Finally, the effect of sea state, duration and codend catch on the selectivity parameters were estimated for the individual phases and for the whole haul. A significant effect of at least one variable was found in all phases.

Keywords: Size selectivity; Haddock; Whiting; Norway lobster; Trawl; Surface escape

1. Introduction

The bottom trawl is a major commercial fishing method for demersal species in most of the world (Watson et al., 2006). Many fish stocks are subject to high fishing pressure. Discarding of undersize fish is widespread, leading to less than optimal exploitation of the resources. Improving trawl gear selectivity, often by mesh size regulations, is one way to alleviate these problems and has become a major management tool in many fisheries to prevent juvenile fish from being caught. An implicit assumption traditionally made in fish stock assessment is that escapees survive the mesh penetration (Breen and Cook, 2002) and are able to make a complete recovery. The escape is, nevertheless, a traumatic experience that can cause stress and physical injury to the escaping animals. Experiments have demonstrated mortality for haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*) (Sangster et al., 1996; Soldal et al., 1993) and Norway lobster (*Nephrops norvegicus*) (Morizur et al., 1982) escaping at depth from a demersal trawl. It has also been demonstrated, by using North Sea haddock as an example, that it is important for fisheries managers to include this additional mortality in their assessment models, particularly if it exceeds a magnitude of 25% (Breen and Cook, 2002).

The question of whether fish escape during the haul-back operation, when the trawl is hauled from the seabed to the surface, has not yet been addressed. Codend selectivity experiments

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conducted in the Baltic Sea cod fishery (Tschernij and Holst, 1999) showed that the selectivity parameters *L*50 (50% retention length) and SR (selection range = *L*75–*L*25) varied between vessel types. Differences in haul-back operations are likely to explain this variation suggesting that escapes take place during the haul-back operation. Isaksen and Løkkeborg (1993) investigated the escape of cod and haddock from a Danish seine during fishing and surface hauling operations. It was found that about half the total number of fish escapes took place at the surface. Individuals escaping from a trawl during the haul-back operation are likely to be exposed to greater stresses, physiological trauma and physical injury compared to those escaping at depth during the towing process. Consequently, this phenomenon needs further attention.

The objective of this work is to estimate the selectivity of a trawl codend during different phases of the haul. The species investigated were haddock, whiting and Norway lobster—three economically important species taken in the North East Atlantic trawl fishery.

2. Materials and methods

2.1. Fishing vessel and area

The vessel used for the sea trials was the commercial trawler "Veracious" (PD 373) having an overall length of 26.2 m and an engine power of 634 kW. The experiment was conducted on fishing grounds outside Loch Gairloch on the west coast of Scotland. Sea trials were carried out in August and September 2003 and 2004.

2.2. Trawls and codends

A commercial fish trawl ("Scotnet", BT 186) was used. The same codend was used during the entire experiment. It was a standard 6 m long diamond mesh codend, with nominal codend mesh size of 100 mm and a circumference of 100 open meshes, with 4 meshes enclosed in each of the two selvedges. The codend was made of 4 mm PET double twine.

Mesh sizes from 80 to 120 mm are used today in commercial demersal fisheries targeting whitefish and Norway lobster in the North Sea, Skagerrak and Kattegat. The choice of a nominal 100 mm mesh size for this experiment was based upon experience from previous trials off the Scottish West Coast where the mean size of fish in the catch is generally small. A larger mesh size might not retain sufficient fish in the codend for a valid selectivity analysis.

2.3. Methodology for collecting escaping fish

One of the main routes of escape of fish from a trawl occurs through the open meshes of the codend (Wileman et al., 1996), which is the aft part of the trawl in which the fish catch is hauled on board. A MultiSampler (Engås et al., 1997) attached to a codend cover was used to collect fish escaping from the trawl codend (Fig. 1). This system was fitted with three 18 m long, non-selective (20 mm mesh size) collection bags. Each collection bag was used to take a discrete sample of fish from the codend cover during one of three separate pre-selected phases. The collection bags were opened in sequence, with an acoustic release mechanism closing one collection bag and in turn opening the next. The codend cover was supported by hoops to avoid physical contact with the codend netting (Wileman et al., 1996).

The fish escape categories assessed in this experiment were defined as:

(1) towing escape: fish escaping from the codend in the period from when the trawl first contacts the seabed and towing begins to when the haul-up is initiated. It is assumed that the trawl is not catching anything before towing is initiated;
(2) haul-up escape: fish escaping in the period from when haul-up initiates until the floats on the headline of the trawl reach the surface;
(3) surface escape: fish escaping in the period from when the trawl floats reach the surface until the codend is hauled on board.

To meet the above definitions the MultiSampler operation procedure was as follows:

(1) the first collection bag of the MultiSampler was opened when the whole trawl was in the water at the surface;
(2) the first collection bag was closed and the second opened when the haul-back was started by starting the warp winches;
(3) the second collection bag was closed and the third opened when the trawl floats reached the surface.

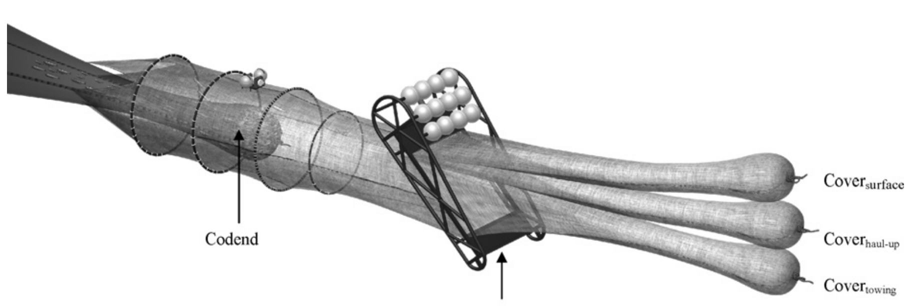

Fig. 1. Illustration of cover methodology.

Commercial haul-back practice was used until the handling of the MultiSampler. A constant slow forward vessel speed kept some tension in the netting during the whole haul-back process. The trawl was hauled back by constant torque warp winches until the doors reached the vessel. The trawl was then attached to the net drum and hauling continued. There was a pause in haul-back to handle the MultiSampler at the stern of the vessel. Commercial practice on this vessel is to heave the codend to gallows mounted forward on the starboard side of the vessel, where the codend is lifted on board. However, it was believed that such a procedure would give biased results because it would take substantially longer time than commercial practice to handle the MultiSampler equipment. Consequently, the codend and cover collection bags were hauled on board on the aft deck, where the net drums were located.

2.4. Measurements

Operational conditions were recorded for each haul, including depth (at the beginning and end of the haul), speed (at several intervals during the tow), sea state (estimated by a scientist), and the time at the start and end of each phase. Headline height, wing spread and spread between the otterboards were measured with Scanmar equipment. The mesh size of each codend (in a wet condition) was measured ($N = 100$ meshes) five times during the sea trials. All mesh measurements were taken using an ICES gauge with 4 kg tension setting (Wileman et al., 1996).

Lengths of haddock and whiting were measured to the nearest whole centimetre below. In subsequent analyses 0.5 cm was added to all lengths. The carapace length (mm) of Norway lobster was not measured in the first two hauls, but in all subsequent hauls. Other species were quantified in baskets. Sub-sampling was avoided as far as possible. For seven hauls it was necessary to sub-sample from the cover that collected escapees during towing because of large catches. A fraction (ranging between 18 and 67%) was randomly chosen and measured from each of these samples. A sub-sample (50%) was taken from the cover that collected during the haul-up phase for one haul.

Length–weight relationships for haddock and whiting (Coull et al., 1989) were used to estimate catch weight by species. Since there are sex-related differences in growth of the Norway lobster, length frequency distributions were obtained for each sex based on sub-samples collected from four hauls. Sex dependent length–weight relationships (ICES, 1995) were used to estimate catch weight.

2.5. Selectivity modelling

Selectivity during each phase of the haul were estimated using the samples of fish retained in the codend and escaping during each of the three phases. No information is lost by the separate estimation of the selectivity for the three phases, as it can be shown that the corresponding estimators are uncorrelated. The codend catch and the three cover sample fractions are illustrated in Fig. 1. Fish escaping and retained during the three investigated phases are then given by:

Towing phase:

$$\text{Escape} = \text{cover}_{\text{towing}}$$

$$\text{Retained} = \text{codend} + \text{cover}_{\text{haul-up}} + \text{cover}_{\text{surface}}$$

Haul-up phase:

$$\text{Escape} = \text{cover}_{\text{haul-up}}$$

$$\text{Retained} = \text{codend} + \text{cover}_{\text{surface}}$$

Surface phase:

$$\text{Escape} = \text{cover}_{\text{surface}}$$

$$\text{Retained} = \text{codend}$$

For comparison, the conventional way of analysing selectivity for the whole haul is given by:

$$\text{Fish escape during whole haul} = \text{cover}_{\text{towing}} + \text{cover}_{\text{haul-up}} + \text{cover}_{\text{surface}}$$

$$\text{Fish retained during whole haul} = \text{codend}$$

A set of selectivity parameters ($L50$, SR) was estimated for each haul for each of the three independent sequential phases: the towing phase, the haul-up phase and the surface phase. Furthermore, conventional selectivity parameters were estimated for the whole haul.

Selectivity parameters for each phase were estimated in a two stage approach analogous to that used in numerous studies of conventional size selectivity (e.g. Graham et al., 2004; Madsen et al., 1999; Madsen and Stæhr, 2005; O'Neill et al., 2002). Estimates for individual hauls were obtained using the SELECT method Millar (1992). The model was fitted to the raw data using sub-sampling ratios as offsets in the linear predictor (Millar, 1994). This ensures reliable estimates of variances and model deviances. A test for goodness of fit (GOF) was made by referring the deviance to a Chi-square distribution. The variances were adjusted whenever the fit indicated over-dispersion (Wileman et al., 1996). REML mean estimates were obtained in a second step using a fixed and random effects model (Fryer, 1991; Wileman et al., 1996). The EC-model software (http://www.constat.dk) was used to estimate mean selection curves for all phases and species.

In a second analysis explanatory variables were included as fixed effects (Wileman et al., 1996). Pairwise plots of explanatory and response variables were inspected to identify possible correlations and indications of non-linear terms. Sea state (m), duration (min) and catch (kg) were considered as potential covariates. The least significant (defined by P-value) covariates were removed one at a time until all covariates were significant ($P < 0.05$). The final models are then reduced versions of these full models.

3. Results

3.1. Gear measurements and operation conditions

A total of 18 successful hauls were conducted. The first 12 hauls were conducted in 2003 and the remaining 6 in 2004. Hauls where irregularities occurred were not used for further analysis, for example due to technical problems with the MultiSampler, catches of plastic sheeting or covers that were not properly closed.

Average values (with standard deviation) were: fishing depth 135.1 ± 16.9 m and sea state 1.3 ± 0.7 m (range: 0.4–2.5 m). Average duration was: towing period 119.2 ± 23.9 min (range: 82–180 min), haul-up phase 9.0 ± 1.3 min (range: 7–11 min) and surface phase 11.9 ± 2.7 min (range: 7–17 min). The towing speed was 3.1 ± 0.1 knots. Average codend catch was 117.9 ± 38.7 kg (range: 40–191 kg) for the towing phase, 101.1 ± 37.5 kg (range: 32–176 kg) for the haul-up phase and 81.6 ± 34.8 kg (range: 15–136 kg) for the surface phase. The average headline height of the trawl was measured with Scanmar equipment to be 4.5 ± 0.4 m, the wing spread 14.0 ± 0.4 m and the spread between the otterboards 61.9 ± 6.5 m. The average mesh size with standard deviation ($N = 500$ mesh measurements) was 94.9 mm ± 3.08 when measured with the ICES 4 kg gauge which corresponds to 98.6 mm if measured with the EEC gauge specified in legislation (Ferro and Xu, 1996).

3.2. Catches

Total catches and escapes (in numbers) during each phase are summarised in Table 1. Catches of haddock were adequate for analysis in most hauls with reasonable numbers of fish in all fractions. Whiting catches were also adequate but few larger individuals were caught and consequently few fish were retained in the codend. Catches of Norway lobster were lower than for both haddock and whiting. A large number of haddock and whiting escaped compared to the catch retained in the trawl (Table 1), whereas only about half of the Norway lobsters escaped. It was evident that escape took place in the relatively short period when the trawl was hauled back from the seabed. The numbers of haddock, whiting and Norway lobster escaping at the surface were 16, 12 and 38% respectively of the total number escaping and 17, 8 and 28% during the haul-up phase, while the escape during towing was 67, 80 and 33%. However, substantial variation between hauls is indicated by the wide confidence limits. Compared to towing, the escape rate (no./min) increased for haddock by a factor of 2.7 during haul-up and by a factor of 1.7 at the surface, whereas the escape rate of whiting was comparable for the three phases. The escape rate of Norway lobster increased by a factor of approximately 7 for both the haul-up and for surface phases, compared to the towing phase.

3.3. Estimates of selectivity parameters

The number of hauls that could be included in the selectivity model for each phase is indicated in Table 2. Several estimates could not be made because the model did not converge. Some hauls were discarded due to extreme parameter or variance estimates: two hauls of Norway lobster during towing; one haul of whiting during the surface phase, and two hauls of whiting for the whole haul.

The GOF test is also indicated in Table 2. The fit was found acceptable for 11 hauls out of 17 hauls for haddock during the towing phase and 11 out of 14 hauls during haul-up phase. For whiting, the fit was acceptable for 8 out of 10 hauls during the towing phase. The fit was generally good for the remaining data sets, with none or only one haul with lack of fit. Ten hauls for whiting could be included during the towing phase and haul-up phase but only seven hauls during the surface phase and the whole haul. The reason is that very few whiting were retained in the codend during the last two phases.

Estimated mean selectivity parameters for each phase are provided in Table 2. The parameter estimates of $L50$ for the towing and haul-up phase are the same for each of the three species. For haddock and Norway lobster the $L50$ is higher during the surface phase than during towing and haul-up, whereas it is slightly lower for whiting. The $L50$ for the whole haul is around 6 cm larger for haddock and whiting and about 9 mm larger for Norway lobster compared to the towing phase. SR is highest for the towing phase for haddock and whiting and smaller during the two later phases.

Selectivity parameters for individual hauls of each phase are shown together with the mean REML estimates with 95% confidence limits in Fig. 2. For all species the overlap of confidence limits indicates that there is no significant ($P > 0.05$) difference in $L50$ for the three separate phases of the haul. The SR is signif-

Table 1
Total catches and escape during the examined phases

Species	Total (no.)		Towing escape			Haul-up escape			Surface escape		
	Caught	Escape	Total (%)	Avg. (%)	Avg. (no./min)	Total (%)	Avg. (%)	Avg. (no./min)	Total (%)	Avg. (%)	Avg. (no./min)
Haddock	2291	12980	72.6	66.6 ± 12.7	4.5 ± 2.9	15.8	17.1 ± 8.4	12.3 ± 8.1	11.5	16.3 ± 10.2	7.7 ± 5.8
Whiting	148	22008	86.3	80.1 ± 13.4	8.8 ± 5.5	6.6	7.8 ± 4.3	9.2 ± 5.1	7.1	12.1 ± 14.2	8.2 ± 9.8
Norway lobster	1972	2149	41.7	33.4 ± 20.0	0.5 ± 0.6	25.6	28.2 ± 13.4	3.4 ± 1.7	32.8	38.4 ± 16.8	3.7 ± 2.4

Total (no.) indicates total catches over all 18 hauls. Total (%) indicates total escape when pooling escape over all hauls. Avg. (%) indicates average escape per haul with 95% confidence limits. Avg. (no./min) indicates average escape per haul of individuals per minute with 95% confidence limits.

Table 2
No. hauls with acceptable fits ($P > 0.05$) according to the goodness of fit (GOF) test and no. included in model is indicated

	No. hauls		$L50$				SR				DF
	GOF ($P > 0.05$)	Included in model	Estimate	S.E.	t-Value	P-Value	Estimate	S.E.	t-Value	P-Value	
Haddock											
Towing	11	17	19.4	1.11	17.4	0.0000	9.64	0.756	12.8	0.0000	29
Haul-up	11	14	19.4	1.22	15.9	0.0000	7.97	0.889	8.97	0.0000	23
Surface	16	17	22.1	1.04	21.3	0.0000	5.25	0.303	17.3	0.0000	29
Whole haul	16	17	25.7	0.805	31.9	0.0000	5.75	0.401	14.3	0.0000	29
Whiting											
Towing	8	10	20.6	0.678	30.4	0.0000	8.16	1.19	6.86	0.0000	15
Haul-up	10	10	20.6	2.87	7.18	0.0000	4.90	5.68	5.68	0.0000	15
Surface	7	7	19.6	1.35	14.4	0.0000	4.53	0.718	6.32	0.0001	9
Whole haul	6	7	26.2	1.64	16.0	0.0000	4.55	0.672	6.77	0.0000	9
Norway lobster											
Towing	12	12	28.6	1.36	21.1	0.0000	9.34	0.875	10.7	0.0000	19
Haul-up	11	11	28.6	1.69	16.7	0.0000	12.3	2.09	5.90	0.0000	17
Surface	16	16	32.6	1.66	19.6	0.0000	10.5	0.974	10.8	0.0000	27
Whole haul	14	16	37.9	1.65	23.0	0.0000	10.9	0.784	13.8	0.0000	27

Parameter estimates for the mean selection curves generated by the REML analysis together with their associated standard errors, t-value and P-value. DF indicates degrees of freedom. Parameter estimates in centimetre for haddock and whiting and mm carapace length for Norway lobster.

icantly lower for haddock at the surface compared to the towing and haul-up phases. There is no significant difference in SR for whiting or Norway lobster when comparing the three phases. The $L50$ is significantly higher when comparing the estimates for the whole haul and the towing phase whereas the SR is significantly lower for haddock only.

The $L50$ confidence levels of whiting are wider than for other species due to the lower number of hauls that could be fitted.

Table 3
Derived REML estimates when including explanatory variables

Parameter	Intercept	Explanatory variable			Final model	
		C: Codend catch (kg)	D: Duration (min)	S: Sea state (m)		
Haddock						
$L50_{towing}$	NS	NS	***	NS	$L50 \sim 0.157D$	DF = 29
SR_{towing}	***	NS	NS	NS	$SR \sim 9.92$	
$L50_{haul\text{-}up}$	NS	NS	NS	NS	$L50 \sim 19.3$	DF = 21
$SR_{haul\text{-}up}$	***	NS	*	*	$SR \sim 22.9 - 2.17S - 1.30D$	
$L50_{surface}$	***	NS	NS	*	$L50 \sim 17.9 + 3.41S$	DF = 27
$SR_{surface}$	***	NS	NS	**	$SR \sim 6.63 - 1.04S$	
$L50_{whole\ haul}$	***	NS	NS	NS	$L50 \sim 25.7$	DF = 28
$SR_{whole\ haul}$	NS	*	***	NS	$SR \sim 0.0165C + 0.0317D$	
Whiting						
$L50_{towing}$	***	*	NS	NS	$L50 \sim 17.4 + 0.0297C$	DF = 14
SR_{towing}	***	NS	NS	NS	$SR \sim 8.42$	
$L50_{haul\text{-}up}$	NS	NS	NS	***	$L50 \sim 15.8S$	DF = 15
$SR_{haul\text{-}up}$	NS	NS	NS	***	$SR \sim 4.43S$	
$L50_{surface}$	***	NS	NS	NS	$L50 \sim 19.5$	DF = 8
$SR_{surface}$	***	NS	*	NS	$SR \sim 8.8 - 0.368D$	
Norway lobster						
$L50_{towing}$	***	NS	NS	NS	$L50 \sim 28.2$	DF = 19
SR_{towing}	NS	***	NS	NS	$SR \sim 0.0863C$	
$L50_{haul\text{-}up}$	***	NS	NS	NS	$L50 \sim 29.1$	DF = 15
$SR_{haul\text{-}up}$	*	**	*	NS	$SR \sim 21.3 + 0.135C - 2.40D$	
$L50_{surface}$	NS	NS	***	***	$L50 \sim 1.99D + 7.59S$	DF = 26
$SR_{surface}$	***	NS	NS	NS	$SR \sim 10.5$	

DF indicates degrees of freedom for the model. NS: non significant ($P > 0.05$).
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

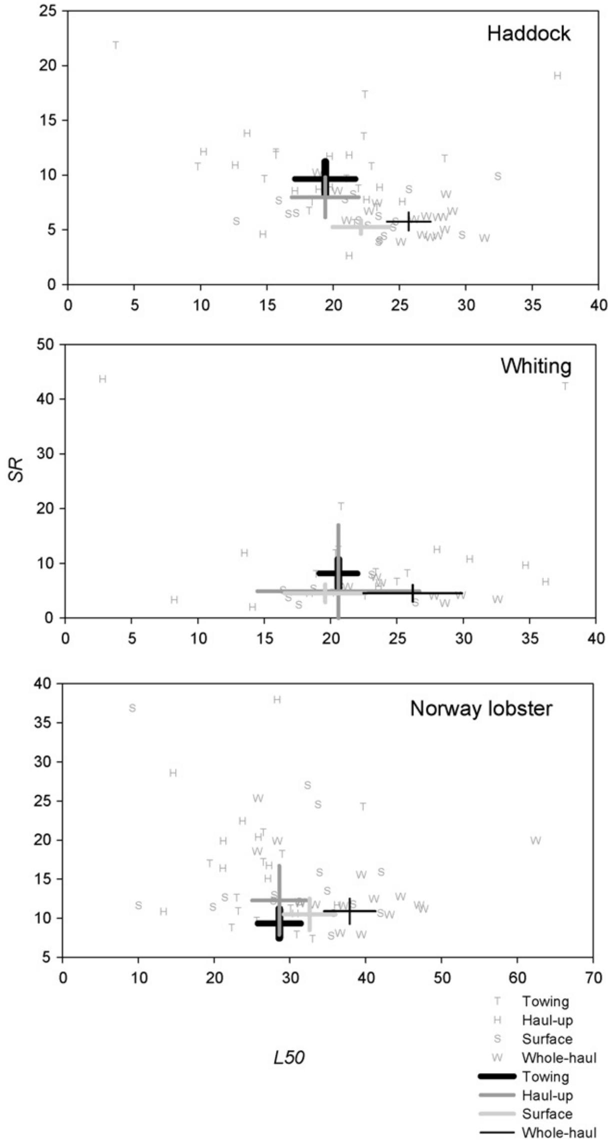

Fig. 2. Estimates of selectivity parameters for individual hauls and the mean selection curves generated by the REML analysis with lines indicating 95% confidence levels. Parameter estimates in centimetre for haddock and whiting and mm carapace length for Norway lobster.

3.4. Effect of explanatory variables

The effect of explanatory variables is described in Table 3 for the three phases of the tow and the whole haul, for all cases where a significant ($P < 0.05$) effect on the selectivity parameters was detected. Also shown are the variables that were removed from the original full model because they were non-significant (NS).

A significant effect of at least one variable was found in all phases. Even though explanatory variables influenced the selectivity parameters for the three different phases, no significant effect was detected when considering the whole haul for whiting and Norway lobster. The catch was found to be significant on SR and the duration was found to be highly significant, when considering the whole haul for haddock. Pairwise plots did not indicate that duration and codend catch were positively correlated, which could have been anticipated.

4. Discussion

This experiment clearly demonstrates that the perception of the selectivity process – where escapes are expected to take place when towing along the seabed – needs to be reconsidered, because a considerable escape takes place during the limited period when the trawl is hauled back, i.e. during haul-up and at the surface. In fact, most Norway lobsters escaped during the haul-back operation with escape rates seven times higher in this limited period than in the towing period.

The estimated *L*50 when towing was about 6 cm lower for haddock and whiting and 9 mm lower for Norway lobster compared to the conventional value estimated for the whole haul. The *L*50s for haddock and Norway lobster were somewhat higher at the surface than during towing and haul-up although there is no significant ($P > 0.05$) difference in *L*50 of the three phases for the three species. The selective process during the haul-back operation, however, takes place in a very limited period compared to towing. Reduced speed, pulsing movements and slack netting in the codend are all likely to promote active escape behaviour during this phase as well as facilitating a simple passive sieving process. This may be particularly true for Norway lobster because their irregular morphology and random escape behaviour make effective escapes during towing less likely.

Several variables can influence the selectivity parameters (Wileman et al., 1996). For whiting and Norway lobster, it was demonstrated that some variables can have an effect on some of the individual phases without having an effect when considering the selective process in the conventional way for the whole haul. It was found that sea state had an effect on selectivity during the haul-up and surface phases. This is likely to be caused by pulsing movements of the codend induced by wave action at the sea surface (O'Neill et al., 2002). This is also in agreement with Polet and Redant (1994) who found that sea state had a positive effect on the *L*50 of Norway lobster. Sea state was estimated visually by a scientist; however, a more objective method should be developed to improve the accuracy and reproducibility of this measurement. It was also found that *L*50 for Norway lobster increased with the duration at surface, suggesting that the longer they are in the water at the surface the greater the likelihood of escape. For whiting the *L*50 was increasing with the codend catch during towing which is supported by computer simulations (Herrmann and O'Neill, 2005) and explained by the mesh opening increasing with the catch size.

Escapes at the end of a tow, during the haul-back phase, are likely to expose individuals to greater stresses, physiological trauma and physical injury than escaping during the towing process. Haddock and whiting (gadoids) are physoclistous (i.e. the swim bladder and gut are not connected) and unable to evacuate excess gas volume quickly from the swim bladder when exposed to decompression (Alexander, 1993). Mortality rates for fish escaping during haul-back are likely to be substantially higher than when escaping during towing. Individuals escaping at the surface may also further subjected to sea bird predation (Tasker et al., 1999). Norway lobster may suffer from retinal damage (Shelton et al., 1985; Gaten, 1988) and in some areas by being exposed to low salinity surface layers (Harris and Ulmestrand, 2004).

In conclusion, these experiments strongly suggest that there might be a substantial additional unaccounted mortality that will require further attention by fisheries managers. Consequently we believe that it is highly important to develop and use selective devices, such as sorting grids (Graham et al., 2004; Kvamme and Isaksen, 2004) and escape windows (Graham et al., 2003; Madsen et al., 1999; Madsen and Stæhr, 2005) that are more likely to allow juveniles to escape at depth during the towing phase. New experiments should be conducted to estimate escapes during haul-back operations for such selective devices. Finally, the towing time in these sea trials was relatively short and consequently catches were limited. In this respect, the results here may be more representative of small-scale fisheries and more data for other fishery patterns are needed.

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