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THE EFFECT OF TWINE STIFFNESS ON CODEND SIZE SELECTIVITY, A FULLSCALE EXPERIMENT

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ABSTRACT

Knowledge of fishing gear selectivity is of fundamental importance when recommendations for harvest strategies are being made. The objective of this experiment was to estimate and compare the selectivity of two types of trawl codends with different stiffness; 135 mm codends of soft and stiff materials. Data were collected using the covered codend method in the Westfjords of Iceland. The results showed that codend stiffness affects selectivity significantly. For haddock L_{50} was reduced by 17.4 cm on average, from 57.4 cm for the soft codend to 40 cm for the stiff codend. For cod L_{50} was decreased by 13.6 cm on average from 57.7 cm for the soft codend to 44.1 cm for the stiff codend. Difference in SR due to stiffness for haddock showed an increase by 3.1 cm on average from 10.2 cm for the soft codend to 13.3 cm for the stiff codend. Similarly, SR for cod increased by 9.4 cm, from 10.2 for soft codend to 19.6 cm for the stiff codend. This study showed that in fisheries where factors other than mesh sizes are not controlled by regulations, fishermen can easily manipulate codend selectivity legally to increase catches of small fish if they want to do so.

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TABLE OF CONTENTS

LIST OF FIGURES **3**

LIST OF TABLES **4**

2 INTRODUCTION **5**

2.1 SELECTIVITY IN NAMIBIA 5
2.2 OBJECTIVES 6
2.3 SELECTIVITY 6
2.4 PARAMETERS AFFECTING CODED SIZE SELECTIVITY 7
2.4.1 Mesh size and shape 7
2.4.2 Twine diameter and stiffness 7
2.4.3 Codend circumference 8
2.4.4 Codend length 8
2.4.5 Mesh opening 8
2.5 METHODS FOR DETERMINING SELECTIVITY 8
2.5.1 Covered codend method 9
2.5.2 Alternate haul method 9
2.5.3 Parallel haul method 10
2.5.4 Twin trawl method 10
2.5.5 Trouser trawl method 11

3 MATERIALS AND METHODS **11**

3.1 DATA COLLECTION AND ANALYSES 13

4 RESULTS **13**

5 DISCUSSION **22**

6 CONCLUSIONS **23**

LIST OF REFERENCES **24**

ACKNOWLEDGEMENTS **26**

LIST OF FIGURES

Figure 1. Map of Namibia 6
Figure 2. Diagrammatic presentation of hooped cover mounting. 9
Figure 3. Selectivity experiment trail map – westfjords.. 12
Figure 4. Drawing of the trawl used in the experiment 12
Figure 5. Haddock size distribution in soft codend and cover 14
Figure 6. Haddock size distribution in stiff codend and cover 15
Figure 7. Cod size distribution in soft codend and cover. 17
Figure 8. Cod size distribution in stiff codend and cover. 18
Figure 9. Selection curves and length distribution (L_{50} and SR) of Haddock. 20
Figure 10. Selection curves and length distribution (L_{50} and SR) of cod. 20
Figure 11. Haddock SR vs L50. 21
Figure 12. Consequences of having L_{50} below (left) or above (right) MLS 22

LIST OF TABLES

Table 1. Selectivity measures in Namibia 5
Table 2. Information on individual tows, positions, time, depth along with number of fish and catch weight... 19
Table 3. Selection parameters for haddock and cod along with average values. The asymmetry parameter □□is presented for hauls 10 (haddock) and the pooled data for cod from the soft codend. The average parameters a, b and □□are derived from L_{50} and SR. 21

1 INTRODUCTION

1.1 Selectivity in Namibia

Namibia's Exclusive Economic Zone (EEZ) commercial biomass contains about 20 different fish species that are commercially exploited, eight of which are regulated through total allowable catch (TAC) (FAO 2007). The Government of Namibia maintains a management system comprising fishing rights, setting annual total allowable catches and allocation of quotas to right holders. The main purpose of the right is to limit entry to the fisheries sector to keep catches sustainable. Due to the increase in commercial fisheries in Namibian waters, catches of undersized fish and unwanted species have increased. Knowledge on fishing gear selectivity and fish behaviour has been identified among the key contributing factors to reduce by-catch and avoid overexploitation of fish (Schneider and Lossius 1999). The Ministry of Fisheries and Marine Resources (MFMR) is responsible for fisheries management, set TAC, policy, research, monitoring of catches, vessel licensing and monitoring, surveillance and control (MSC). The MFMR has established three institutes to assist in its duties, namely Namibian Marine Information and Research Centre (NATMIRC), dealing with research and monitoring of the marine living resources to inform policy development, stock assessment and TAC, the Namibian Fisheries Observer Agency (FOA) to act as a watch dog on behalf of government for MSC, to counter illegal fishing, control overfishing, bycatch and unwanted sizes or target species and the Namibian Maritime and Fisheries Institute (NAMFI) to provide training to the staff of ministry and supporting agencies. Ideal fishing gear selectivity would result in only catches of the desired size of the target species, with full survival of all other specimens. Growth overfishing occurs when harvesting removes so many juvinal fish that the maximum growth potential of the stock cannot be achieved. Overfishing and harvesting of unwanted fish sizes and species is mainly due to poor knowledge of fishers about gear selectivity, fish behaviour and lack of laws (Gordoaa 2006). The MFMR has selectivity measures in place, such as minimum mesh size for hake 110 mm, horse mackerel 60 mm, pilchard 12.7 mm, orange roughy 110 mm, monk and sole 75 mm, restricted fishing area depth for hake and horse mackerel is shallower than 200 m and 20 cm minimum body size (minimum landing size) for both hake and horse mackerel and 110 cm for monk and sole (Table 1). The ministry has also introduced closing season to allow spawning and fines for bycatch as well for different species (Directorate of Marine Resources, 2002). Other parameters that are known to affect selectivity, like codend length and circumference and twine stiffness (Ingolfsson 2006) are not documented for Namibia.

Table 1. Selectivity measures in Namibia

Species	Minimum mesh size (mm)	Restricted fishing depth (m)	Minimum body size (cm)
Horse Mackerel	60	<200	20
Pilchard	12.7		20
Hake	110	<200	
Monk and Sole	75		110
Orange roughy	110		

Mesh size regulations and area restrictions seem not to be sufficient, and thus gear studies to improve the size selectivity of hake trawls started in 1997. From experiments conducted in 1997 it was shown that square mesh top panels on codend gave almost no size selection, as virtually no hake tried to escape (Isaksen 1997). Due to the passive behaviour of hake in a trawl a more direct sorting approach is needed like a rigid sorting grid, to size select hake. Several other similar experiment were caried out between 1999 – 2003 in Namibia for Monk and Hake using “Ex – it” – and “ Single” grid with two different lifting panels and Gillnet (280 mm mesh). It is not unlikely that the hake makes escape attempts downwards when it has entered the codend (B. Isaksen *pers. comm.*) Little has been done on size selectivity experiment using different codends (normal narrow diamond, square mesh and same size different material) of the same size with cover of small mesh size, except for the square mesh top panel experiments and direct under-water video-observations in Namibian hake trawl fishing by Isaksen (1997).

Namibia is a country in southwestern Africa at latitudes 17°S and 29°S and longitudes 11°E and 26°E. On its southern border is South Africa, to the east is Botswana & in the north Angola, other neighbouring countries include Zimbabwe & Zambia (Figure 1).

Figure 1. Map of Namibia

1.2 Objectives

The objective of this experiment was to estimate and compare the selectivity of two types of trawl codends with different stiffness.

- 135 mm codend of soft material
- 135 mm codend of stiff material

1.3 Selectivity

Selection of fish by a fishing gear is the process which causes the catch of the gear to have a different length and species composition to that of the fish population in the geographical area in which the gear is used (Wileman *et al.* 1996). Fishing gear selectivity measures the selection process and describes how fishing gear select size and species to allow juvenile fish to escape and reduce bycatch (FAO 2007, Ingolfsson 2006). Knowledge of fishing gear selectivity is of fundamental importance when recommendations for harvest strategies are being made (Huse *et al.* 2000).

Trawl consists of a conical shaped net towed by a vessel. The mouth of the net is held open vertically by floats attached at the top and by the trawl doors that spread the trawl horizontally, rigged to the warps each side (Galbraith *et al.* 1989). During trawling, fish are herded and guarded by the warps, otterboards, sweeps and wings of the trawl into to the net, for them to be guided towards the codend. Most escape attempts occur at the codend with larger fish being more likely to be retained than smaller fish. Selectivity of trawl occurs mostly at the codend and is determined primarily by the codend size and shape of the mesh openings (Wileman *et al.* 1996). Mesh selectivity can be illustrated graphically, and is usually termed the mesh selection curve. The horizontal axis represents the fish length and the vertical axis the proportion of fish that are retained in the test codend. The codend selection curves tipically have a sigmoid shape (Wileman *et al.* 1996). Quite a number of selection curve models are available but the logistic selection curve is widely used to describe the propability that a fish of particular length entering the codend will be retained. The model is fit to the haul by haul catch data analysing the numbers of fish of a given length retained in the test codend and the numbers of that length found to have entered the codend (Wileman *et al.* 1996).

Two parameters are widely used to characterise codend mesh selection of fish (Maclennan *et al.* 1992). The first is the 50% retention length (L_{50}), which is the length of fish that has a 50% probability of being retained after entering the codend. It is a basic measure of the selectivity of the gear stating that the gear will retain most of the fish above this length that enter the codend. The second is the selection range (SR), which is the difference in length between the fish that has a 75% probability of retention (L_{75}) and that with a 25% probability of retention (L_{25}). This is a measure of the sharpness of the selection i.e. the slope of the selection curve. A gear with a large SR will start to retain fish of a smaller length and fail to retain fish at larger lengths than a gear with the same L_{50} but narrower SR (Wileman *et al.* 1996). In most models of towed gear selectivity there is a simple relationship between these two parameters and the parameters defining the selection curve. Another parameter often used to describe a gear's selection is the selection factor (SF), L_{50} divided by codend mesh size. Mesh size here should be what is commonly referred to as the inside mesh size. Reeves *et al*. (1992) found that the selection factor increased with mesh size for demersal round fish. It is, however, useful for practical purposes to quote a particular selection factor value for a species at a given nominal mesh size.

Although it is mainly the girth of a fish that determines whether or not a fish is able to pass through a mesh opening, it is easier to measure fish length. For most fish species there is a significant linear relationship between length and girth but this will vary with condition, with season and between different fishing areas.

1.4 Parameters affecting coded size selectivity

1.4.1 Mesh size and shape

The most obvious parameter affecting codend size selectivity is mesh size. Bigger mesh sizes means bigger escape opening, which in turn increases escape probabilities and thereby increases L_{50}.

1.4.2 Twine diameter and stiffness

The diameter of the twine used for constructing the codend has an effect on the twine stiffness and thereby mesh opening of the codend. The flexibility of the material used for the codend has an effect on the selectivity (L_{50}) (Robertson 1993). Stiffer nets will have a greater resistance to deformation when fish attempts to escape through partly open meshes. This may cause fish to be retained in the cod-end which would otherwise escape (Lowry 1995). The fish which attempt to escape may suffer scale damage and are thus less likely to survive. The stiffness of the twine may also have an effect on mesh opening in that the meshes of stiffer netting will open less for the same circumferential force caused by water pressure on the catch (Tokac *et al.* 2004).

1.4.3 Codend circumference

Codend circumference affects selectivity, as the mesh opening is affected by the waterflow (Reeves *et al.* 1992). When the area covered by the codend is too wide, the flow of the water will cover a large area, which reduces its force and will not be strong enough to open the mesh fully. A larger circumference means a wider area the fish have to swim in the attempt escape, some fish will not escape due to fatigue. A codend with a big circumference has an effect on the mesh opening, compared to a codend with a smaller circumference under the same conditions. The meshes open better when using a smaller circumference. A codend with larger circumference has reduced lateral opening of meshes, with lesser probability of fish entering the codend to escape, compared to the codend of smaller circumference (Broadhurst and Kennelly 1996).

1.4.4 Codend length

Reeves *et al*. (1992) showed that the parameters of the logistic curve or L_{50} can depend on variables such as codend length. Not all fish that enter the trawl end up in the codend. When the codend is too long the fish sometimes return back to escape through the belly or trawl mouth without reaching the codend end. The codend length also has an effect on the mesh opening, because of the area covered by the flow of water which aids in the mesh opening (Galbraith *et al.* 1989). If a large school of fish enters the codend at once, it gets blocked in the codend and therefore cannot escape. When the codend is too long it becomes less selective.

1.4.5 Mesh opening

By opening up the meshes, L_{50} increases for most roundfish (Krag 2009). Mesh opening can be affected in several ways. A common method is to use square mesh codends or square mesh windows in the codend or the trawl belly. The meshes are then turned 45° so the bars of the meshes point forward and back instead of the knots of a diamond meshes (Arkley 2001). Other methods include turning the meshes 90° (T90) where the side knots are constructed to point forward (Herrmann *et al.* 2009) and attaching last ridge ropes than the codend that are shorter to the meshes to force a greater mesh opening (Duzbastilar *et al.* 2010).

1.5 Methods for determining selectivity

Selectivity of a codend is determined by selectivity experiments where number of fish that have been retained by the codend and the total numbers of fish that have entered the codend is estimated (Wileman *et al.* 1996). A small mesh cover is often fitted around the codend when testing in order to catch the fish escaping through the meshes. Alternatively, an identical trawl fitted with a small mesh codend is towed under conditions that match that of the test trawl as closely as possible (Wileman *et al.* 1996). The first method gives a direct measurement of the total numbers of fish that have entered the test codend, the second gives an estimate of the numbers that should have entered the test codend (Wileman *et al.* 1996). The lengths of the fish retained in the codends and codend cover are measured. The following sections describe available methods as they are described in Wileman *et al.* (1996).

1.5.1 Covered codend method

Small mesh covers surrounding codends have been used in selectivity experiments for years to retain the fish escaping from a codend. The catch in the codend and cover together provide a measurement of the population entering the codend and hence allow the codend selectivity to be estimated. For the covered codend method, to give a true measure of selectivity, it is essential that the cover does not affect the relative ability of fish of different sizes to escape from the codend. It has been recognized since covers were introduced that they may physically mask the codend meshes and prevent fish escape to some extent. The use of hoops reduces the risk of masking. The cover is held away from the codend by attaching two or more hoops around its circumference on the outside of the cover (Figure 2). The hoops prevent any contact between cover and codend especially at the point where the catch expands to form a bulge.

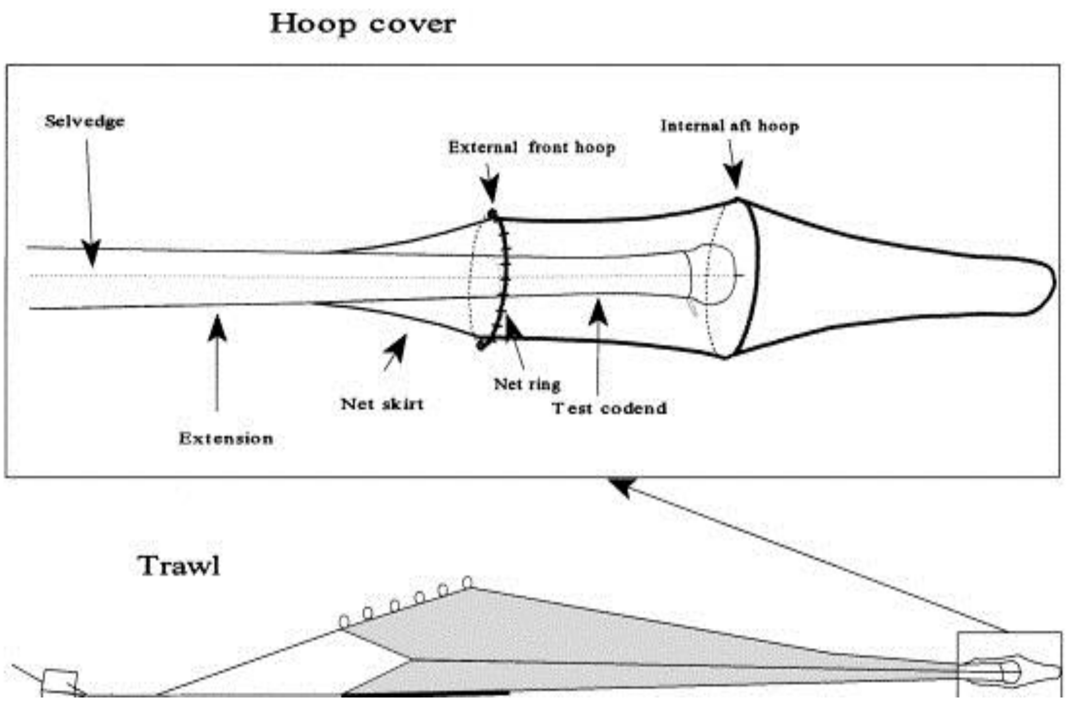


Figure 2. Diagrammatic representation of hooped cover mounting.

1.5.2 Alternate haul method

This is the one of four different "paired gear" methods, which is suitable for measuring whole gear selectivity as well as codend selectivity. Hauls are made alternately with the gear whose selectivity is to be measured and then with the same gear with a small mesh codend. The latter obtains an estimate of the fish population entering the test codend. If whole gear selectivity were being measured then the second set of gear would be made in small mesh throughout. It is essential that the pairs of hauls should be similar in every respect except for the mesh size in the part of the gear whose selectivity is being measured. As in the case of all the "paired gear" methods the main aim of this method is to avoid any bias caused by a cover. The test codend is used as in normal commercial fishing. The major drawback is the need for a larger number of hauls, which will increase the cost of the experiment. Two hauls are necessary in order to calculate a single selection curve for one codend. There are several further potential disadvantages. The population estimate may not represent accurately the population met by the test codend which is fished at a different time, under possibly different conditions of e.g. light level and, to some extent, over a different area of seabed.

1.5.3 Parallel haul method

The parallel haul method involves two vessels fishing on the same grounds at the same time. The only difference between their gears is the gear design feature whose effect on selectivity is to be measured. When measuring codend selectivity for example, the experimental gear whose selectivity needs to be measured is towed by one vessel and a gear of identical design, but with a small mesh codend, is towed by the other in order to obtain an estimate of the population of the target species entering the test codend. The two vessels fish in the same area and tow at the same speed so that the fishing operation is duplicated closely on the two vessels. As in the case of the alternate haul method the main aim of this method is to avoid the bias caused by a cover. The two codends are tested at the same time and on adjacent seabed areas, which are assumed to have similar populations of fish. The fishing powers of the test codend and small mesh codend may not be equal. The major drawback is that the need for two vessels approximately doubles the cost of the experiment. Also the two nets will not in general encounter the same populations despite their proximity. This bias can be taken into account in the analysis method but larger variance is likely in the calculated selectivity parameters, compared to the covered codend method. The variance in the parallel haul method is increased compared to the alternate haul method in that there are more vessel gear differences but may be decreased because of the reduction in time and environmental differences.

1.5.4 Twin trawl method

One trawler tows two similar trawls simultaneously side by side, using special rigging. The test codend is attached to one of the twin trawls. A small mesh codend is attached to the other trawl to obtain an estimate of the total fish population entering the test codend. Thus the length-frequency distributions of fish from the two codends allow the calculation of the selectivity parameters of the uncovered test codend as used in commercial fishing. This method is particularly recommended for fisheries in which twin trawls or beam are commonly used. The twin trawl method can also be used for measuring the selectivity parameters of a conventional single demersal trawl. It may also be used to estimate whole trawl selectivity and to conduct catch comparison trials. The twin trawl method is free from any bias caused by the use of a cover and improves the simulation of commercial fishing conditions. It is however, true that a twin trawl rig has some features, which are different from a conventional single trawl. The behaviour of the fish ahead of the trawl and hence their susceptibility to capture may be affected by the change in wire rigging between the trawl and the vessel. The two twin trawls will have smaller dimensions than a single trawl towed by the same vessel. Hence, if the aim is to estimate the selectivity of a trawl suitable for a given size of trawler it may be necessary to conduct the experiment on a trawler approximately double the power to ensure that two trawls of the original size can be towed side-by-side. Although the two trawls are working close to each other in the same conditions there is no certainty that the same population of fish will enter each trawl. Generally, there is a haul-to-haul variation in catches and a somewhat larger number of hauls are usually required to achieve the same precision of estimation as is given by the covered codend. The fishing powers of the nets with the test codend and small mesh codend may not be equal. Specialized methods are needed to analyse twin trawl data.

1.5.5 Trouser trawl method

The trouser trawl method is a variation of the twin trawl method whereby a standard trawl is divided down the middle by a vertical panel. Two codends are attached to the aft end, one on each side of the panel. The trawl is towed from one vessel and the test codend is attached to one side while the control (small mesh codend) is attached to the other side. The design is based upon the premise that an equal number of fish will enter each side of the trawl. As in the case of the twin trawl, length frequency data are collected from both codends to allow calculation of the fish selection characteristics of the test codend. The trawl can be handled in a similar manner to a standard trawl and no special rigging is needed. There are no covers to impede escape of fish from the codend. The trouser trawl can also be used to make direct catch comparisons between codends. While the trouser trawl does not have any special rigging, which may affect the behaviour of fish in front of the trawl, it nevertheless can show significant haul-to-haul variation as in the twin trawl method. Also, strong currents, inaccurate wire lengths or other effects can cause bias towards one side of the net.

2 MATERIALS AND METHODS

Data were collected using a hooped covered codend on a demersal trawl selectivity trials carried out on board the FV Aldan IS-47 (length 19.47 m and 381 HP) between 31 March and April 14, 2012 (5 days). Fishing was conducted in the Westfjords of Iceland (Figure 3), where cod *(Gadus morhua)* and haddock *(Melanogrammus aeglefinus)* were the target species. In the first three days of the experiment the regular softer diamond mesh codend was tested and during the remaining two days the stiffer codend was tested for 3 - 5 hauls a day. The experiment was carried out using a conventional bottom trawl (Figure 4) with 135 mm nominal mesh size Polyethylene (PE) netting codend, 42 meshes in its circumference and 4.8 m long (32 meshes). One of the codend was constructed of 6 mm soft PE and the other of 8 mm stiff PE (“hotmelt” material). The cover used was 16 m in length and made of 42 mm mesh size (36 mm inside mesh) PE netting supported by two hoops, 1.6 m in diameter, made of 60 mm plastic pipes. Warp lengths used for this depth range were 200 m. Towing duration was approximately 1 hour for most hauls and towing speed varied between 2.2 and 2.5 knot (Table 2). Mesh sizes were measured with an Omega gauge (ICES 2005) where measuring jaws with 125N force were used for measuring. Twenty meshes in a row were measured on the top panel of the codend whilst wet, and mean and standard deviations presented. As the concept of “stiffness” is subjective, the meshes were also measured crosswise as a measurement of stiffness.

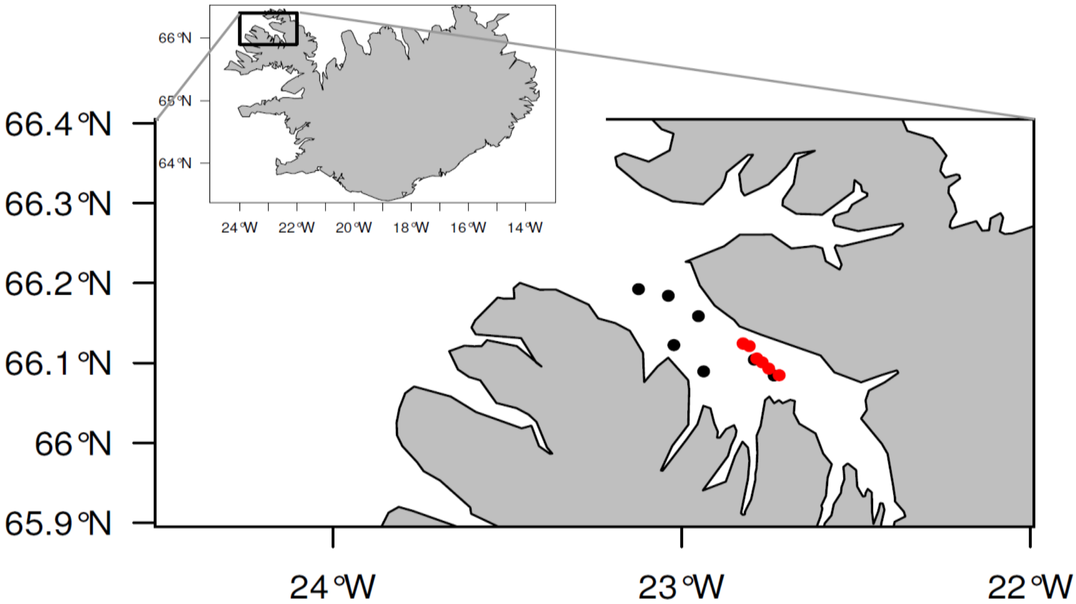


Figure 3. Selectivity experiment trail map – Westfjords. The red dots show where the stiff codend was used while the black dots represent where the soft codend was tested. Starting positions for valid hauls are shown.

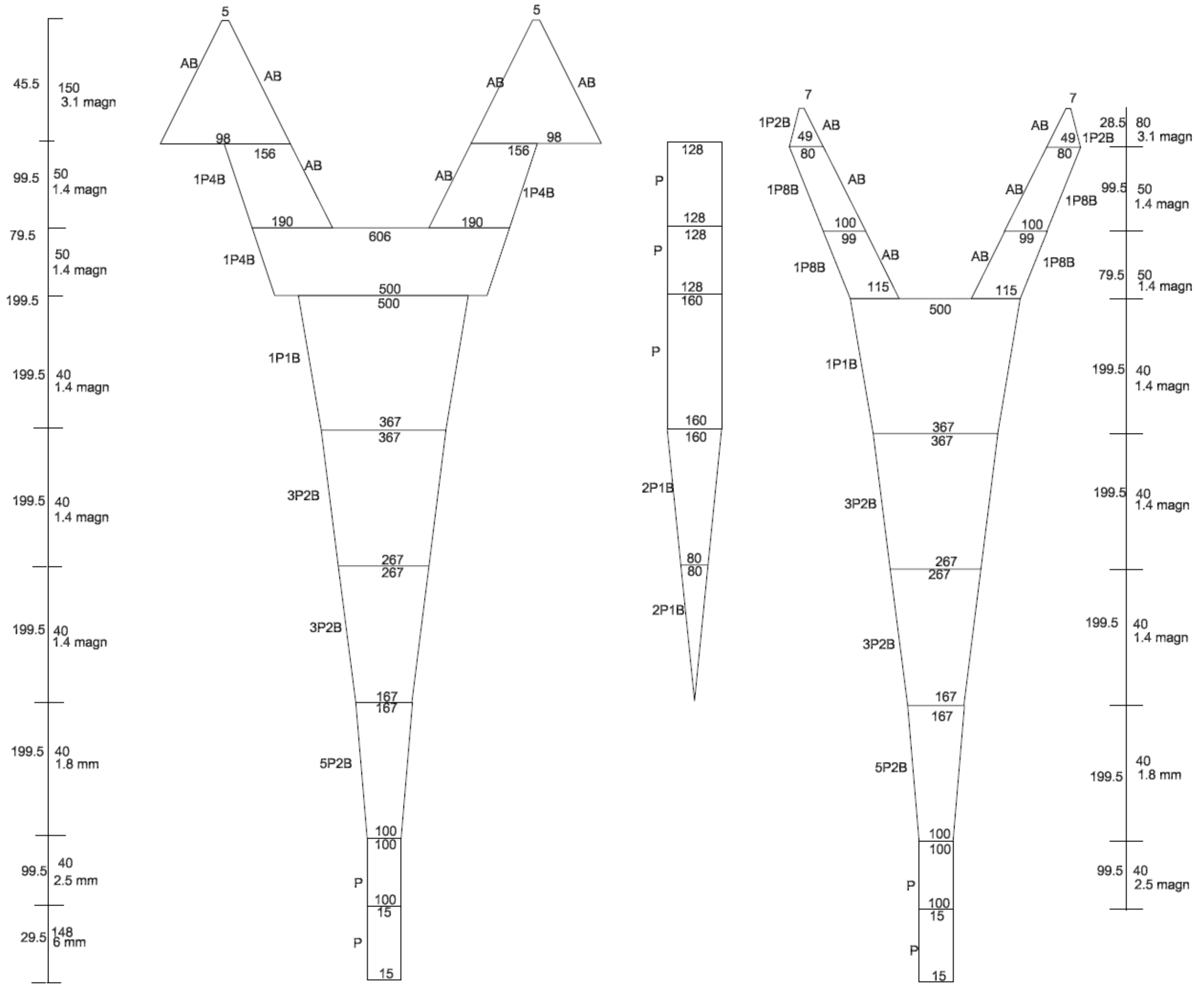


Figure 4. Drawing of the trawl used in the experiment. Redrawn for this project.

2.1 Data collection and analyses

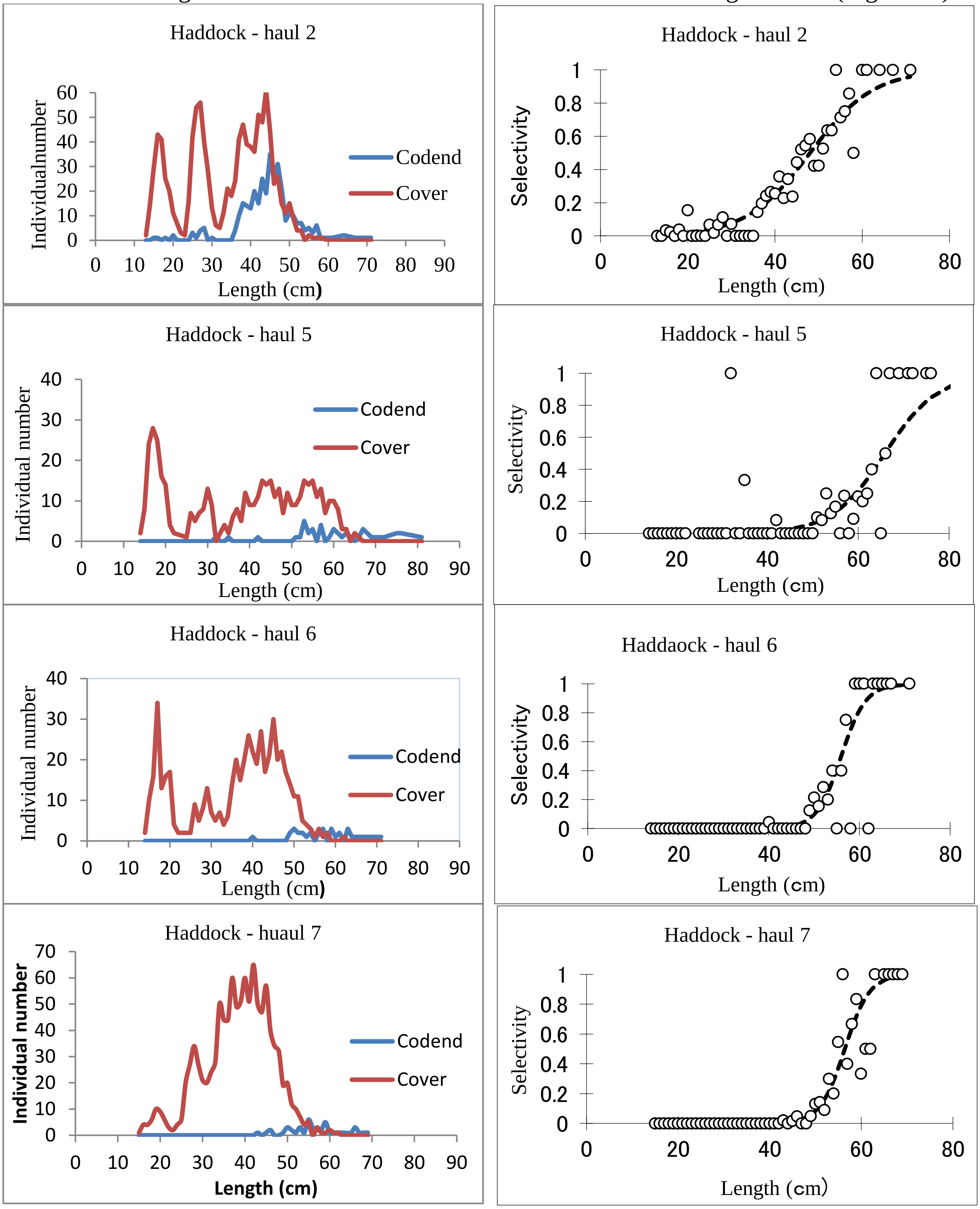
During hauling the trawl codend was pulled and lifted to the starboard side of the vessels with a hydrolic winch. Once the catch was taken on board, the catch in the cover and codend were kept separate in the fish bin and a fish tub. To calculate the selection parameters, fish lengths were measured to the nearest centimeter for seven commercial species namely cod (*G. morhua*), haddock (*M. aeglefinus)*, plaice (*Pleuronectes platessa*), whiting (*Merluccius merluccius*), redfish (*Sebastes marinus*), wolffish (*Anarhicas lupus*) and dab (*Limanda limanda*). This work focused on selectivity of cod and haddock, which constituted the bulk of the catch. The catch weight was calculated using length weight relationship. The proportion of each species that was retained in the codend and cover was calculated for each haul. The solver function in MS Excel was used to fit the selection curves to the data as well as the L_{50} and the SR. Haddock data were calculated on haul–to–haul basis, while cod data for the soft codend were pooled because of small catches. The selectivity program was also used to draw both individual and average selection curves for all hauls with the same codend. The symmetric logistic curve was applied as it gave reasonable fit to most of the data. In case when it was found to give inadequate fit, the asymmetric Richards curve was fitted and the model presented gave "best" fit based on the AIC – scores (Venables and Ripley 2002). Differences in L_{50} and SR were tested formally using a t-test.

3 RESULTS

A total of 19 hauls were taken, whereof haul 1 (h1), h11 and h12 were considered invalid due to clogging of meshes because of seaweed, or high proportion of the catch was in the trawl belly and had not entered the codend. Some hauls for haddock and cod were also considered to be invalid because it had too little fish. Of those, six hauls had sufficient catches of haddock in the softer codend and seven in the stiffer one to perform a haul-by-haul analysis (Figures 5 and 6). Catches of cod were in general smaller and the cod data were therefore pooled for the softer codend (Figure 7 and 8). In general, the logistic curve provided adequate fit, but for haddock in h10 the Richard's curve gave better fit, based on AIC values. The pooled cod data for the softer codend was also better modelled with the Richard's curve. The catches constituted mostly of cod and haddock and ranged from 17 to 136 kg for cod with an average of 60 kg, and 6 to 716 kg for haddock with an average of 262 kg (Table 2). The total catch weight calculated for haddock was 4452 kg and for cod was 962 kg. The number for haddock in soft codend and cover were 1544 and 5759, while the stiff codend had 3076 fish with 3541 fish in the cover. For cod, soft codend retained 275 and 769 were held in the cover, while the stiff codend had 411 and 545 were in the cover (Table 2). The mesh size for the softer codend was 135.2 mm on average with standard deviation of 2.4 mm. Corresponding values for the stiffer codend were 133.8 and 2.5 mm. The crosswise measurement for the soft and stiff codend gave 130.2 mm and 79.6 mm on average with standard deviation of 2.3 mm and 6.4 mm respectively.

For haddock, L_{50} ranged from 48.1 to 65.9 cm for the softer codend giving an average of 57.4 cm (Table 3 and Figure 9). L_{50} for the stiffer codend ranged from 36.3 to 46 cm, with 40 cm on average. The shift in L_{50} by 17.4 cm for haddock was significant ($p<0.001$) (Figures 9 and 11). SR for haddock ranged from 5.9 to 12.9 cm for the softer codend with 10.2 cm on average, and for the stiffer codend it ranged from 8 to 20.3 cm, with 13.3 cm on average (Figure 9).

The difference in SR was not significant (p>0.05). For cod, pooled data, L_{50} and SR for the softer codend were 37.4 and 7.2 cm respectively. For the stiffer codend, L_{50} was 37.9 to 48.2 cm with 44.1 cm on average and SR was 10.1 to 28.4 cm with 19.6 cm on average for cod (Figure 10).



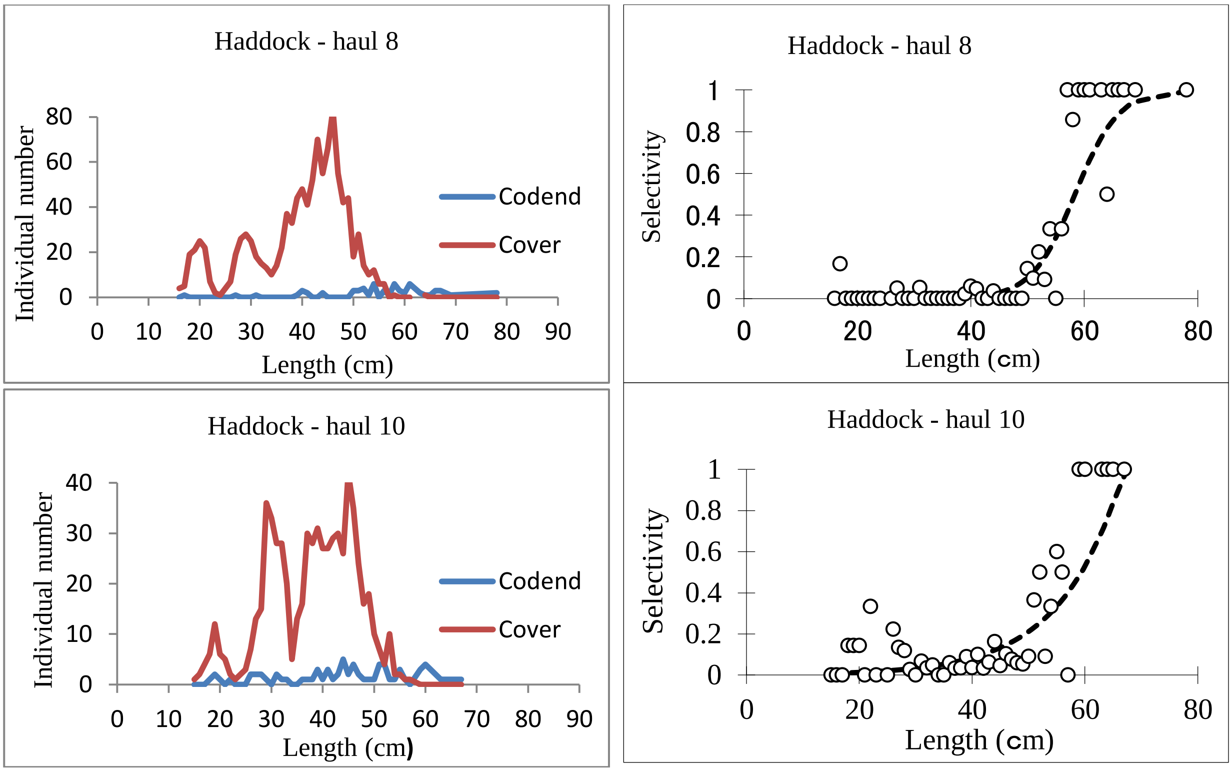
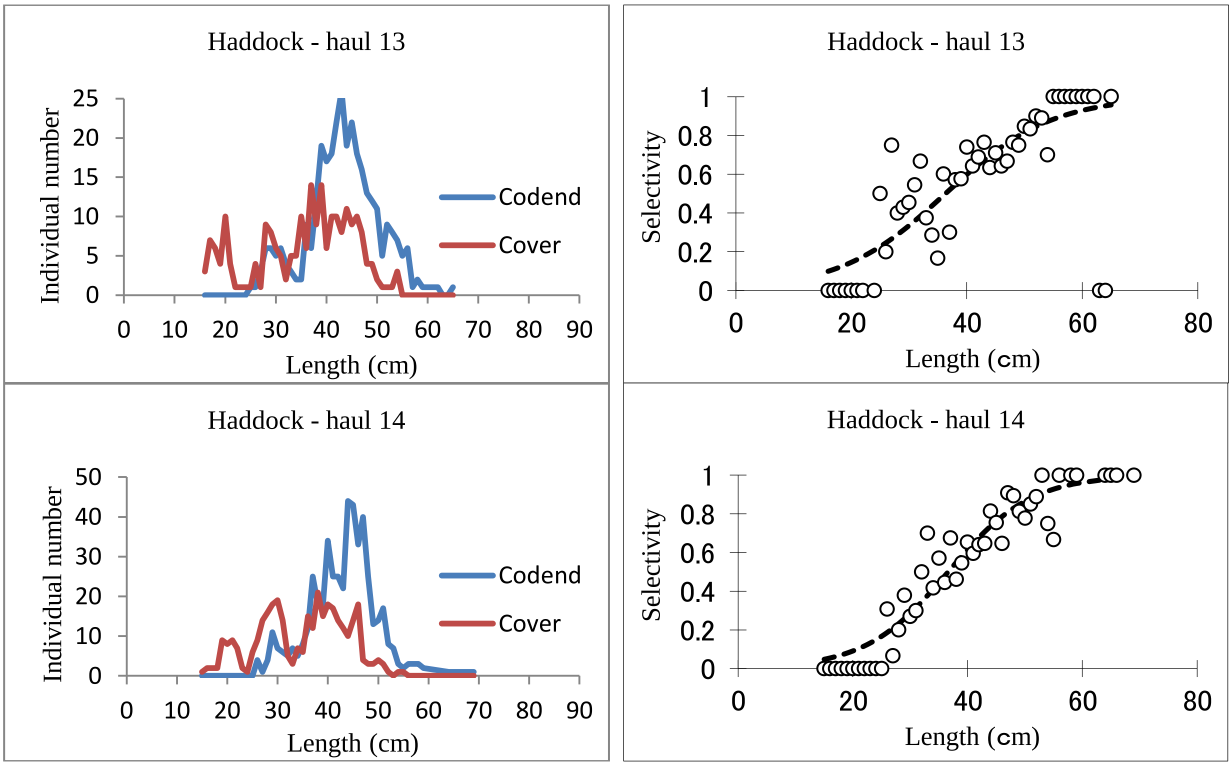
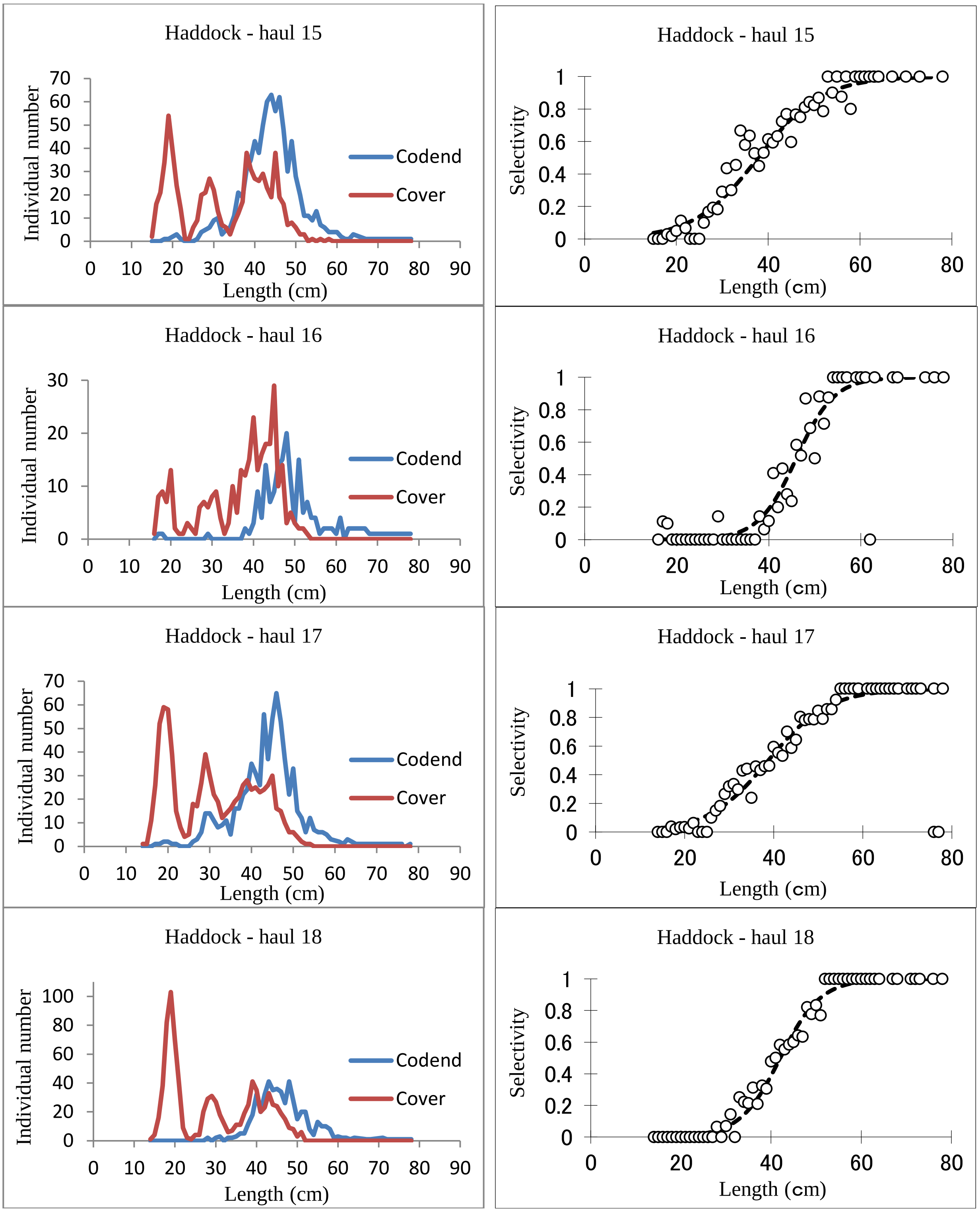


Figure 5. Haddock size distribution in soft codend and cover (left) and selection curve (right).





Haddock - haul 15
Individual number
Codend
Cover
Length (cm)
Haddock - haul 15
Selectivity
Length (cm)
Haddock - haul 16
Individual number
Codend
Cover
Length (cm)
Haddock - haul 16
Selectivity
Length (cm)
Haddock - haul 17
Individual number
Codend
Cover
Length (cm)
Haddock - haul 17
Selectivity
Length (cm)
Haddock - haul 18
Individual number
Codend
Cover
Length (cm)
Haddock - haul 18
Selectivity
Length (cm)

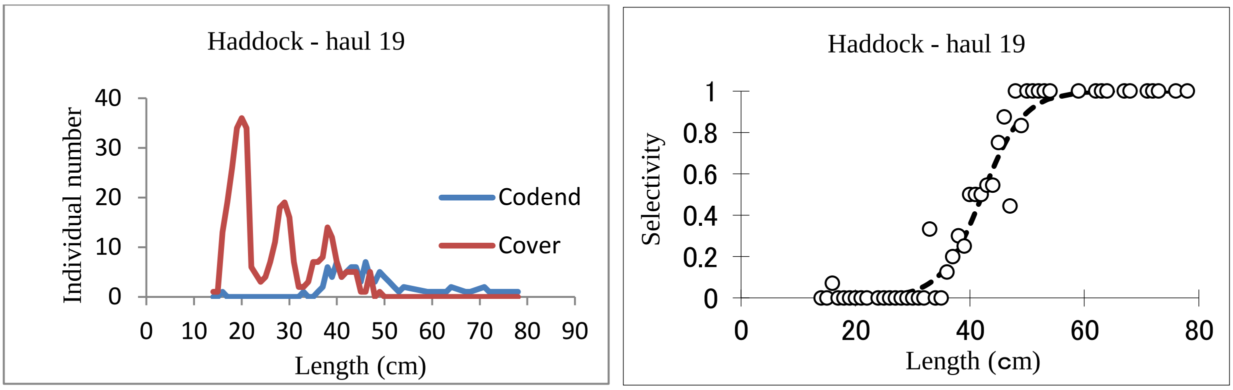


Figure 6. Haddock size distribution in stiff codend and cover (left) and selection curve (right).

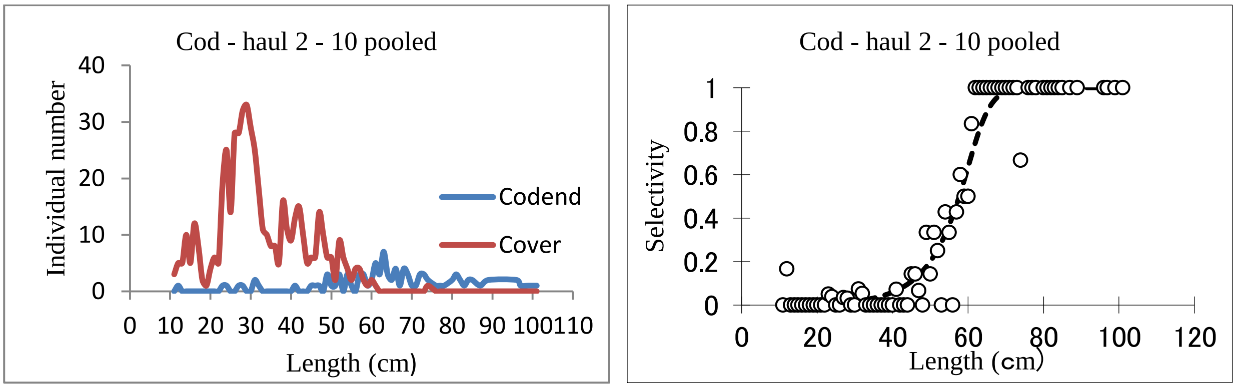
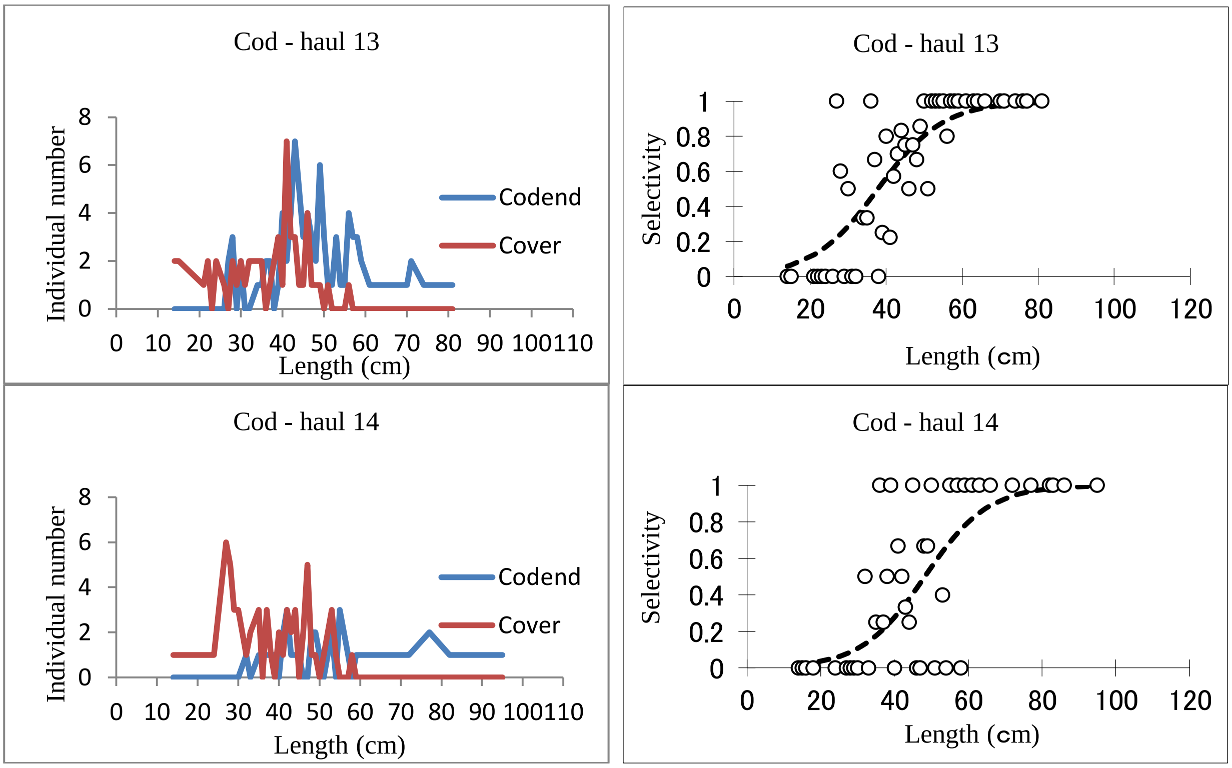


Figure 7. Cod size distribution in soft codend and cover (left) and selection curve (right). The figure contains pooled data from hauls 2 to 10 apart from hauls 4 and 9, which were invalid.



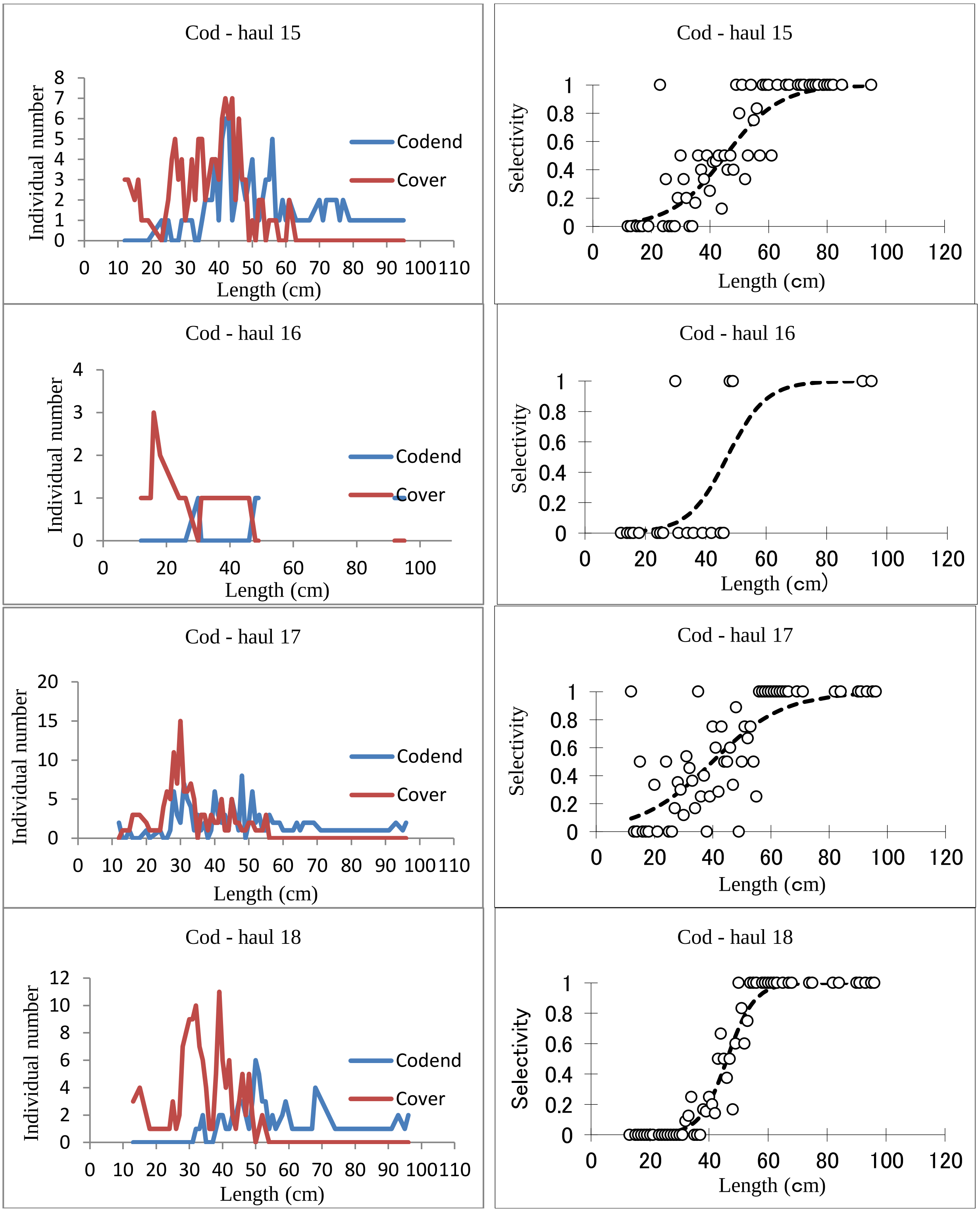


Figure 8. Cod size distribution in stiff codend and cover (left) and selection curve (right).

Table 2. Information on individual tows, positions, time, depth along with number of fish and catch weight.

			Tow duration	Start			End		Mean depth	Catch (Kg)			No.Haddock		No.Cod	
Haul	**Date**	**Codend**	**(min)**	**Time**	**Lat**	**Lon**	**Lat**	**Lon**	**(m)**	**Cod**	**Haddock**	**Total**	**Codend**	**Cover**	**Codend**	**Cover**
2	31/03	Soft	92	11:12	66°07.58'N	23°01.57'W	66°05.81'N	22°55.45'W	89	22	310	332	334	1048	5	46
3	31/03	Soft	109	13:17	66°05.62'N	22°56.36'W	66°05.60'N	22°56.77'W	69	89	6	95	14	257	36	39
5	02/04	Soft	175	11:09	66°06.42'N	22°47.86'W	66°09.52'N	22°56.19'W	126	90	97	187	41	469	27	45
6	02/04	Soft	59	14:17	66°09.86'N	22°57.20'W	66°10.52'N	23°01.88'W	113	19	62	81	32	530	4	28
7	02/04	Soft	51	16:16	66°11.08'N	23°02.50'W	66°11.69'N	23°06.98'W	117	23	83	106	44	1076	10	37
8	02/04	Soft	117	17:44	66°11.91'N	23°07.70'W	66°08.32'N	23°03.41'W	121	20	115	135	62	1069	5	55
10	13/03	Soft	77	14:51	66°05.11'N	22°44.19'W	66°04.94'N	22°38.64'W	111	13	73	86	70	656	11	240
13	14/04	Stiff	72	11:18	66°07.74'N	22°49.64'W	66°05.82'N	22°45.34'W	116	92	284	376	327	223	87	53
14	14/04	Stiff	63	13:20	66°06.08'N	22°46.23'W	66°08.01'N	22°50.42'W	121	62	416	478	498	346	37	58
15	14/04	Stiff	127	16:15	66°07.79'N	22°49.74'W	66°06.54'N	22°46.78'W	117	136	716	852	795	673	96	117
16	14/04	Stiff	145	19:29	66°06.57'N	22°47.12'W	66°08.11'N	22°56.12'W	126	17	205	222	167	304	5	18
17	15/04	Stiff	124	09:35	66°07.45'N	22°48.60'W	66°05.01'N	22°39.69'W	96	143	645	788	706	800	118	130
18	15/04	Stiff	107	12:33	66°05.14'N	22°43.35'W	66°05.86'N	22°44.88'W	101	133	538	671	504	541	66	142
19	15/04	Stiff	72	14:43	66°05.97'N	22°45.04'W	66°07.54'N	22°50.61'W	81	55	110	165	79	344	2	27

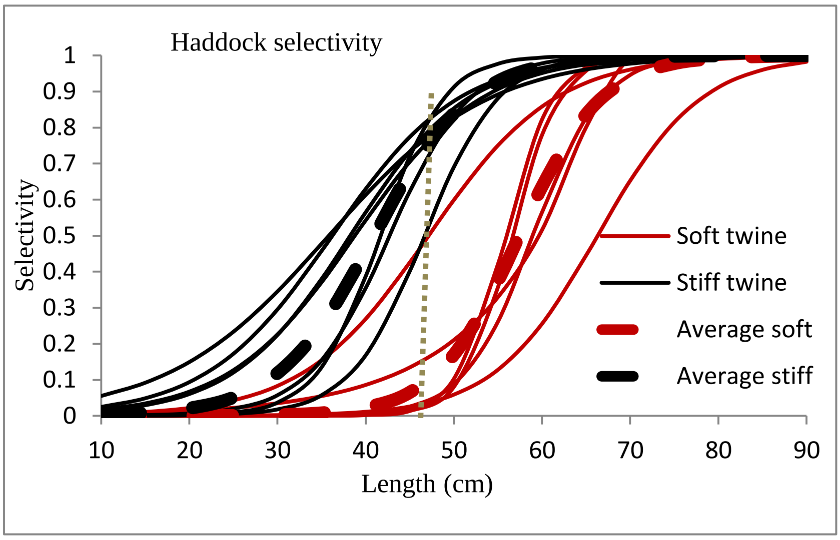
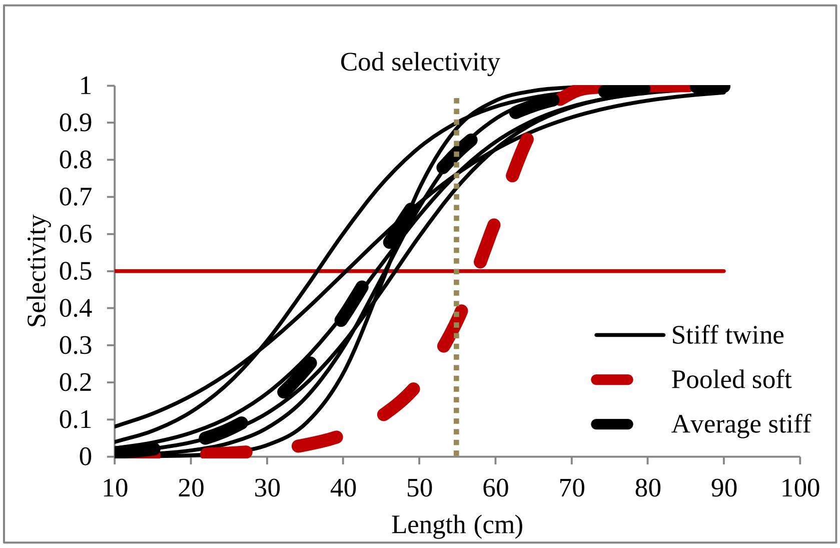


Figure 9. Selection curves and length distribution (L_{50} and SR) for Haddock. Selection curves from soft codend (red), stiff codend (black), mean selection curves (thick broken lines), individual selection curves (thin drawn lines), minimum legal size (MLS) in Iceland (vertical dotted lines).



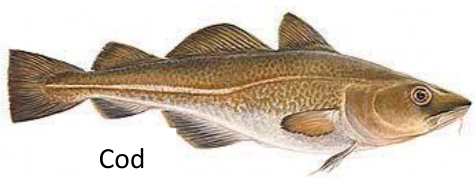


Figure 10. Selection curves and length distribution (L_{50} and SR) for cod. Selection curves from soft codend (red), stiff codend (black), mean selection curves (thick broken lines), individual selection curves (thin drawn lines), minimum legal size (MLS) in Iceland (vertical dotted lines).

Table 3. Selection parameters for haddock and cod along with average values. The asymmetry parameter □□is presented for hauls 10 (haddock) and the pooled data for cod from the soft codend. The average parameters a, b and □□are derived from L_{50} and SR.

Haul No.	Experiment	Specie	Length range	a	b	□	L_{50}	SR
2	Soft	Haddock	13 - 71 cm	-6.60	0.140		48.1	16.0
5	Soft	Haddock	14 - 81 cm	-11.27	0.170		65.9	12.9
6	Soft	Haddock	14 - 71 cm	-20.67	0.370		56.0	6.0
7	Soft	Haddock	15 - 69 cm	-20.94	0.370		56.4	5.9
8	Soft	Haddock	16 - 78 cm	-15.34	0.260		58.4	8.4
10	Soft	Haddock	15 - 67 cm	-122.9	1.837	20.0	59.4	12.0
			Average	**-12.33**	**0.215**		**57.3**	**10.2**
13	Stiff	Haddock	16 - 65 cm	-3.94	0.110		36.3	20.3
14	Stiff	Haddock	14 - 69 cm	-5.07	0.140		36.6	15.9
15	Stiff	Haddock	15 - 78 cm	-5.43	0.140		37.8	15.3
16	Stiff	Haddock	16 - 78 cm	-11.20	0.240		46.0	9.0
17	Stiff	Haddock	14 - 78 cm	-5.74	0.150		38.8	14.8
18	Stiff	Haddock	14 - 78 cm	-9.40	0.220		42.1	9.8
19	Stiff	Haddock	14 - 78 cm	-11.66	0.280		42.2	8.0
			Average	**-7.49**	**0.183**		**40.0**	**13.3**
2	Soft pooled	Cod	11 - 101 cm	-24.61	0.391	3.17	57.7	10.2
13	Stiff	Cod	14 - 81 cm	-4.39	0.120		37.9	18.9
14	Stiff	Cod	14 - 95 cm	-5.62	0.120		48.2	18.9
15	Stiff	Cod	12 - 95 cm	-4.88	0.110		45.2	28.4
16	Stiff	Cod	12 - 95 cm	-7.28	0.160		47.1	14.2
17	Stiff	Cod	12 - 96 cm	-3.23	0.080		39.9	27.1
18	Stiff	Cod	13 - 96 cm	-10.0	0.220		46.1	10.1
			Average	**-5.91**	**0.135**		**44.1**	**19.6**

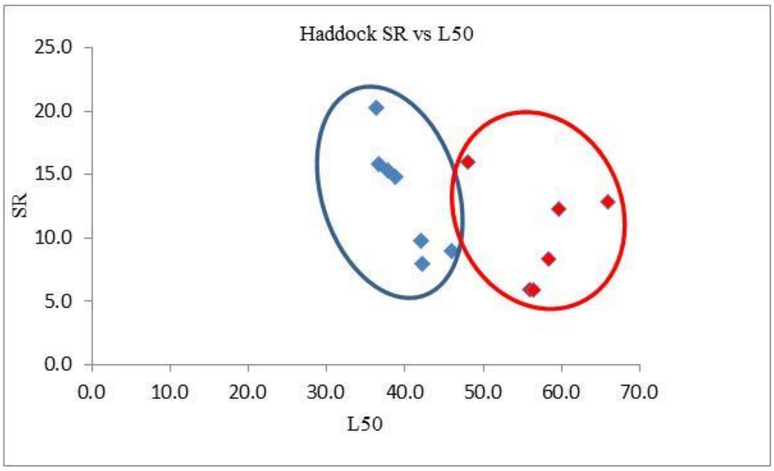


Figure 11. Haddock SR vs L_{50}. The circles are drawn by hand, the blue circle indicates stiff codend and red circle indicates the soft codend. It shows the selection parameter difference in terms SR and L_{50}.

4 DISCUSSION

The results showed that codend stiffness reduces selectivity significantly. For haddock, L_{50} was reduced by 17.4 cm on average, from 57.4 cm for the soft codend to 40 cm for the stiff codend. For cod L_{50} decreased by 13.6 cm on average from 57.7 cm for the soft codend (pooled data) to 44.1 cm for the stiff codend. The results were in agreement with previously published results on the effect of twine thickness on codend selectivity (Lowry 1995) and shows twine stiffness affects codend selectivity. Minimum legal size (MLS) for haddock is 45 cm. A codend with L_{50} of 45 cm would retain most fish above that size and release most fish below. When the L_{50} is below MLS, higher proportion of undersized fish will be caught, but most fish above MLS will be retained. When the L_{50} is above MLS, less undersized fish will be caught, but at the cost of losing catches of marketable fish above MLS (Figure 12).

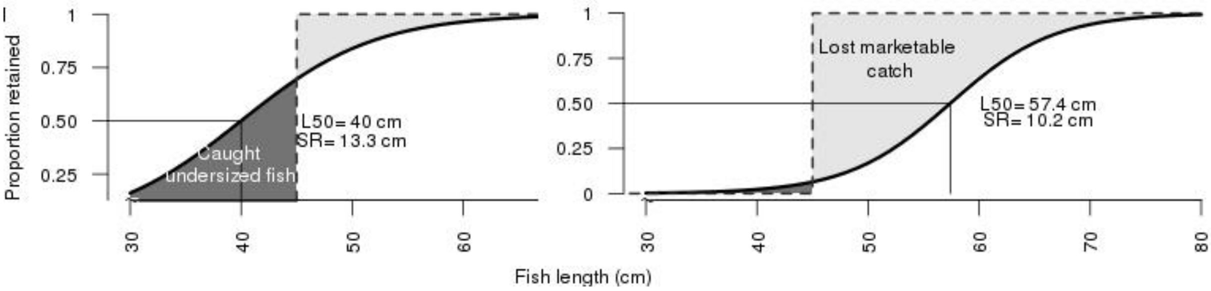


Figure 12. Consequences of having L_{50} below (left) or above (right) MLS. The figure shows the case for haddock in this experiment at MLS of 45 cm.

Difference in SR due to stiffness for haddock showed an increase by 3.10 cm on average from 10.2 cm for the soft codend to 13.3 cm for the stiff codend. Similarly, SR for cod increased by 9.4 cm, from 10.2 for soft codend to 19.6 cm for the stiff codend. The difference was not significant, but the trend is opposite to what one would have expected, i.e. SR increasing with L_{50} (Madsen *et al.* 1999). The trend for cod was similar. The SR for the stiffer codend was 12.4 cm higher, but due to pooling of the data from the soft codend, testing significance is not a straightforward process. Increased SR means that the gear will start to retain fish of a smaller length than a gear with the same L_{50} but narrower SR (Wileman *et al.* 1996).

The mesh sizes of the two codends were 135.2 mm and 133.8 mm, thus the difference was insignificant and cannot explain the differences that we got. The crosswise measurements of mesh sizes, however, were significantly lower for the stiffer codend. While the crosswise opening of the soft codend was about 5% lower than the measurements with the standard procedure, the crosswise measurements for the stiffer codend was 40% lower than when measuring the standard way. Crosswise measurement of meshes may therefore be useful measure of stiffness.

Mesh size is arguably the best-known parameter to have effect on size selectivity (Wileman *et al.* 1996), circumference is also known to have substantial effect (Reeves *et al.* 1992), and this study shows how twine stiffness can greatly influence. Mesh size has an effect, as it is a direct measure of the size of the escape hole that fish can penetrate. Circumference has effect because it influences the mesh opening; the bigger the circumference the smaller the mesh opening and vise – versa. Twine stiffness has effect in a similar manner, as we had difficulties stretching the mesh size crosswise, increased stiffness will hamper mesh opening.

The combination of the narrow codend and stiff material in this experiment may exaggerate the measured differences in selectivity. The softer codend that we compared had higher L_{50} than would have been expected from previous research (Ingolfsson 2006, Einarsson *unpublished*). Comparing two codends of different stiffness but with higher circumference would thus possibly have resulted in less difference in L_{50} due to less mesh opening of the softer codend (Reeves *et al.* 1992). Also, catch size might affect codend selectivity, i.e. bigger catches may result in shift in L_{50}. Such factors might result in less difference between soft and stiff codend, but would not alter the fact that the differences are considerable.

Two codend of different twine diameter were used, one with 6 mm (soft) and the other 8 mm (stiff). Twine diameter and stiffness are correlated, but the difference in stiffness cannot be explained by twine diameter alone. The stiffer twine is made of so-called “hotmelt” material, which is substantially stiffer than traditional PE netting. We could, however, not have a chance to evaluate if the stiffness changes over time, which in turn could reduce the observed differences.

The experiment was conducted over a longer period of time than anticipated, because of weather. This is not considered to have an effect on the result because the condition and circumstances were similar throughout the experiment.

There were some variances between hauls, which is a well-known phenomenon (Millar 2004). The reason is not always clear, but this emphasizes that replicates are needed to measure a difference between two selectivity devices. Number of replicates is dependent on e.g. the differences one wishes to detect, given the great differences that we detected, the number of hauls that we took was sufficient. Also, when planning such experiments, one must take into account that some hauls can be invalid due to e.g. too few fish or seaweed blocking as in our case.

5 CONCLUSIONS

Increasing twine stiffness in codends results in significantly reduced L_{50} and possibly elevated SR. In fisheries where factors other than mesh sizes are not controlled by regulations, fishermen can therefore easily manipulate codend selectivity legally to increase catches of small fish if they want to do so. Due to the properties of the stiffer twine (“hotmelt” material), the water and accumulated catch are not strong enough to open the trawl circumference fully, which again hampers the mesh opening resulting in lower L_{50}. This shows that fishiries management only regulating mesh size is inefficient in avoiding catches of small fish. To successfully manage MLS, stiffness of codend material must be included in the regulation

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