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„Towing vs. Heaving“ – When does the fish escape?

The escaping behavior of cod (*Gadus morhua*), flounder (*Platichthys flesus*) and plaice (*Pleuronectes platessa*) from legal cod ends in the Baltic Sea (BACOMA 120/105 mm-trawl; T90 120 mm-trawl)

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Bachelor of Science Thesis – Biosciences

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Abstract

Fish, which encounter the fishing gear have to survive different stressors. One of them is the barotrauma (injury by pressure) caused by differences in hydrostatic pressure occurring during heaving. Therefore, it is important for the fish to leave the codend as soon as possible to increase the survival probability. To find out, when the fish escape, different tests and analyses have been done in this study. The two codends, which are legal in the Baltic Sea (BACOMA 120/105 mm and T90 120 mm) have been tested by the help of a modified covered codend method and a Dualsampler-device. In this way it was possible to separate the total catch of the trials into a) fish caught in the main codend; b) fish, which escaped during towing and c) fish, which escaped while heaving. Using the length distributions of the caught fish, several analyses were conducted – for example with the selectivity-program SELNET. The results show that the major part of the escapees leaves the net during towing, but there are no significant differences between both tested codends. Only by regarding the separated retention rate of sized and undersized fish and by comparing the standard selectivity parameters it was shown that the T90 120mm codend retains more sized and fewer undersized fish and that its selectivity is sharper.

Content

1. Introduction

Cod (*Gadus morhua L.*) is an important target species of the Baltic fishery. In 2010, 64,397 t of cod were caught in the Baltic Sea, where 50,277 t were caught in the eastern part (ICES SD 25-32) and 14,120 t in the western part (ICES SD 22+24) (pers com. ICES WGBFAS/Ulrich Berth (vTI-OSF))(Appendix-Figure 1). The major fraction was caught by Denmark, followed by Germany, Poland and Sweden.

The goal of fisheries management should be the protection of fishery resources and the facilitation of a sustainable exploitation. Here, one of the main problems and challenges is the discard. To avoid misunderstandings, the terminology has to be clarified. Several definitions were published. The definitions used in this thesis are adapted from McCaughran (1992), FAO (1994), Clucas (1997) , Hall (1999) and Jennings (2001):

While trawling, the fish encounter the gear. Some individuals are able to escape and flee – some during towing, others even at haul-back. Some of the escapees die as a result of the fishing operation. The other individuals are retained and reach the deck of the fishing vessel – they are defined as the **total catch**. The total catch splits into two categories: the **landed catch** and the **discard**. The discard is that portion thrown away to the sea as a result of economic, legal, or personal considerations (e.g. individuals below Minimum Landing Size, reached quota, species of little value).

The landed catch can be split into two parts too: **target catch** and **incidental catch**. The **target catch** is the catch of the species or species assemblages, which is most valuable and primarily sought in a fishery. The other part of the landed/retained catch is the incidental catch. It contains every specimen which does not belong to the target species but is still retained due to its value. Incidental catch and discard are termed as **bycatch**, thus every individual of the total catch which does not belong to the target species. Figure 1 gives a general view of these terms.

Another important term is a strategy named **high-grading**: Some fishers even discard marketable individuals, for example if they are too big or still not big enough to be more valuable. If they discard less valuable specimen, their fish-holds (or their catch quota) are not be filled up with low-value fish, but they have room for more valuable fish, that maybe will be caught later. Nevertheless, this strategy is not relevant for this work, because it does not depend on the selectivity of fishing gears.

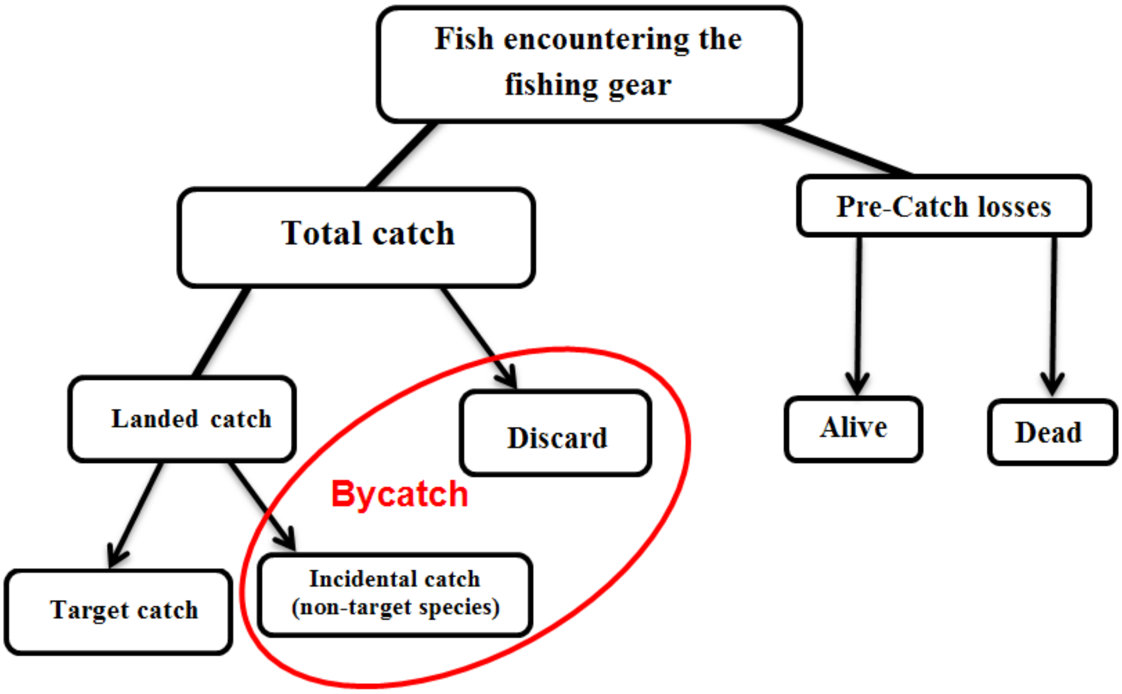

Figure 1: Terms respecting bycatch and discard (for explanation see text)

The cod discard in 2010 is estimated to 21.53 % of the total catch in the western Baltic Sea and to 15.26 % in the eastern part (pers.com. ICES WGBFAS/Henrik Degel (DTU Aqua)) (Table 1). The discard splits up to discard from passive fishery (e.g. gillnets) and discard from active fishery (trawls), where the discard-rates of passive gears are lower.

Table 1: Discards in the Baltic Sea 2007-2010 (data 2007-2009 from ICES (2010), data for 2010 from Henrik Degel (DTU Aqua) pers.com.)

Region	Year	PassiveGears [numbers]			Active Gears [numbers]			Total [numbers]			% of total Catch		% of total Discards	
		Landings	Discard	%	Landings	Discard	%	Landings	Discard	%	Passive	Active	Passive	Active
ICES SD 22-24	2007	5 083 000	178 590	3.39	15 679 000	4 775 220	23.35	20 762 000	4 953 810	19.26	20.46	79.54	3.61	96.39
	2008	5 217 000	26 170	0.50	11 275 000	2 617 270	18.84	16 492 000	2 643 440	13.81	27.40	72.60	0.99	99.01
	2009	3 607 000	475 110	11.64	11 072 000	2 072 910	15.77	14 679 000	2 548 020	14.79	23.70	76.30	18.65	81.35
	2010	4 283 000	306 000	6.67	9 330 000	3 430 000	26.88	13 613 000	3 736 000	21.53	26.45	73.55	8.19	91.81
ICES SD 25-32	2007	11 161 000	496 310	4.26	29 793 000	10 561 870	26.17	40 954 000	11 058 180	21.26	22.41	77.59	4.49	95.51
	2008	12 533 000	2 452 420	16.37	28 082 000	6 275 420	18.27	40 615 000	8 727 840	17.69	30.37	69.63	28.10	71.90
	2009	12 781 000	1 243 520	8.87	34 040 000	7 538 310	18.13	46 821 000	8 781 830	15.79	25.22	74.78	14.16	85.84
	2010	9 764 000	1 595 000	14.04	40 660 000	7 483 000	15.54	50 424 000	9 078 000	15.26	19.09	80.91	17.57	82.43

Based on these numbers, the Baltic cod trawl fishery is responsible for the major part of cod discards in both parts of the Baltic Sea (Figure 2, Appendix-Figure 1).

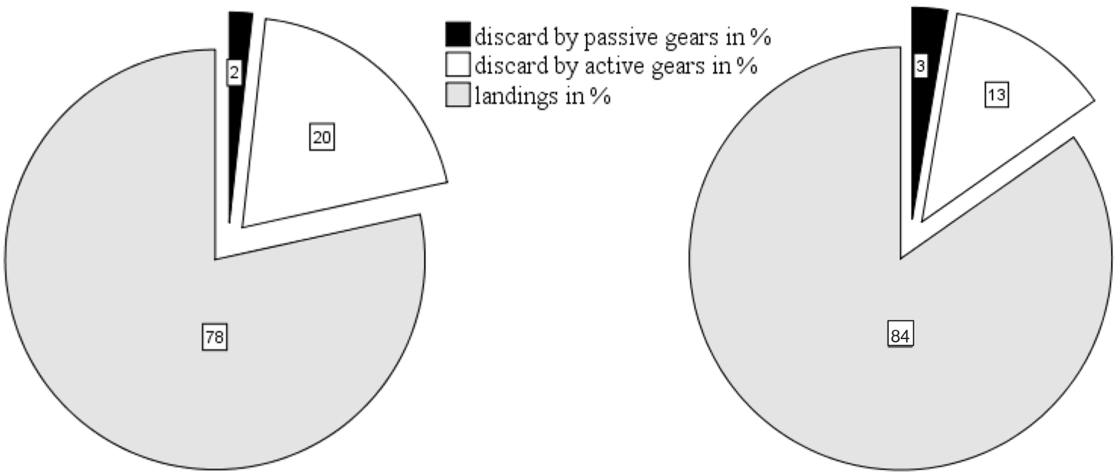

Figure 2: Discards 2010 in percent by number of individuals (left: ICES SD 22-24, right: 25-32)

During the past years, significant effort was spent to the reduction of discards in the Baltic Sea. Different technical measures were applied to the Baltic cod fishery, such as increase of MLS and several gear changes.

Nevertheless the discard-rates of the gears have to be reduced further, especially the relatively high discard rates caused by active gears - therefore, selectivity investigations are carried out to measure and improve the selectivity of different fishing gears.
For selectivity investigations of active fishing gears, different methods are used, e.g.:

- **covered codend:** test codend is covered by a small mesh cover codend (most common setup)
- **trouser-trawls:** one gear ends in two codends: test codend and control codend
- **alternate hauls:** one vessel uses at first the test codend and later the control codend
- **parallel hauls:** test codend and control codend are fished in parallel, either on one vessel (twin trawler) or on two vessels

In this study a modified covered codend was the method used (for details see chapter 2.1).
While comparing different codends, the conditions (e.g. area, trawl duration, speed of the vessel, catch weight, weather and season) should be as equal as possible.

One result of these investigations is the selection curve (Figure 3), describing the length depending retention rate of fish for a given selection device by a logit-curve:

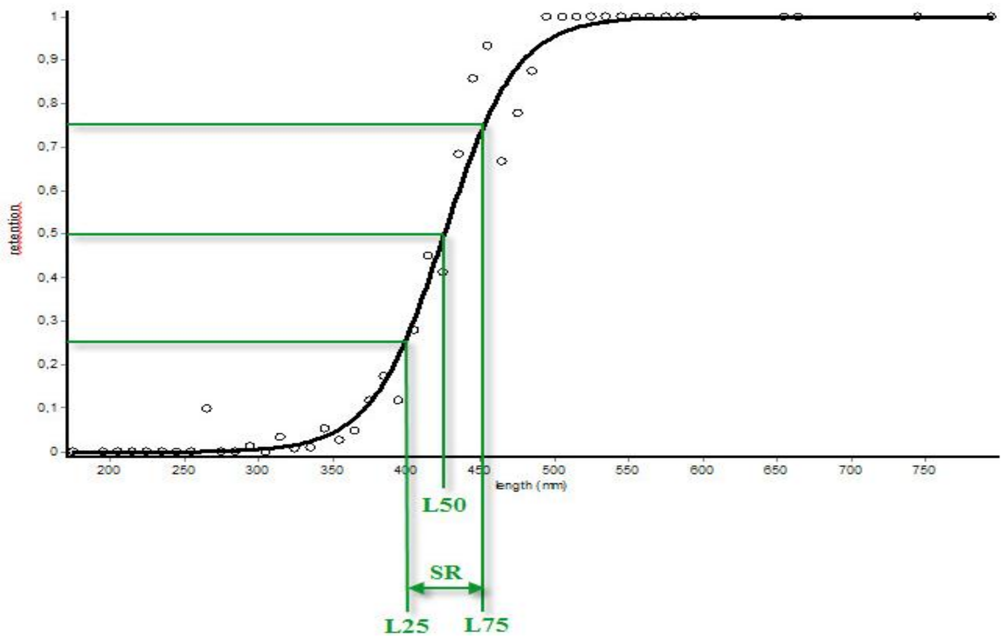

Figure 3: Example for a selection curve with indicated selectivity parameters L50 and SR (dots: raw data of retention rate per length class; black line: fitted selection curve)

Some parameters are often used to describe the selection curve: L50 and the selection range (SR). L50 defines the length of fish, where 50 % of the specimens are retained in the codend. The second parameter frequently used is the SR which is defined as the difference of L75 and L25 (definitions of L25 and L75 analog to L50). The smaller the range, the sharper is the selection of the tested fishing gear.

Since 1999, eight gear types were in use in the Baltic Sea cod trawl fishery. Their selectivity differs dramatically (Figure 4 and Figure 5) (Stepputtis *et al.*, 2010), whereas a major step of this development took place when T0 codends were banned. These T0 codends had rhombic meshes in normal orientation and no escape window, resulting in a poor selectivity. Today two codends are legal in the Baltic Sea: The BACOMA 120/105 mm with exit window and the T90 120 mm with meshes turned by 90°.

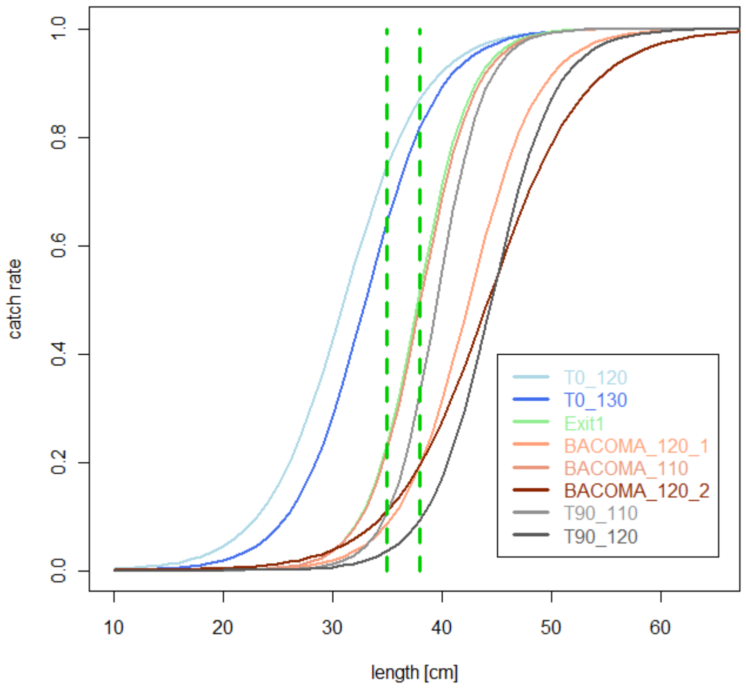

Figure 4: Selection curves of legalized codends for the Baltic cod trawl fishery. The numbers 110,120 or 130 state the nominal mesh opening in millimeters. Dashed green vertical lines represent MLS (1999-2002: 35 cm; 2003-2010: 38 cm) (Stepputtis *et al.*, 2010)

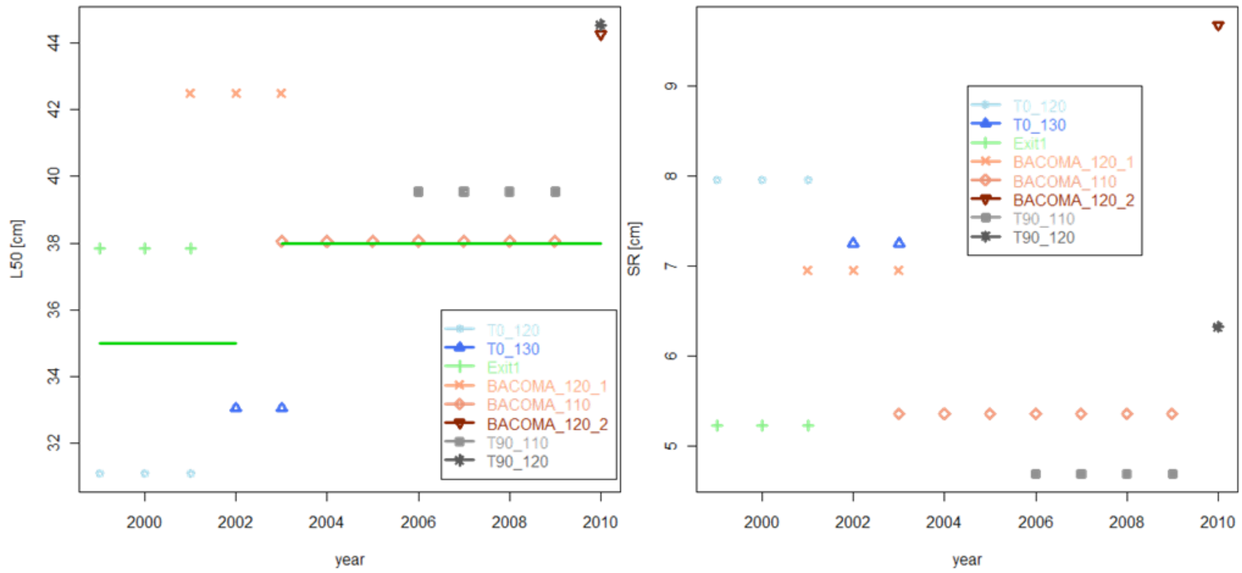

Figure 5: Selection parameter (L50 left, SR right) of legalized cod ends for the Baltic cod fishery; Left: Green line represents the corresponding minimum landing size. The numbers 110,120 or 130 state the nominal mesh opening in millimeters. (Stepputtis *et al.*, 2010)

The BACOMA 120/105 mm (Figure 6):

The name of the BACOMA 120/105 mm codend is the abbreviation for the project “Baltic Cod Management”, which operated between 1997 and 2000 and developed this type of codend (Suuronen *et al.*, 2007).

It has a nominal mesh opening of 105 mm and the meshes are rhombic (in T0-configuration). Its characteristic is an escape window with quadratic meshes (mesh opening: 120 mm) of knotless material. It is located in the upper panel, since it is assumed that most round fish often try to escape upwards.

From August 2003 to January 2006, the BACOMA 120/105 mm codend was the only legal codend used in the Baltic demersal trawl fishery. In 2006, the mesh opening of the escape window was reduced from 120 mm to 110 mm. In 2010, it was raised back to 120 mm.

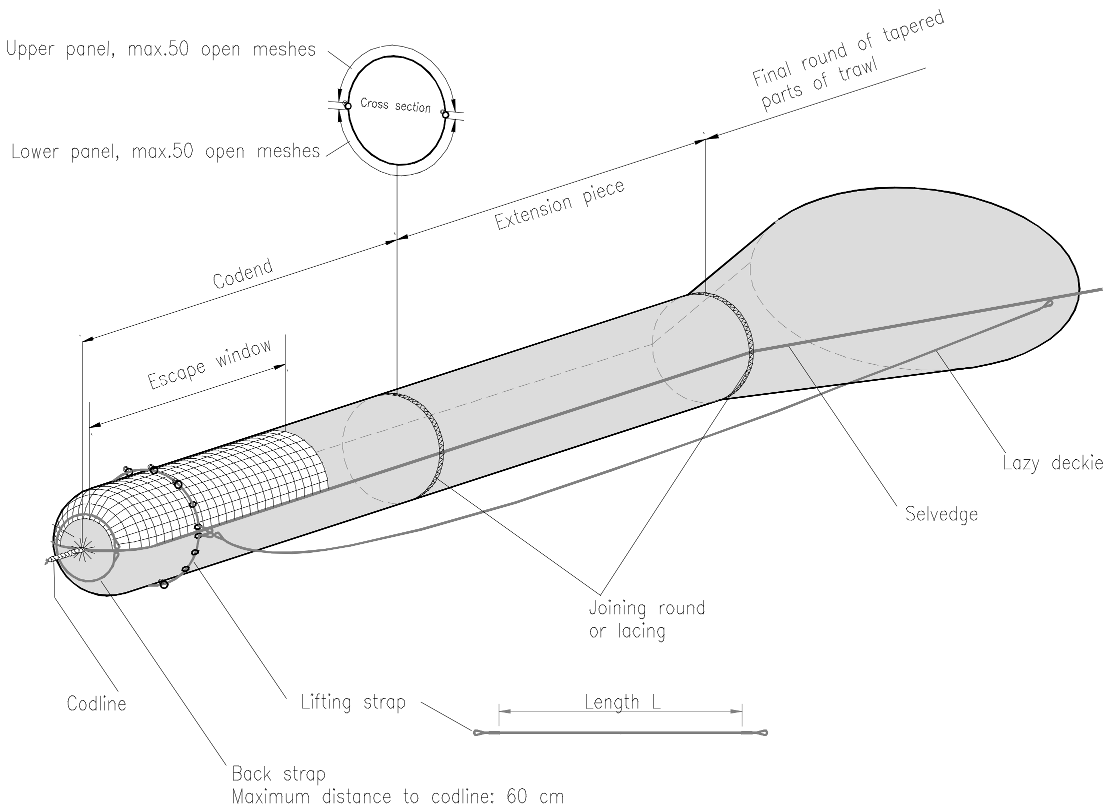

Figure 6: Schematic drawing of a BACOMA codend (drawing by W. Rehme/vTI-OSF)

<u>T90 120 mm (Figure 7):</u>

In 2006, the T90 110 mm codend, was introduced. It is constructed of normal netting material turned by 90° without exit window, by what its construction is cheaper. Today a nominal mesh opening of 120 mm is legal. An exit window or the like does not exist.

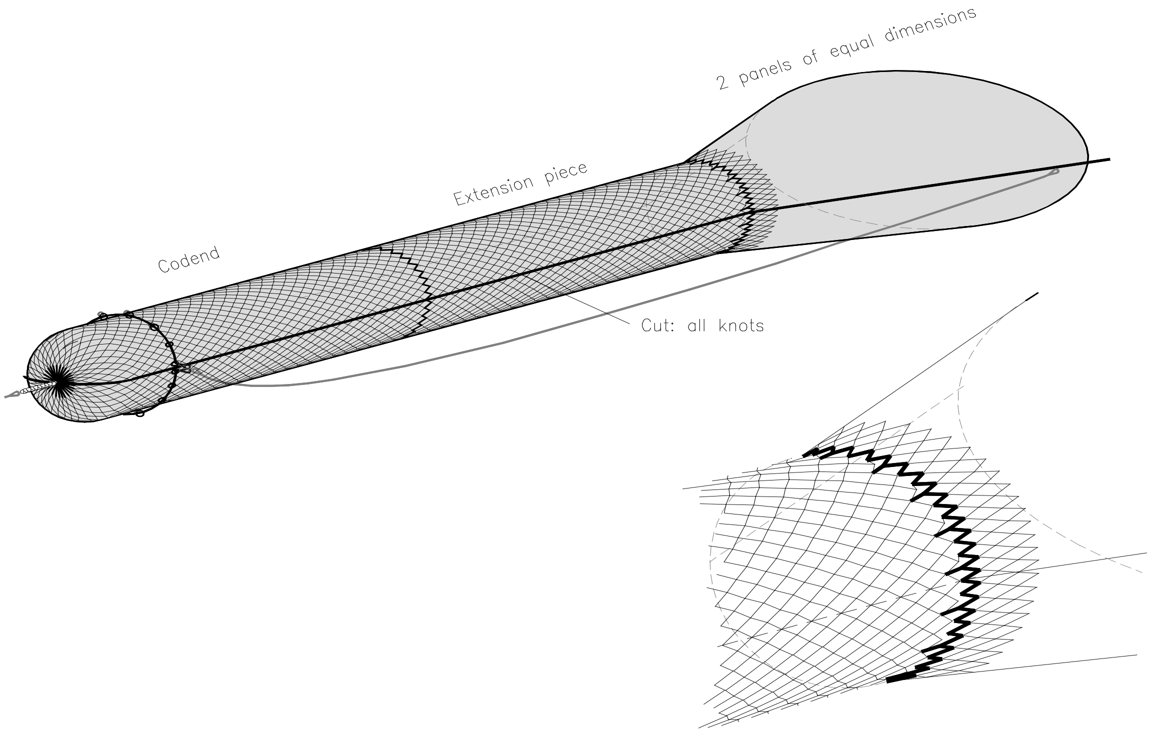

Figure 7: Schematic drawing of the T90 codend (drawing by W. Rehme/vTI-OSF)

The discard definitions as used above, only reference the part of the catch which is lost after bringing on deck. But other losses or injuries may occur during the fishing operation.

Potential reasons are net contact or violent pressure in the codend, what can lead for instance to loss of scales (weak point for parasites).

Another major stressor is related to the heaving process, when the net is heaved to the surface – the barotrauma.

There are two forces influencing the buoyancy of fish, the vertically downward directed force of gravity and the contrary acting hydrostatic lift force. Both forces have to be balanced to maintain a neutral buoyancy, which allows the fish to "hover" in one depth without using energy for moving their fins (Stengel and Fridmann, 1977). Therefore, many fish have a gas bladder filled with different gases, such as oxygen, nitrogen and carbon dioxide. The volume of the swim bladder can be adjusted to adapt the specific weight of the fish to the specific weight of the water.

Several species e.g. herring (*Clupea harengus*)) are able to reduce the amount of the gases fast, because they have a connection to their gut - the pneumatic duct (*ductus pneumaticus*). In this way they can release the gases fast. They are called physostomes.

Fish of the second group are called physoclists, e.g. cod. These fish are not able to adjust their swim bladder as fast as the physostomes. They do not regulate it by the pneumatic duct, but by exchange with the blood, a time-consuming process.

Other types of fish even do not have a gas bladder, because they live on the sea floor; so they do not need one, e.g. flounder (*Platichthys flesus L.*) or plaice (*Pleuronectes platessa L.*).

When the fish in the gear are pulled up, the gas volume in the swim bladder increases because the gas decompresses due to the decreasing pressure (1 bar per 10m). Physically, this occurrence is described by the Boyle-Mariotte law. Since some fish, especially physoclists, cannot adjust their gas bladder as fast as necessary, this decompression may leads to a damage of the internal organs.

International studies by Norwegian, Scottish and Danish scientists within the Project SURVIVAL have shown that fish of the order *Gadiformes* which escape during towing have a higher chance to survive than fish escaping during heaving (Breen *et al.*, 2007).

These methods of investigating net selectivity, as mentioned above, normally focus on the selectivity of the entire fishing process, but they are not suitable to describe the timing of escapement.

For that reason, a modified covered codend method was used: The test codend was encased by two covers. In this way, caught fish can be divided into retained fish, fish escaped during towing and fish escaped during heaving (for details see chapter 2.1).

Aims and justification:

The main aim of this study is to investigate the point in time when the fish is escaping from the two legal codend types (BACOMA 120/105 mm and T90 120 mm). The timing of escapement significantly influences the survival probabilities of escaped fish and is therefore important for the comparison of the real selectivity of both codends. The investigation includes the timing of escapement and estimation of the selectivity parameters for the different phases of the fishing process.

These investigations will be conducted for cod (*Gadus morhua L.*) and the main bycatch species flounder (*Platichthys flesus L.*) and plaice (*Pleuronectes platessa L.*).

2. Material and Methods

2.1. The Equipment

This study uses the codends BACOMA 120/105 mm and T90 120 mm. These are the codends, which are legal in the Baltic Sea. Both are used with a codhopper-trawl. To collect the escaped fish during the different phases of the haul, a modified covered codend-method using a Dualsampler device was used (Madsen *et al.*, 2010). The mesh opening of the cover was 80 mm nominal.

<u>The Dualsampler:</u>

By help of the Dualsampler it was possible to separate the caught fish in three categories: “caught fish” (fish caught in the test codend), fish escaped during towing (caught in cover 1) and fish escaped during heaving (caught in cover 2).

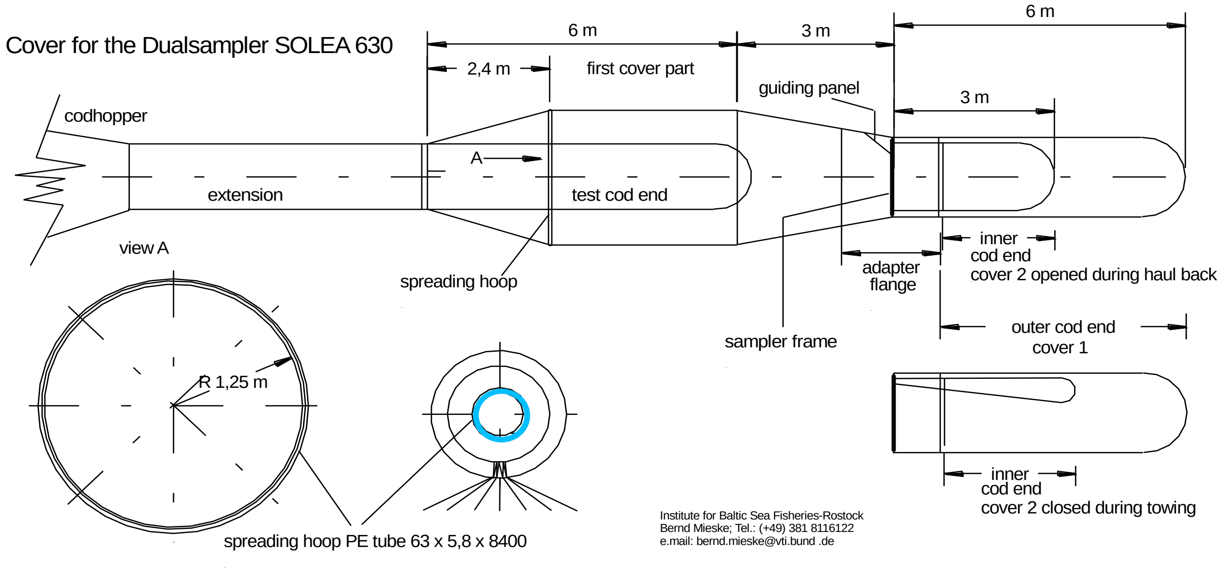

Figure 8: Side view of the used cover with Dualsampler (drawing by Mieske (vTI-OSF) after Madsen (2010))

The codend which should be tested is covered by the first cover-part (Figure 8). The cover is stabilized by an expanding hoop. Its first part is reduced backwards and ends at a sample frame with floating elements (to compensate the weight). This sample frame has a remotely controlled opening/closing-mechanism for the two covers.

At the beginning of the haul, a bar attached at the sample frame is in the upper position and cover one is open. Consequently the “escaping” individuals are collected in cover 1. This setting was used for the towing process. Prior to the haul-back of the trawl an acoustic signal is sent to the device. Consequently the bar switches to the lower position, whereby cover 1 becomes closed and cover 2 opened. Hence the fish, escaping at the process of hauling back, are guided into cover 2.

This Dualsampler is based on the Danish Minisampler (Madsen *et al.*, 2010). The frame (Figure 9), the covers and the special control system for the frame were constructed at the Institute of Baltic Sea Fisheries Rostock. Differences to the Minisampler are the size and weight of the bar as well as the tapered first cover part to minimize the resistance in the water and to ease the handling.

Figure 9: Sample frame with lifted bar (Photo by B. Mieske (vTI-OSF))

The opening/closing of the two cover codends with the Dualsampler was controlled by an acoustic releaser. The used releaser was an OCEAN NO 500 of IXSEA with controller TT701 and hydrophone PET 801P Nr.139, made available by the DTU (Technical University of Denmark). This releaser does not have a feedback mechanism to control the proper functioning of the device.

Therefore the frame, the mounting claw for the frame and the bar were equipped with Reed-contacts. Now it was possible to open the mounting claw and make the bar fall down by giving an acoustic signal from the vessel and to ascertain the position of the bar. To transmit these information to the vessel, a modified tensions-sensor of the SCANMAR Catch Control System was used.

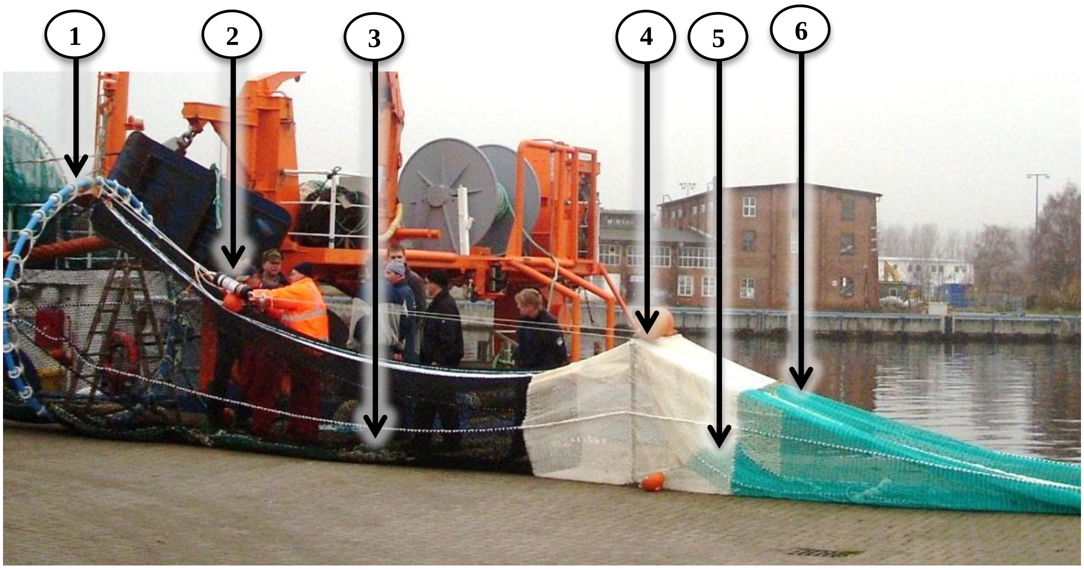

Figure 10: Setup of the Dualsampler with expanding hoop (1), acoustic releaser (2), test codend (3), Dualsampler frame (4), cover 1 (5), cover 2 (6)

2.2. Data Sampling

On the 21th of November 2010, the RV “Solea” (42.4 m LOA, 1780 kW, stern trawler) started its 630th cruise from Rostock with Bernd Mieske (vTI-OSF) as cruise leader.

At first the equipment, especially the releasing-mechanism, was tested off the coast of Warnemünde. These tests were performed with an open codend, whereby almost no fish was caught.

Afterwards the vessel was on the way to the Arkona-Sea in the northeast of Rügen (ICES SD 24), the research-area. The first and the second haul, performed with the BACOMA 120/105 mm, offered problems: at the first haul the second cover was clenched forward and at the second one the mechanism did not work. As the consequence both hauls will not be considered in later analyses – they are not valid.

Until the 26th of November, eight hauls were completed for the BACOMA 120/105 mm in total. Then the codend was changed to the T90 120 mm and 6 hauls were accomplished until the 29th of November 2010 (Figure 11). In total six valid hauls were conducted for each codend (Table 3).

The caught fish reached the deck of the vessel in three catch compartment: “test codend”, “cover 1” and “cover 2”. The species composition was determined for each of the catch compartments, whereby the weight of each species was recorded. Additionally, the length distribution for cod, flounder and plaice was measured on the cm below using a measure board (Figure 12). There was no subsampling. Length distribution data for plaice data for haul 14 were not recorded accurately; therefore this haul was not used for analysis regarding plaice.

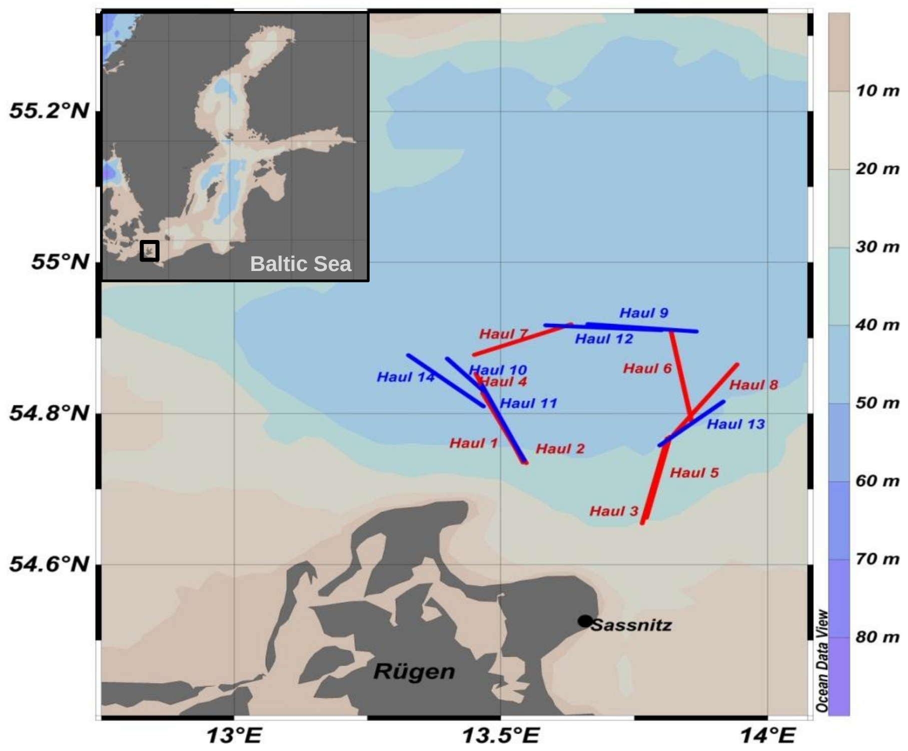

Figure 11: Tracks of the 630th cruise of the FV Solea (red: BACOMA 120/105 mm, blue: T90 120 mm) (created with OceanDataView (Schlitzer, 2011))

The catch data provide the basis for the following analyses, such as the comparison of the length distributions or the time of escapement. Furthermore, the retention rate of sized fish was treated. Sized fish are these fish, which reached the Minimum Landing Size (MLS). For cod the MLS is 38 cm and for plaice it is 25 cm in the entire Baltic Sea. For flounder the MLS differs in the particular Subdivisions: 23 cm (ICES SD22-25), 21 cm (ICES SD 26-28) and 18 cm (ICES SD 29-32). Since the study was conducted in ICES SD24, every flounder below 23 cm was considered as undersized.

Figure 12: Hook-nose (*Agonus cataphractus*) on a measure board

As already mentioned in chapter 1, the SR- and the L50-value are important and often used parameters to describe the selectivity of a codend. For calculating theses parameters, the software SELNET, developed by Bent Herrmann (DTU Aqua), was used. This software is able to use many different statistical models and it was designed for analyses like this.

Based on the experiment design, three models can be applied: a) logit_product model, b) logit_dualseq model (Sistiaga *et al.*, 2010) and c) logit_dualredseq model. Compared with the logit_product model, the logit_dualseq model involves an additional factor: C_{tow}. This factor, called contact factor, describes the percentage of fish, which try to escape during towing. Because some fish, especially cod, do not notice the danger, they swim with the trawl. Even at haul-back the conditions are changing and every fish becomes active and wants to leave the net.

The logit_product model can be considered as a special case of the logit_dualseq-model because the contact factor is one.

Further, SELNET is able to determine the SR- and L50-value for the different phases of the fishing process: towing, heaving and both phases.

All models were tested and the model with best statistic power (p-value, AIC-value) was used. To emulate the variability in selectivity data, bootstrapping was conducted with 10,000 repetitions (Millar and Fryer, 1999).

For more details about SELNET, see Sistiaga et al. (2010).

Furthermore, these analyses were conducted with the assumption, that the fate of every fish is independent of each other and all cod below 33 cm were excluded to avoid potential bias due to an overlap of cover and test codend selection (Wienbeck *et al.*, 2011).
The mesh openings were determined with the OMEGA gauge and compared with the nominal values. The measured values are within a reasonable range. Solely the measured values of the posterior cover-part are much smaller than the nominal value, but this does not influence the investigations in a strong way (Table 2, Appendix-Table 4).

Table 2: Mesh openings of BACOMA and T90 measured with the OMEGA gauge

Part of the gear	**Mesh opening nominal [mm]**	**Measured mesh opening [mm]**	**Standard deviation**
Main part BACOMA	105	104.5	1.85
BACOMA window	120	125.7	0.95
Codend T90	120	124.1	1.32
Cover anterior part	80	76.2	1.48
Cover posterior part	80	73.2	1.40

3. Results

3.1. Catch composition and length distribution

In total 18544.03 kg of fish were caught during the sea trials, whereof 8375.37 kg were cod. The total catch weight of flounder (5234.11 kg) is much higher than the weight of plaice (603.37 kg) although the number of caught individuals does not differ with the same relation (Table 3, Appendix-Table 1). The reason for that is the different average length of both species (Figure 13, Figure 15).

Table 3: Total catch of Cod, Flounder and Plaice of the cruise SO630

Date	Haul	Codend	Validity	Weight [kg]			
				Cod	Flounder	Plaice	Total
22.11.10	1	BACOMA	no	253.15	135.26	14.17	**402.58**
22.11.10	2	BACOMA	no	823.36	399.36	45.53	**1268.25**
23.11.10	3	BACOMA	yes	412.97	381.29	72.22	**866.48**
24.11.10	4	BACOMA	yes	542.35	168.76	28.87	**739.98**
25.11.10	5	BACOMA	yes	262.28	473.94	63.52	**799.74**
25.11.10	6	BACOMA	yes	1200.44	1206.44	53.78	**2460.66**
25.11.10	7	BACOMA	yes	1171.10	1178.10	67.62	**2416.82**
26.11.10	8	BACOMA	yes	583.55	527.06	41.82	**1152.42**
26.11.10	9	T90	yes	560.40	169.08	67.58	**797.06**
26.11.10	10	T90	yes	359.67	214.99	38.12	**612.78**
27.11.10	11	T90	yes	691.91	172.55	41.82	**906.28**
27.11.10	12	T90	yes	656.49	79.07	40.24	**775.80**
27.11.10	13	T90	yes	524.40	68.66	13.04	**606.10**
28.11.10	14	T90	yes	333.30	59.56	15.05	**407.91**
All Days	**Average**	**BACOMA**	**yes**	**695.95**	**655.93**	**54.64**	**1406.02**
All Days	**Average**	**T90**	**yes**	**521.03**	**127.32**	**35.98**	**684.32**
All Days	**Total**	**-**	**12/14**	**8375.37**	**5234.11**	**603.37**	**14212.86**

The results of the total length distribution, separated into the different gear types, catch compartments and species are very similar for both codends (Figure 13-Figure 16).

For cod a range from 13 to 82 cm is covered and there is a peak at about 31 cm.

The smallest flounder, which was caught during all trials, had a length of 15 cm, while the biggest one was 46 cm long. A peak is to find at 28 to 29 cm.

The range of plaice reaches from 14 to 47 cm, what is similar to flounder, but there are two peaks: a larger one at 17 to 20 cm and a smaller one at about 27 cm.

Regarding the catch- and escapement-pattern of cod, only a little part of the catch would be retained, but the bigger part can escape. Most of them leave the codend already during towing (cover 1). Also around the MLS, many specimens can escape. Both codends are similar (Figure 13, Figure 15).

In contrast to cod, more undersized flatfish (flounder and plaice) were caught in the test codend (Table 14, Table 16). Considering flounder, the major part of the total catch is retained in the test codend, but approximately one third of all undersized flounders appertains to the part in the test codend.

The escapees of plaice were also found most in cover 1, i.e. they can flee during towing (Table 14, Table 16).

To enforce the hypothesis of "escapement during towing", more precise analyses will be done in chapter 3.2 by considering the absolute and relative values.

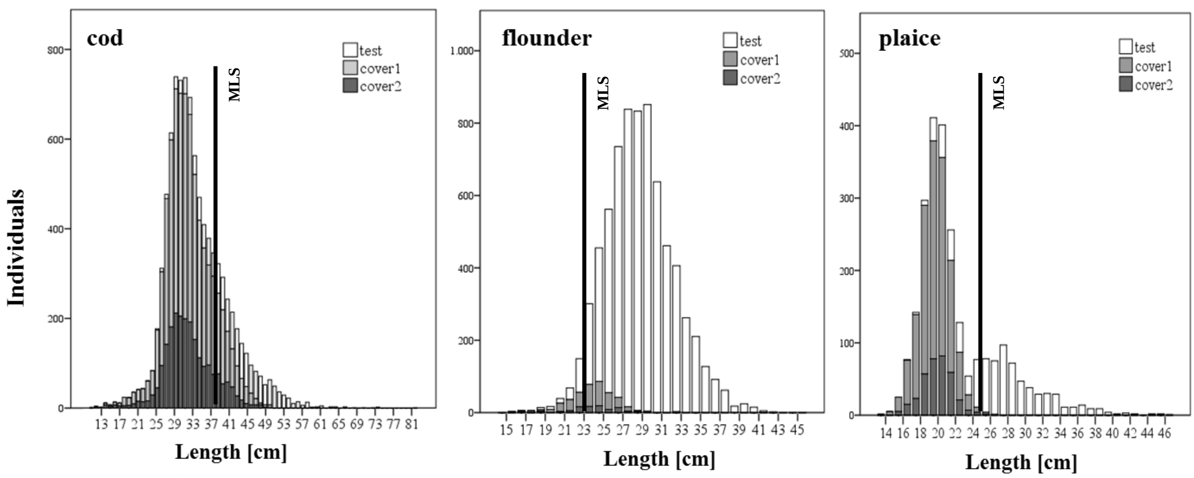

Figure 13: Length distribution in BACOMA 120/105 mm codend for haul 1-8 of cruise SO630

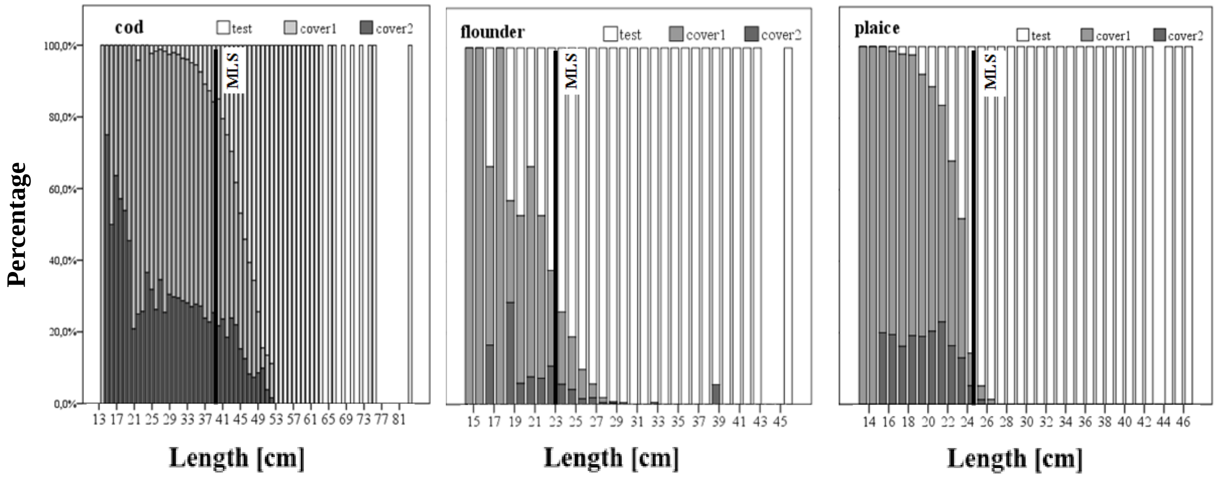

Figure 14: Percental length distribution in BACOMA 120/105 mm codend for haul 1-8 of cruise SO630

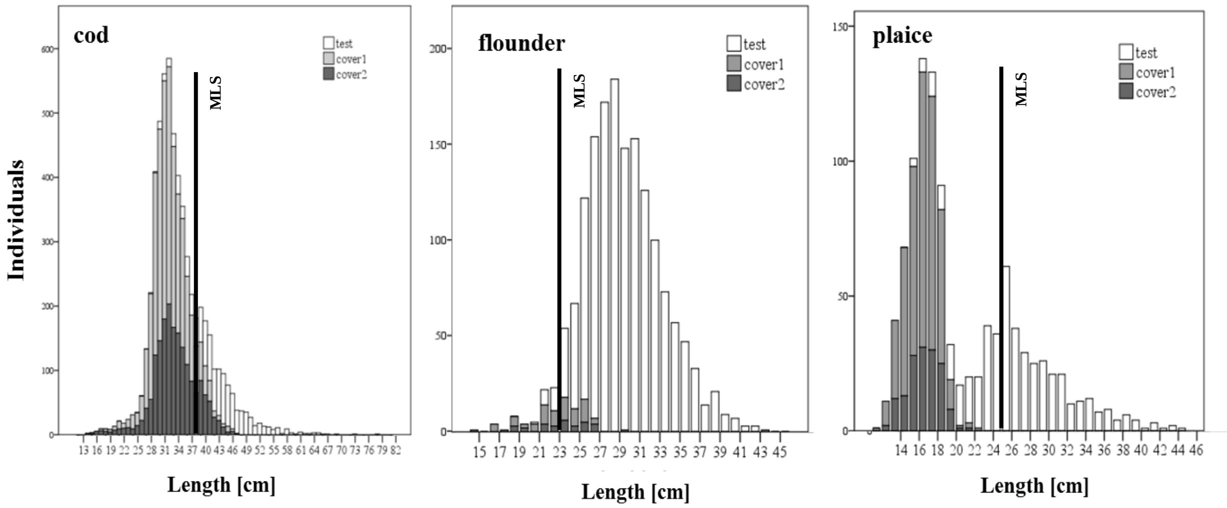

Figure 15: Length distribution in T90 120 mm codend for haul 9-14 of cruise SO630

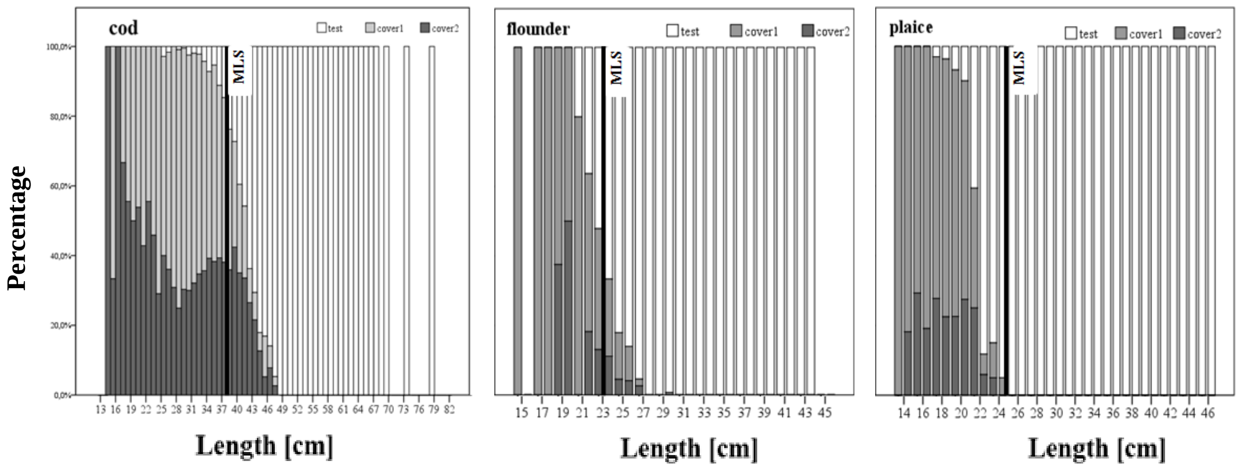

Figure 16: Percental length distribution in T90 120 mm codend for haul 9-14 of cruise SO630

3.2. Temporal pattern of escapement

The chief aim of this work is to figure out, when the fish escape. Since it is assumed that the escapement pattern for the three species cod, flounder and plaice differ, these species will be treated separately.

Considering cod, 6648 individuals or 85.7 % of the catch escaped from the BACOMA 120/105 mm codend. 68.1 % of these escapees escaped during towing and 31.9 % during heaving (Table 4).

From the T90 120 mm codend 5123 individuals or 83.8 % of the total catch escaped (64.1 % during towing and 35.9 % during heaving) (Table 5).

Table 4: Distribution of cod in the different catch compartments of the BACOMA 120/105 mm-trials

Haul	Validity	Test	Cover 1 (towing)	Cover 2 (heaving)	TOTAL
1	no	140	294	0	**434**
2	no	213	1099	150	**1462**
3	yes	73	542	72	**687**
4	yes	231	358	215	**804**
5	yes	85	149	140	**374**
6	yes	174	1518	615	**2307**
7	yes	302	1307	764	**2373**
8	yes	223	588	280	**1091**
Total	**-**	**1088**	**4462**	**2086**	**7636**
% Total	**-**	**14.3**	**58.4**	**27.3**	**100.0**
% of total escapees	**-**	**-**	**68.1**	**31.9**	**100.0**

Table 5: Distribution of cod in the different catch compartments of the T90 120 mm-trials

Haul	Validity	Test	Cover 1 (towing)	Cover 2 (heaving)	TOTAL
9	yes	168	865	225	**1258**
10	yes	171	242	248	**661**
11	yes	256	421	543	**1220**
12	yes	141	986	242	**1369**
13	yes	153	407	420	**980**
14	yes	101	361	163	**625**
Total	**-**	**990**	**3282**	**1841**	**6113**
% Total	**-**	**16.2**	**53.7**	**30.1**	**100.0**
% of total escapees	**-**	**-**	**64.1**	**35.9**	**100.0**

To support the visual similarity in catch distribution of cod in both codends (Figure 17), a t-test was conducted for the following average values:

a) test codend BACOMA 120/105 mm – test codend T90 120 mm (p-value: 0.984)

b) cover 1 BACOMA 120/105 mm – cover 1 T90 120 mm (p-value: 0.627)

c) cover 2 BACOMA 120/105 mm – cover 2 T90 120 mm (p-value: 0.480)

According to the p-values, it becomes obvious that there are no significant differences between the catch distributions of the BACOMA 120/105 mm and the T90 120mm.

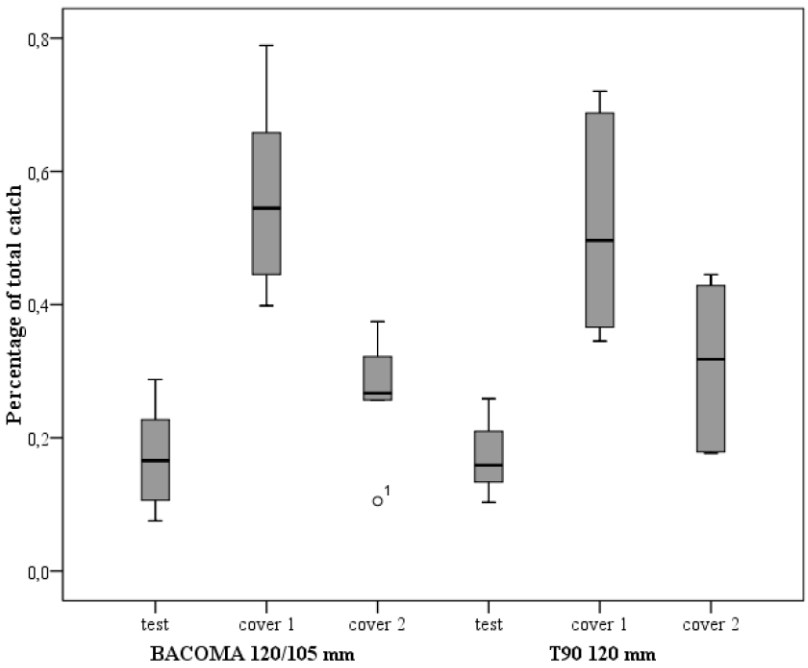

Figure 17: Box-Whisker-Plot: comparison of catch distribution for cod in BACOMA 120/105 mm and T90 120mm (shown is mean (line in the box); 25th and 75th percentile (upper and lower margin of the box), highest and lowest value ("whiskers"), outliner (dots))

In comparison to cod, the catch numbers of flounder are quite low, whereby the escapement pattern is also similar for both codends. From the BACOMA 120/105 mm totally 331 out of 5684 individuals were able to escape (5.8 %), at what 70.4 % escaped during towing and 29.6 % during heaving (Table 6). From the T90 120mm, 70.6 % escaped during towing and 29.4 % during heaving. Totally 102 individuals or 5.1 % of the total catch escaped (Table 7).

Furthermore, it is obvious that the distribution of escapees is quite similar to cod.

Table 6: Distribution of flounder in the different catch compartments of the BACOMA 120/105 mm-trials

Haul	Validity	Test	Cover 1 (towing)	Cover 2 (heaving)	TOTAL
1	no	365	19	0	**384**
2	no	1055	88	0	**1143**
3	yes	1136	100	5	**1241**
4	yes	432	22	17	**471**
5	yes	1329	87	57	**1473**
6	yes	714	11	7	**732**
7	yes	394	2	5	**401**
8	yes	1348	11	7	**1366**
Total	**-**	**5353**	**233**	**98**	**5684**
% Total	**-**	**94.2**	**4.1**	**1.7**	**100.0**
% of total escapees	**-**	**-**	**70.4**	**29.6**	**100.0**

Table 7: Distribution of flounder in the different catch compartments of the T90 120 mm-trials

Haul	Validity	Test	Cover 1 (towing)	Cover 2 (heaving)	TOTAL
9	yes	380	3	1	384
10	yes	515	5	1	521
11	yes	445	57	19	521
12	yes	198	3	3	204
13	yes	178	2	4	184
14	yes	178	2	2	182
Total	**-**	**1894**	**72**	**30**	**1996**
% Total	**-**	**94.9**	**3.6**	**1.5**	**100.0**
% of total escapees	**-**	**-**	**70.6**	**29.4**	**-**

The lowest catch numbers were recorded for plaice. In the BACOMA 120/105 mm codend 66.1 % of the total catch (1358 individuals) escaped, 74.1 % during heaving and 25.9 % during towing (Table 8). In the T90 120 mm only 56.1 % escaped (583 individuals) (Table 9). The relative values of “towing-escapees” and “heaving-escapees” are exactly the same in both codends: 74.1 % of the fish escaped during towing and 25.9 % during heaving.

Table 8: Distribution for plaice in the different catch compartments of the BACOMA 120/105 mm-trials

Haul	Validity	Test	Cover 1 (towing)	Cover 2 (heaving)	TOTAL
1	no	37	28	0	**65**
2	no	91	230	0	**321**
3	yes	107	477	20	**604**
4	yes	61	69	28	**158**
5	yes	108	265	176	**549**
6	yes	137	78	42	**257**
7	yes	186	31	23	**240**
8	yes	96	86	63	**245**
Total	**-**	**695**	**1006**	**352**	**2,053**
% Total	**-**	**33.9**	**49.0**	**17.1**	**100.0**
% of total escapees	**-**	**-**	**74.1**	**25.9**	**-**

Table 9: Distribution for plaice in the different catch compartments of the T90 120 mm-trials

Haul	Validity	Test	Cover 1 (towing)	Cover 2 (heaving)	TOTAL
9	yes	176	41	15	232
10	yes	89	52	12	153
11	yes	61	267	96	424
12	yes	102	38	7	147
13	yes	28	34	21	83
14	no	-	-	-	-
Total	**-**	**456**	**432**	**151**	**1039**
% Total	**-**	**43.9**	**41.6**	**14.5**	**100.0**
% of total escapees	**-**	**-**	**74.1**	**25.9**	**-**

3.3. Comparison of sized and undersized fish

In the BACOMA 120/105 mm, 18 % of the retained fish were undersized and in the T90 120 mm 14.2 % were undersized (Table 10). That result means in effect a lower discard-rate for the T90 120 mm.

Only 14.2 % (BACOMA 120/105 mm) respectively 16.2 % (T90 120 mm) of all cod, which encountered the gear, would be caught (Table 11).

Regarding sized cod, 56.3 % (BACOMA 120/105 mm) or 49.6 % (T90 120 mm) were able to escape despite their size (Table 11).

Undersized fish can escape in almost every case: Only 3.6 % of undersized fish were retained in the BACOMA 120/105 mm, in the T90 120 mm even 3.2 % (Table 11).

Table 10: Total number of sized or undersized cod in test codend

codend	**BACOMA 120/105 mm**			**T90 120 mm**		
size	**<38 cm**	**>38 cm**	**total**	**<38 cm**	**>38 cm**	**total**
number of individuals	199	889	1088	141	849	990
%	18.0	82.0	100.0	14.2	85.8	100.0

Table 11: Flight pattern of cod from BACOMA 120/105 mm and T90 120 mm

	BACOMA 120/105 mm			**T90 120 mm**		
	caught	**escaped**	**total**	**caught**	**escaped**	**total**
all lenghts	1088	6548	7636	990	5123	6113
	14.2 %	85.8 %	100.0 %	16.2 %	83.8 %	100.0 %
≥ 38 cm	889	1145	2034	849	835	1684
	43.7 %	56.3 %	100.0 %	50.4 %	49.6 %	100.0 %
< 38 cm	199	5403	5602	141	4288	4429
	3.5 %	96.5 %	100.0 %	3.2 %	96.8 %	100.0 %

Considering flounder, only 0.5 % of the fish caught with the T90 120 mm and 0.8 % caught with the BACOMA 120/105 mm were undersized (Table 12).

Both codends retained almost every fish (BACOMA 120/105 mm: 94.2 %, T90 120 mm: 94.9 %) (Table 13).

Thereby 4.6 % (BACOMA 120/105 mm) or 3.4% (T90 120 mm) of sized fish escaped (Table 13).

The values for undersized flounders are quite high: The T90 120 mm retained 20.0 % of them, the BACOMA 120/105 mm even 37.8 % (Table 13).

Table 12: Total number of sized or undersized flounder in test codend

codend	BACOMA 120/105 mm			T90 120 mm		
size	**<23 cm**	**>23 cm**	**total**	**<23 cm**	**>23 cm**	**total**
number of individuals	45	5308	5353	9	1885	1894
%	0.8	99.2	100.0	0.5	99.5	100.0

Table 13: Flight pattern of flounder from BACOMA 120/105 mm and T90 120 mm

	BACOMA 120/105 mm			T90 120 mm		
	caught	**escaped**	**total**	**caught**	**escaped**	**total**
all lenghts	5353 94.2 %	331 5.8 %	5684 100.0 %	1894 94.9 %	102 5.1 %	1996 100.0 %
≥ 23 cm	5308 95.4 %	257 4.6 %	5565 100.0 %	1885 96.6 %	66 3.4 %	1951 100.0 %
< 23 cm	45 37.8 %	74 62.2 %	119 100.0 %	9 20.0 %	36 80.0 %	45 100.0.0 %

The BACOMA 120/105 mm (84.4 %) contained more undersized plaices than the T90 120 mm (76.4 %) (Table 14).

In total the number of escaped plaices is higher than the number of escaped flounders. The T90 120 mm retained 43.9 % of all plaices, the BACOMA 120/105 mm only 33.9 %. One reason could be the different position of the length distribution curves of both species (Figure 13-Figure 16).

Only 1.7 % of sized plaice escaped from the BACOMA 120/105 mm, from the T90 120mm even 1.0 %.

Undersized plaices had a good chance to escape from both codends: 89.2 % escaped from the BACOMA 120/105 mm, 89.1 % from the T90 120 mm.

Table 14: Total number of sized or undersized plaice in test codend

codend	**BACOMA 120/105 mm**			**T90 120 mm**		
size	**<25 cm**	**>25 cm**	**total**	**<25 cm**	**>25 cm**	**total**
number of individuals	164	531	695	71	385	456
%	23.6	76.4	100.0	15.6	84.4	100.0

Table 15: Flight pattern of plaice from BACOMA 120/105 mm and T90 120 mm

	BACOMA 120/105 mm			**T90 120 mm**		
	caught	**escaped**	**total**	**caught**	**escaped**	**total**
all lenghts	695	1358	2053	456	583	1039
	33.9 %	66.1 %	100.0 %	43.9 %	56.1 %	100.0 %
≥ 25 cm	531	9	540	385	4	389
	98.3 %	1.7 %	100.0 %	99.0 %	1,0 %	100.0 %
< 25 cm	164	1349	1513	71	579	650
	10.8 %	89.2 %	100.0 %	10.9 %	89.1%	100.0

3.4. Selection curves and selection parameters

For creating the selection curves and estimating the selection parameters it is necessary, to decide for one of the statistic models. This study uses in almost every case the logit_dualseq model. Only for the plaice data of the BACOMA 120/105 mm hauls, the logit_dualredseq model was used. The decision criterion was the p-value (Table 16).

Cod:

The selection curve (Figure 18), which results from the catch data of cod, shows a smaller SR for the T90 120 mm, i.e. a steeper curve. The L50 of the BACOMA 120/105 mm is higher.

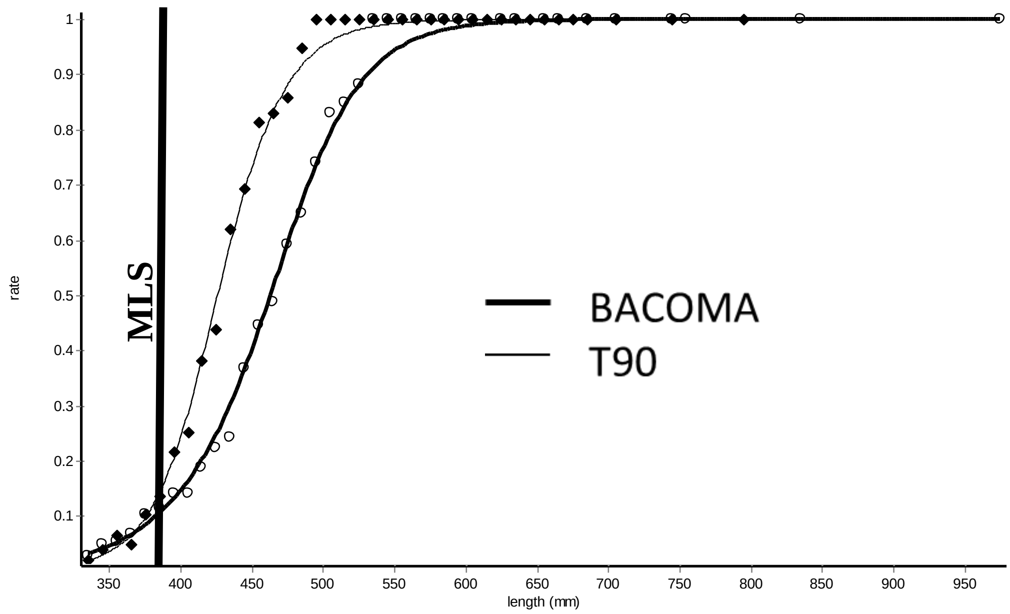

Figure 18: Retention rate of test codend (cod-pooled hauls of cruise SO630; logit_dualseq model)

Considering the curves for both covers, it becomes clear that more than 60 % of the fish at MLS can escape from the BACOMA 120/105 mm while towing. This value decreases during heaving to about 27 %. From the T90 less than 50 % of fish at MLS can escape, but during heaving it decreases to a peak of approximately 35 % (Figure 19, Figure 20).

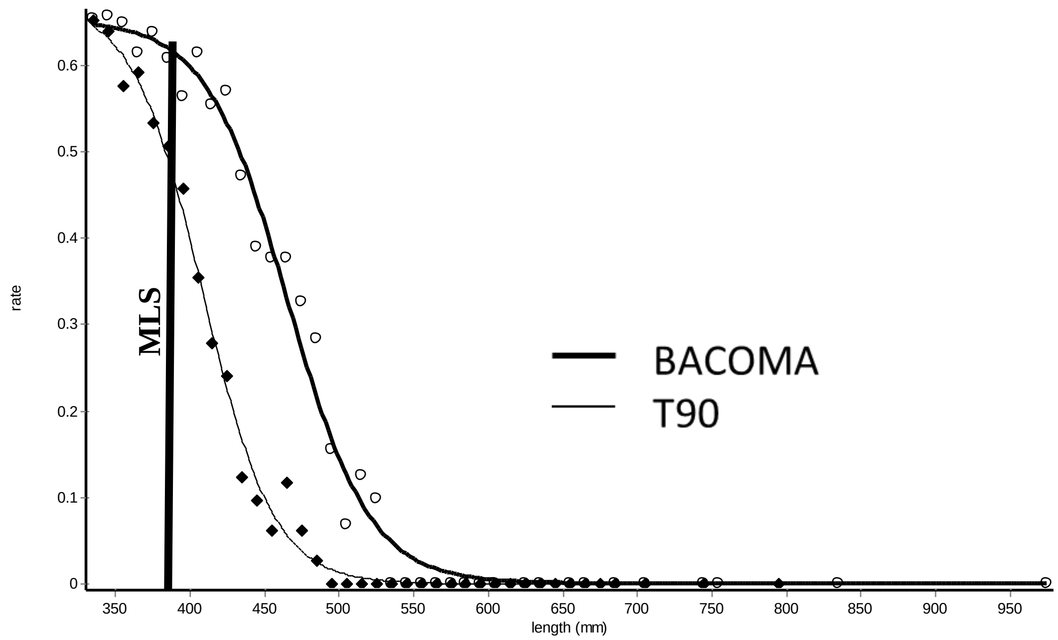

Figure 19: Escapement rate of cover 1 (cod- pooled hauls of cruise SO630; logit_dualseq model)

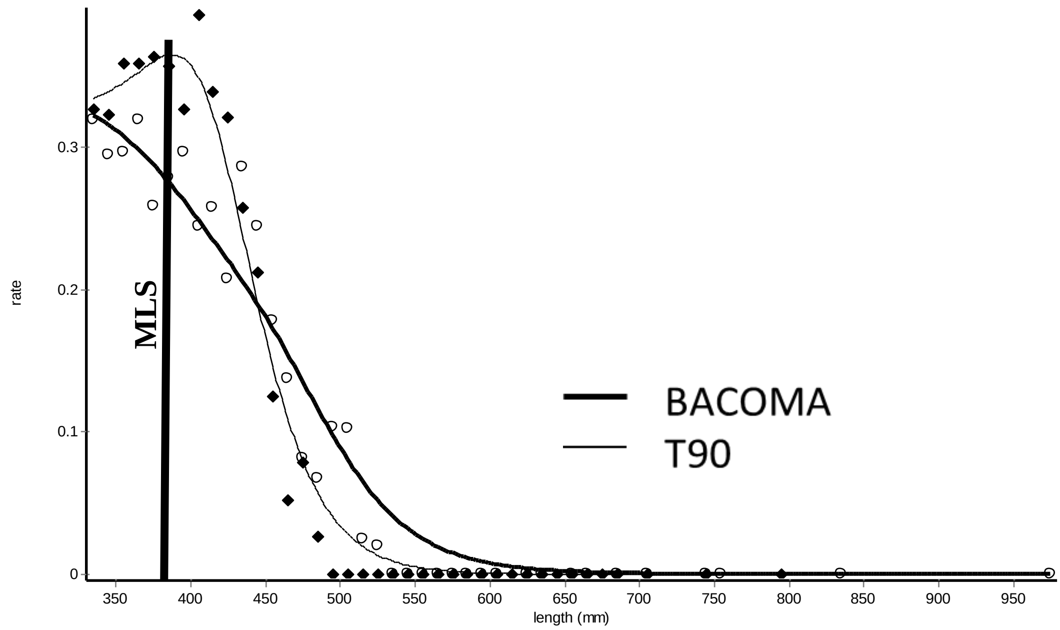

Figure 20: Escapement rate of cover 2 (cod- pooled hauls of cruise SO630; logit_dualseq model)

Flounder:

Resulting from the data for flounder, the T90 120 mm shows a steeper curve than the BACOMA 120/105 mm does, i.e. the SR of the T90 120 mm is smaller. Furthermore, its L50 is higher (Figure 21).

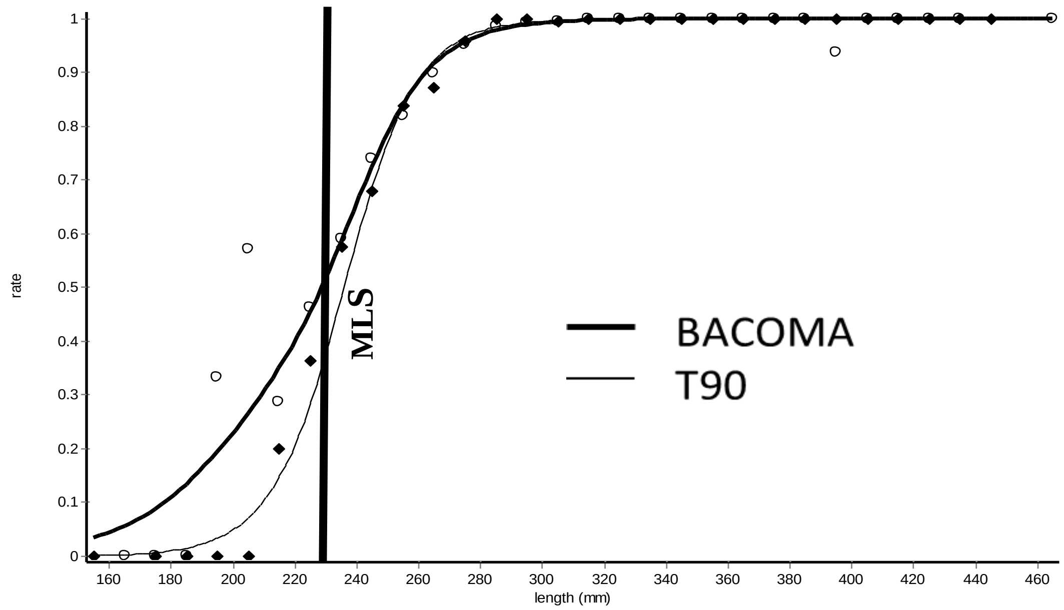

Figure 21: Retention rate of test codend (flounder- pooled hauls of cruise SO630; logit_dualseq model)

Separated into the different phases towing and heaving, from the T90 120 mm more undersized specimen can escape while towing than from the BACOMA. The chance to escape while heaving decreases for both codends: for BACOMA from about 40 % to 11 % at 23 cm and for the T90 from about 45 % to 18 % (Figure 22, Figure 23).

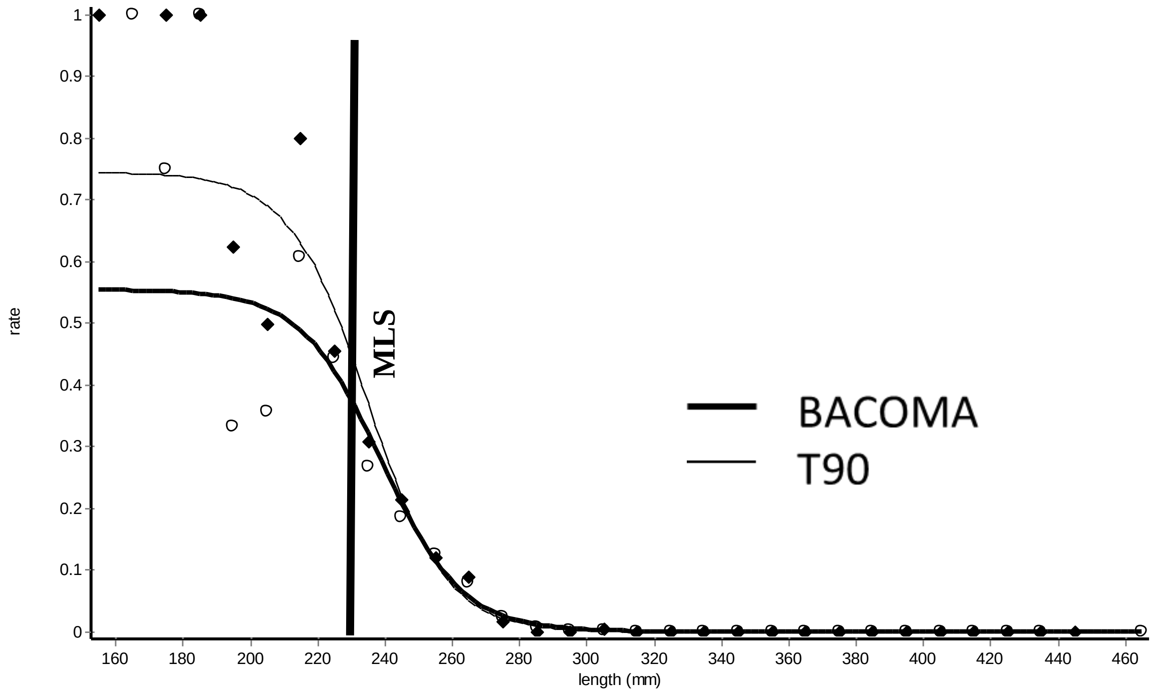

Figure 22: Escapement rate of cover 1 (flounder- pooled hauls of cruise SO630; logit_dualseq model)

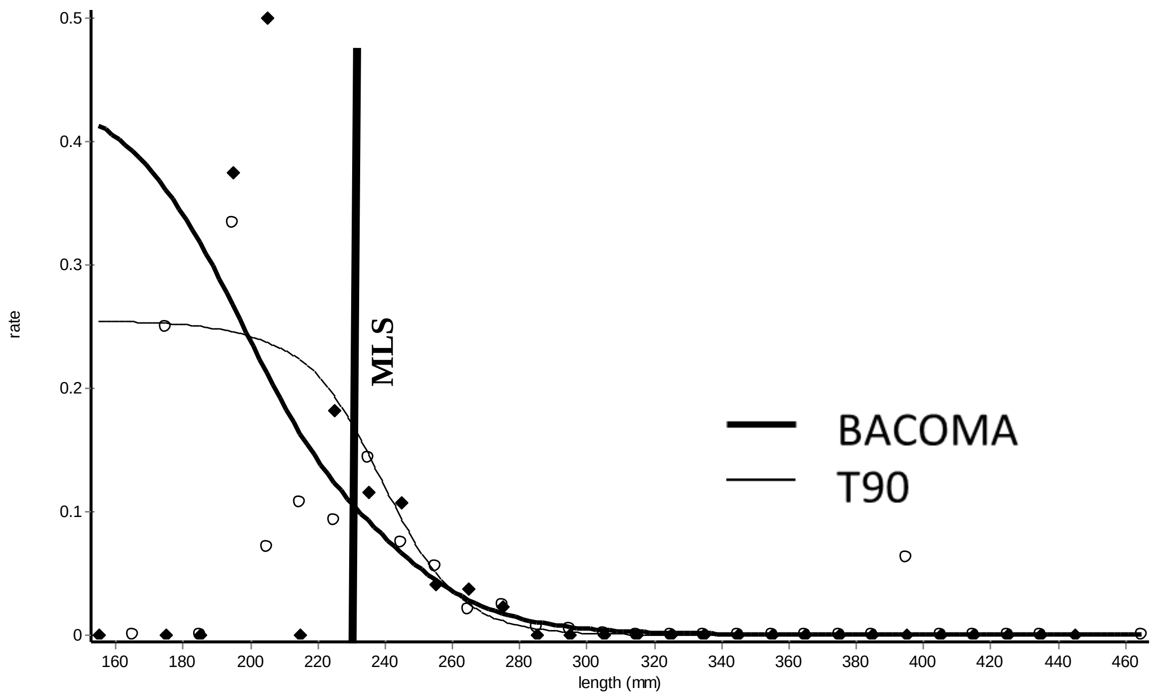

Figure 23: Escapement rate of cover 2 (flounder- pooled hauls of cruise SO630; logit_dualseq model)

Plaice:

The resulting selection- and retention curves for plaice look similar for both tested codends. BACOMA 120/105 mm and T90 120 mm have a L50 at a length of approximately 24 cm. The SR and the resulting slope of the curve is nearly the same in both codends (Figure 24).

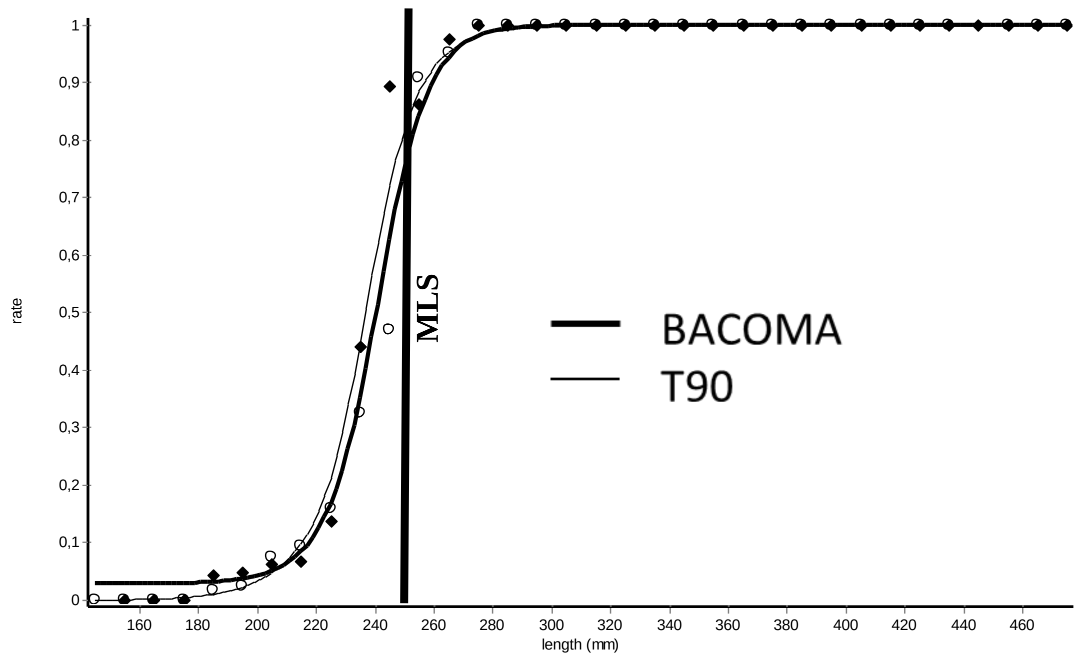

Figure 24: Retention rate of test codend (plaice- pooled hauls of cruise SO630; BACOMA: logit_dualredseq model; T90: logit_dualseq model)

In both phases, towing and heaving, fish at the MLS have a chance of about 11 % to escape from both codends (Figure 25, Figure 26).

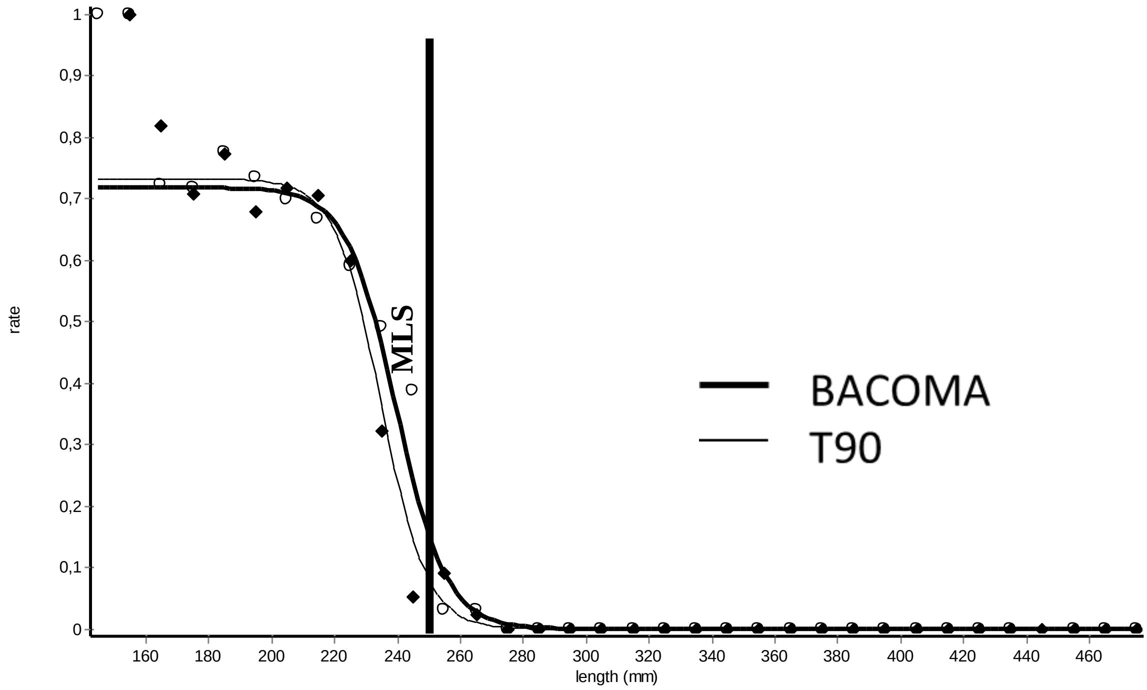

Figure 25: Escapement rate of cover 1 (plaice- pooled hauls of cruise SO630; BACOMA: logit_dualredseq model; T90: logit_dualseq model)

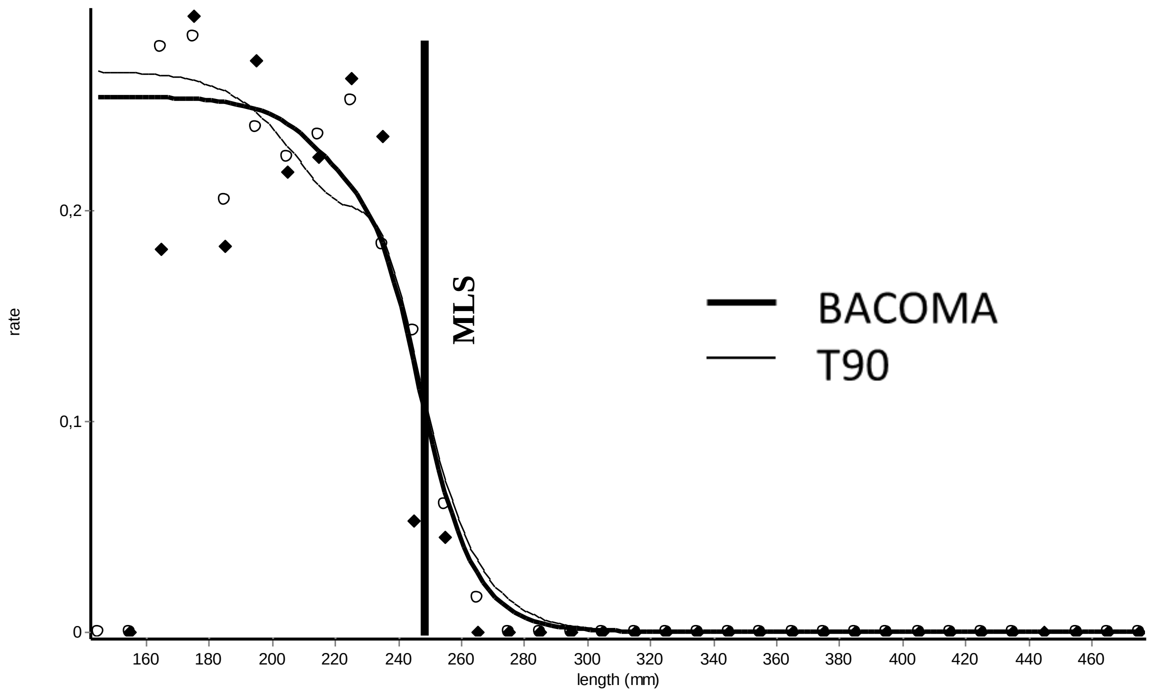

Figure 26: Escapement rate of cover 2 (plaice- pooled hauls of cruise SO630; BACOMA: logit_dualredseq model; T90: logit_dualseq model)

Table 16: Selection parameters of BACOMA 120/105 mm and T90 120 mm (logit_dualseq model or logit_dualredseq (italic))

	BACOMA 120/105 mm			T90 120 mm		
	cod	**flounder**	***plaice***	**cod**	**flounder**	**plaice**
L50 [cm] – overall **SR [cm] – overall**	46.32 7.194	22.87 4.39	*24.05* *1.96*	42.55 5.15	23.57 2.58	23.67 1.93
C_{tow}	0.65	0,55	*0.72*	0.67	0.75	0.73
L50 [cm] – towing **SR [cm] – towing**	46.59 14.36	23.90 2.64	*23.98* *1.74*	40.84 5.19	23.47 2.56	23.48 1.59
L50 [cm] – heaving **SR [cm] – heaving**	42.07 8.10	20.10 4.04	*23.01* *2.25*	40.98 5.91	22.00 2.74	22.42 2.69
p-value	0,93	0,97	*0,99*	0,99	0,99	0,99

In every case, the overall SR of the T90 120 mm reaches smaller values than the SR of the BACOMA 120/105 mm. The overall L50 values are very similar, only the L50 of cod in BACOMA 120/105 mm is quite large. Furthermore, the $L50_{tow}$ reaches higher values (than the $L50_{heave}$ does) in almost every case. The only exception is the result for cod in the T90 120 mm.

Considering SR_{tow} and SR_{heave}, it looks similar. Values for cod in the T90 excluded, the SR_{tow} is higher than the SR_{heave}. Furthermore significant differences were found for the BACOMA 120/105 mm between towing and heaving, whereas both SRs for the T90 120 mm are similar.

The C_{tow}-values, which show the percentage of fish, which try to escape during towing differ between the different species and for flounder between both codends, but all values are around 0.6 and 0.7.

The p-values of the logit_dual-seq model, which were calculated with SELNET, are near 1, what means a high significance (Table 16).

4. Discussion

4.1. The moment of escape

If undersized or unwanted fish come on deck, they have to survive many stressful factors, before they will be thrown back. Examples for these stressors are (Grimaldo *et al.*, 2009):

- differences in temperature
- solar radiation
- desiccation
- suffocation
- predation from seabirds

But also under water escaping individuals, especially physoclists, have to suffer other stressors if they cannot leave the codend directly – the bulk catch (if many fish are in the codend, they "change" and block the meshes and it becomes more difficult to escape) and the barotrauma. Generally speaking: The sooner the fish are able to escape, the better.
As figured out in chapter 3.2, the catch distribution for the different species cod, flounder and plaice differs for the both codends BACOMA 120/105 mm and T90 120 mm. Best would be, if every escaped fish is situated in cover 1, i.e. "escaped during towing".
Regarding cod (the only physoclist species, regarded in this work), the values for the BACOMA 120/105 mm codend are slightly better than the values for the T90 120 mm. From the BACOMA 120/105 mm, 68.1 % of all escapees, escaped during towing; from the T90 120 mm only 64.1 %. The comparison of the average values by the help of the t-test showed small differences of the catch distribution, but these differences were not significant. For flounder and plaice, no significant differences were found.
The differences between the catch distribution of both flatfish species can be explained by the different average length. Although the specimen of flounder and plaice were smaller than cod, they had a lower chance to escape. The reasons are the different shapes of the fish and the shape/size of the meshes.

Furthermore, the moment of the escapement was considered. Thereby it is noticable that the relative number of fish which escape during heaving is quite high compared to the relative short time needed. The process of towing took approximately two hours, whereas the heaving took only 15 minutes.

The reason of this late escapement during the haul-back is that many fish, especially cod swim with the gear and do often not want to flee during towing because they do not sense the danger. This is reflected by the relative low contact factor (C_{tow}). Even when the codend is pulled up, they realize the danger and want to escape.

For solving this problem the danger has to be shown more obviously to the fish to increase the C_{tow}-factor and make the fish more active. Another possibility for reducing the number of "fish, which escaped during heaving" could be the usage of a grid based selectivity system (Figure 27), where smaller fish have the chance to leave the net before they reach the codend. Analogue to the contact factor C_{tow}, the contact probability with the grid could be described by C_{grid}. It is quite high, because almost every individual, entering the net, has to come in contact with the grid. One grid type was tested by Sistiaga et al. (2010), where also the flight pattern of different species was observed by the help of two covers. But this method implicates problems too, such as the blocking of the grid by different objects organisms like other fish, seaweed or garbage.

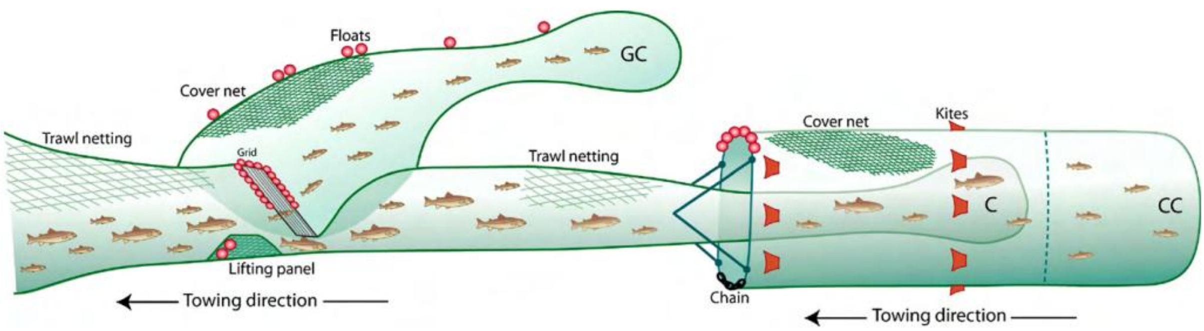

Figure 27: Grid and codend setup used by Sistiaga et al. (2010)

4.2. The catch of sized fish

For a sustainable fishery it would be the best, if every undersized fish which encounters the gear, escapes (as soon as possible) and every sized fish will be retained.
The result of the trials, which were conducted for this study, is that the T90 120 mm retains more sized fish than the BACOMA does (Table 11, Table 13, Table 15).
In addition the escapement rate of undersized fish was regarded: The BACOMA 120/105 mm retains more undersized fish, which would become discarded. Thus the T90 120 mm got an advantage over the BACOMA 120/105 mm, because more sized fish are caught and more undersized fish can escape. This is good for both fisherman and fish stock.

4.3. L50 and SR

Regarding the selectivity parameters for the complete process, it is difficult to compare both codends (Table 16). The most obvious result is that the T90 120 mm has always a smaller SR. Thus the curve becomes steeper and the selectivity is sharper (Figure 18, Figure 21, Figure 24).
The higher L50 values and smaller SR values during heaving are caused by the different conditions of both processes. During towing, the fishing-gear is towed relative slowly and constant through the water and the meshes have a relative stable opening (at least in calm water conditions). When the gear is hauled back, it becomes tighter and the mesh openings decrease. In addition the fish are pressed into the end of the codend whereby some bigger fish are pressed out of it and other fish block the meshes (particularly big fish and flatfish or also macrophytes and garbage) and the chance to escape decreases further.
Comparing the towing- and heaving-values ($L50_{tow}$-$L50_{heave}$ and SR_{tow}-SR_{heave}), larger differences were found for the BACOMA 120/105 mm codend. Consequently, the T90 120 mm codend does not react as strong as the BACOMA 120/105 mm to the changes between towing and heaving.

4.4. Conclusions

This work has shown that many individuals can leave the codend already during towing, but some individuals can escape even at the haul-back. If the two processes will be regarded by the time they need, it is a quite high value of “escapees while heaving”, which should be decreased. To increase the percentage of escapees during towing, it may be useful, to simplify their escape by modifying the gears. One example could be the usage of special grids. The second aim of this work was the comparison of the two in the Baltic Sea legal codends regarding their selectivity. It is difficult to prefer one codend, because the values are nearly the same or vary in this way, that in one case the values for the T90 120 mm look better, in the other case the values for the BACOMA 120/105 mm.

Concluding it can be said that both codends have very similar characteristics concerning their selectivity.

Differences are:

- Cod escapes slightly earlier from the BACOMA 120/105 mm, but overall there are no significant differences for the moment of escapement between both codends
- The T90 120 mm retains more sized and less undersized fish
- The T90 120 mm have a sharper selection because the SR is smaller

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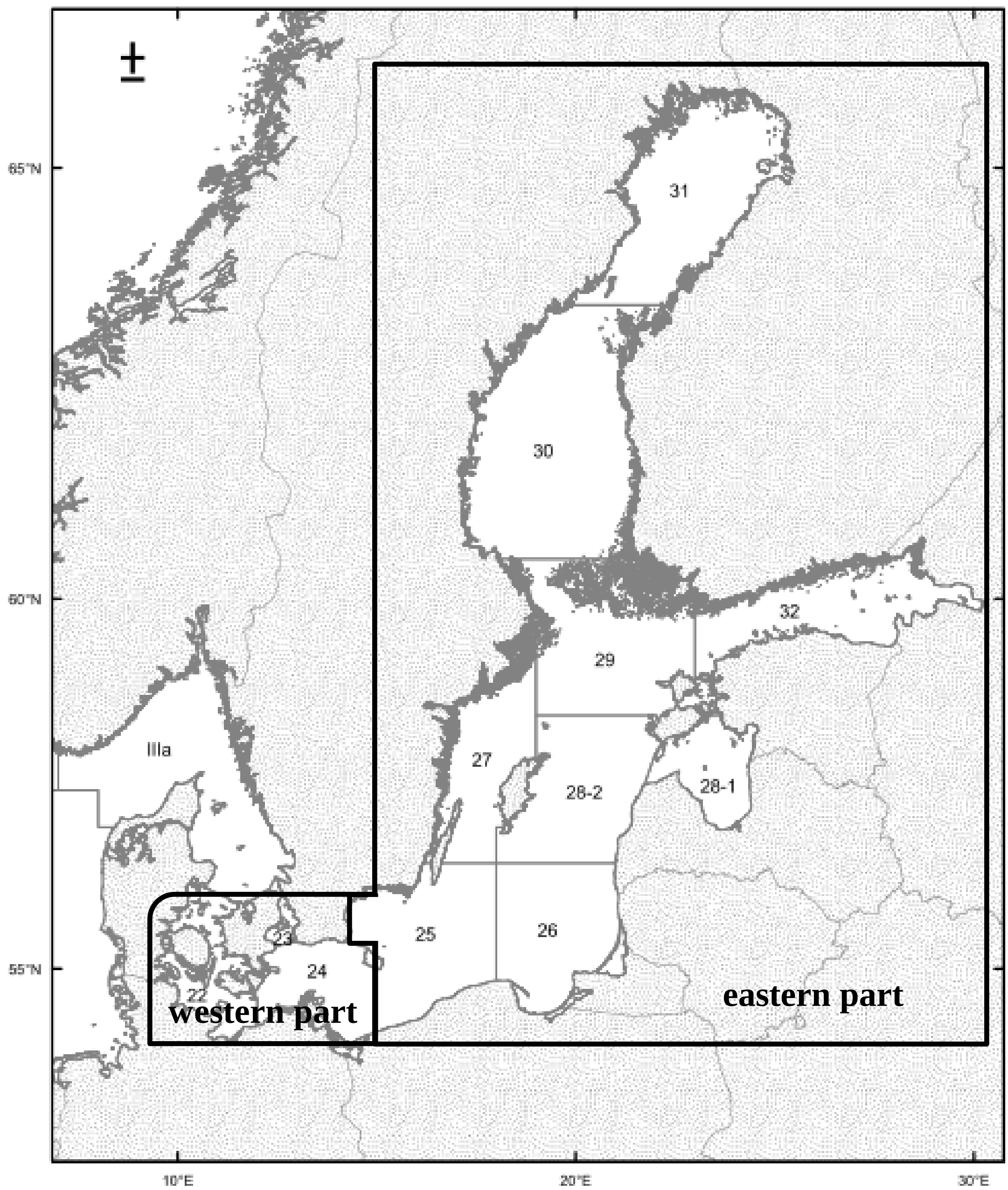
Appendix A - List of Abbreviations

AIC-Value	"Akaike Information Criterion" – the smaller it is, the better is the relative goodness of fit of a statistical model
BACOMA	One of the legal codends in the Baltic Sea; Abbreviation derived from the project name "Baltic Cod Management" (for further explanation see chapter 1. Introduction)
ICES	International Council for the Exploration of the Sea
ICES SD	ICES Subdivision
L25	The length at which 25% of the fish are retained
L50	The length at which 50% of the fish are retained
L75	The length at which 75% of the fish are retained
MLS	Minimum Landing Size
(F)RV	(Fishery) Research Vessel
SELNET	Computer software for analysis of gear selectivity data (SELection in trawl NETting)
SR	Selection Range; difference between L25 and L75
T90	One of the legal codends in the Baltic Sea with meshes turned by 90°
Total Length	Greatest length of the whole body between the most anterior point of the body and the most posterior point measured in a straight line
vTI-OSF	Johann Heinrich von Thünen-Institute / Institute of Baltic Sea Fisheries Rostock

Appendix B – Map of the Baltic Sea



Appendix-Figure 1: Map of the Baltic Sea with marked Ices-Subdivisions (modified after ices.dk)

Appendix C - Raw Data

Appendix-Table 1: Length distribution of cod of the cruise SO630, separated by codend type and catch compartment

Length [cm]	BACOMA			T90		
	test	cover 1	cover 2	test	cover 1	cover 2
14	0	1	0	0	0	0
15	0	1	3	0	0	2
16	0	1	1	0	2	1
17	0	4	7	0	0	5
18	0	3	4	0	3	6
19	0	6	7	0	4	5
20	0	6	5	0	4	4
21	0	19	5	0	6	7
22	1	17	6	0	12	9
23	0	26	9	0	8	10
24	0	26	15	0	13	11
25	1	29	14	0	22	9
26	1	44	16	1	20	14
27	1	54	29	1	38	22
28	3	129	45	0	92	41
29	8	209	95	2	164	55
30	10	325	142	2	283	124
31	16	417	181	12	329	146
32	27	500	212	11	370	180
33	29	497	205	13	369	203
34	36	502	199	20	281	167
35	38	463	192	29	216	158
36	42	368	153	19	200	136
37	51	307	112	31	137	109
38	52	264	93	32	103	83
39	60	223	96	43	73	65
40	52	219	75	54	60	84
41	66	180	76	70	45	62
42	73	165	54	71	32	52
43	72	113	58	65	10	27
44	82	85	47	72	8	22
45	83	67	27	78	5	12
46	78	48	18	64	9	4
47	74	38	10	55	4	5
48	63	26	7	36	1	1
49	61	14	7	37	0	0
50	60	4	7	35	0	0
51	45	5	2	27	0	0

52	56	6	1	14	0	0
53	49	0	0	18	0	0
54	36	0	0	13	0	0
55	29	0	0	12	0	0
56	22	0	0	8	0	0
57	10	0	0	11	0	0
58	14	0	0	2	0	0
59	6	0	0	9	0	0
60	13	0	0	3	0	0
61	2	0	0	1	0	0
62	3	0	0	4	0	0
63	5	0	0	2	0	0
64	0	0	0	2	0	0
65	3	0	0	3	0	0
66	3	0	0	3	0	0
67	0	0	0	1	0	0
68	3	0	0	1	0	0
69	0	0	0	0	0	0
70	1	0	0	1	0	0
71	0	0	0	0	0	0
72	1	0	0	0	0	0
73	0	0	0	0	0	0
74	1	0	0	1	0	0
75	2	0	0	0	0	0
76	0	0	0	0	0	0
77	0	0	0	0	0	0
78	0	0	0	0	0	0
79	0	0	0	1	0	0
80	0	0	0	0	0	0
81	0	0	0	0	0	0
82	0	0	0	0	0	0
83	1	0	0	0	0	0

Appendix-Table 2: Length distribution of flounder of the cruise SO630, separated by codend type and catch compartment

Length [cm]	BACOMA			T90		
	test	cover 1	cover 2	test	cover 1	cover 2
15	0	1	0	0	1	0
16	0	3	0	0	0	0
17	2	3	1	0	4	0
18	0	5	0	0	1	0
19	6	4	4	0	5	3
20	8	8	1	0	2	2
21	13	23	3	1	4	0
22	32	31	5	8	10	4
23	93	40	16	12	8	3
24	223	61	17	36	12	6
25	369	67	19	55	9	3
26	507	46	9	105	12	5
27	693	28	14	147	3	4
28	822	12	4	172	0	0
29	827	3	3	184	0	0
30	847	3	1	147	1	0
31	638	0	0	153	0	0
32	461	0	0	126	0	0
33	404	2	0	100	0	0
34	262	0	0	73	0	0
35	210	0	0	57	0	0
36	127	0	0	47	0	0
37	92	0	0	33	0	0
38	62	0	0	14	0	0
39	17	0	1	21	0	0
40	24	0	0	9	0	0
41	15	0	0	7	0	0
42	5	0	0	3	0	0
43	2	0	0	3	0	0
44	0	0	0	1	0	0
45	0	0	0	0	0	0
46	1	0	0	0	0	0

Appendix-Table 3: Length distribution of plaice of the cruise SO630, separated by codend type and catch compartment

Length [cm]	BACOMA			T90		
	test	cover 1	cover 2	test	cover 1	cover 2
14	0	1	0	0	1	0
15	0	5	0	0	9	2
16	0	20	5	0	29	12
17	1	61	15	0	55	13
18	3	116	23	3	70	28
19	7	233	57	5	102	31
20	32	301	78	9	94	30
21	45	274	82	9	57	25
22	42	155	59	13	11	8
23	41	66	21	15	1	1
24	26	21	7	17	2	1
25	66	7	4	19	1	0
26	74	3	1	39	0	0
27	74	1	0	36	0	0
28	97	0	0	61	0	0
29	72	0	0	38	0	0
30	47	0	0	29	0	0
31	38	0	0	25	0	0
32	29	0	0	26	0	0
33	30	0	0	21	0	0
34	29	0	0	21	0	0
35	11	0	0	10	0	0
36	11	0	0	11	0	0
37	14	0	0	12	0	0
38	9	0	0	7	0	0
39	9	0	0	8	0	0
40	4	0	0	4	0	0
41	2	0	0	6	0	0
42	3	0	0	4	0	0
43	2	0	0	1	0	0
44	0	0	0	3	0	0
45	2	0	0	1	0	0
46	2	0	0	2	0	0
47	1	0	0	1	0	0

Appendix-Table 4: Mesh openings, measured with OMEGA gauge

Metering	Main part BACOMA	BACOMA window	Codend T90	Cover anterior part	Cover posterior part
1	104	125	123	76	75
2	102	125	123	75	73
3	100	126	124	78	71
4	107	125	125	77	75
5	105	126	125	76	72
6	106	125	123	76	72
7	105	125	125	78	74
8	105	126	124	73	74
9	106	128	126	77	72
10	104	126	122	76	74
11	105	-	125	-	-
12	106	-	126	-	-
13	104	-	124	-	-
14	-	-	126	-	-
15	-	-	124	-	-
16	-	-	125	-	-
17	-	-	123	-	-
18	-	-	122	-	-
19	-	-	122	-	-
20	-	-	124	-	-

Appendix-Table 5: Weight of caught fish in kilograms of the cruise SO630

Haul	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**TOTAL**
Date	***22.11.***	***22.11.***	***23.11.***	***24.11.***	***25.11.***	***25.11.***	***25.11.***	***26.11.***	***26.11.***	***26.11.***	***27.11.***	***27.11.***	***27.11.***	***28.11.***	-
Cod	253.15	823.36	412.97	542.35	262.28	1200.44	1171.1	583.55	560.4	359.67	691.91	656.49	524.4	333.3	**8375.37**
Whiting	81.877	223.404	478.404	34.748	49.11	991.218	245.94	302.592	1028.96	124.92	77.998	683.23	205.3	205.838	**4733.539**
Flounder	135.3	399.4	381.3	168.8	473.9	53.78	68.23	527.1	169.1	215	172.6	79.07	68.66	59.56	**2972**
Plaice	14.17	45.53	72.218	28.87	63.518	53.778	67.624	41.815	67.582	38.122	41.815	40.242	13.04	15.05	**603.374**
Four-bearded Rockling	-	-	-	-	0.654	-	0.604	1.114	0.118	-	-	-	0.144	0.16	**2.794**
Hook-nose	-	-	-	-	-	-	-	-	-	-	0.048	-	-	-	**0.048**
Mackerel	-	-	-	-	-	-	-	-	1.45	-	-	1.23	-	-	**2.68**
Eel	-	-	-	-	-	-	-	1.29	1.126	-	-	1.13	-	-	**3.546**
Haddock	-	-	-	-	-	-	1.24	-	-	-	-	-	-	-	**1.24**
Brill	-	-	-	-	-	0.5	-	-	-	-	-	-	-	-	**0.5**
Herring/ Sprat	3.734	2.55	27.512	11.054	42.666	39.28	29.112	40.898	25.386	4.16	7.93	20.432	74.08	16.5	**345.294**
Turbot	0.362	3.112	7.66	3.328	6.855	3.534	2.82	5.5	2.282	-	1.962	0.834	0.78	-	**39.029**
Dab	0.346	0.792	-	0.43	0.096	-	0.33	0.408	0.45	0.93	2.614	0.338	0.3	-	**7.034**
TOTAL	**489.00**	**1498.11**	**1380.06**	**789.54**	**899.12**	**2342.53**	**1587.00**	**1504.22**	**1856.83**	**742.79**	**996.83**	**1483.00**	**886.70**	**630.41**	**18544.03**

Appendix D - Acknowledgement

At first I would like to thank my first supervisor Cornelius Hammer for making this work and my start at the vTI-OSF possible. Furthermore, I would like to thank Laszlo Rakosy – my second supervisor and “host father” in Romania, where I began to study and Daniel Stepputtis, who supported me during writing and leaved many useful tips – sometimes I thought too many, but now I´m glad about every hint. Another really great person, who taught me many things, is Bernd Mieske – cruise leader, employee and friend. Also I would like to give special thanks to two Danish persons: Niels Madsen for nice evenings and talks on the FV Solea and Bent Herrmann for teaching the basics of SELNET. Last but not least I say thank you to the scientific crew on the cruise: Kerstin Schuhmann, Peter Schael and Ulf Böttcher, to the crew of the vessel and to these people, who get different data and literature for me. I apologize for the fish, which did not survive the process of measuring.

Appendix E - Declaration of Authorship

I, Thomas Noack, hereby declare that this thesis and the work presented in it is entirely my own. Where I have consulted the work of others, this is always clearly stated.

Thomas Noack

Date: 14.06.2011