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Selective fishing methods for the reduction of cod bycatch in flatfish fisheries

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geboren am 15.11.1995

Matrikelnummer: 214205309

eingereicht am 18.04.2017

Abgabedatum: 20.06.2017

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BACHELORARBEIT im Bachelor-Studiengang Biowissenschaften

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Abstract

Large amounts of bycatch still occur in Baltic Sea trawl fisheries. Historically, unwanted bycatch was discarded back to sea with little survival possibility. This discarding practice is seen in many societies as an unnecessary waste of natural resources. Therefore, the European commission has adressed this issue with the reform of the common fisheries policy by an introduction of a landing obligation in 2015.

With this, law quoted fish species can no longer be thrown back to sea but must be landed and counted against quota.

The landing obligation as well as the reduction in cod quotas (Gadus morhua), because of poor numbers of cod stocks, may have drastic effects on flatfish fisheries in 2017.

As soon as the quota of cod is reached, the fishing boats are theoretical not allowed to go out anymore, since cod bycatch has to be expected.

Therefore, it is of great importance to find ways to minimize the cod bycatch without a loss in flatfish catch.

Previous systems which were designed to reduce the flatfish bycatch in the cod fishery served as a foundation. An idea was not to modify the trawls but the behaviour of the fishermen. A theoretical study based on existing data showed that in the Baltic Sea it is possible to reduce bycatch in cod fishery by avoiding certain regions at appointed periods of time. However, often fishermen are not willing or it is no possible to change their fishing behaviour continuously.

For that reason, the different natural behaviour of fish was used to modify the trawls. Fishermen are not obliged to change their fishing behaviour with the modification of the trawls. Generally, the flatfish moves in the lower part of the trawl, whereas cod moves higher.

The FLEX system uses exactly this different behaviour of fish to catch cod and let flatfish escape. For this purpose, a steel frame opening was integrated in the lower panel of the extension piece, allowing flatfish to escape. Since this system was a success, it was inverted.

The iFLEX system is now designed to catch flatfish and let cod escape.

Therefore, the BACOMA-codend is, through an adapter, attached to the steel frame opening and the extension is open. With this new construction it is expected to obtain a decrease of cod bycatch without a decline of the sought-for species.

The Trawl was tested in the Baltic Sea, close to Warnemünde, with an unmodified trawl as reference. Ten hauls were conducted within a period of two weeks.

The data obtained from the hauls were analysed and the performance of the trawls were evaluated. Furthermore, underwater cameras were installed to observe the behaviour and the setup of the trawl.

Images of the underwater cameras show partially different behaviour than anticipated.

Despite that, the results show a significant loss of bycatch of cod but also a loss of flatfish.

Contents

1. Introduction

1.1 History of fishing and today's situation

The first historical discoveries for the fish trade were already found in the antique (800v Chr. - about 600n Chr.). However, the fishery history dates goes back to the Stone Age (Koster, 1923). During this time, vessels for sea fishery and several fishery equipment's, which are still used in commercial fishing, were build. A professional and extensive fish trade was operated, with the beginning of the middle ages. Fishing techniques and equipment have been steadily improved to meet the rapidly growing demand (Koster, 1923). In the 18th century the steamships that emerged, as well as the improved technology were creating an enormous upswing, especially in deep- sea fishing (Bohn, 2011). Fishing methods such as gillnets and pound nets, trawls, longlines and purse seines allow every imaginable species to be caught and made available to the population. Gillnets and pound nets are mainly used in coastal- and inland fishing and are stationed there. Trawls, longlines and purse seines are methods also used in deep sea fishing. Longlines can be up to 160km long and are for example specialized in single and fast swimming individuals where trawls and purse seines catch mainly schools of fish (Commission of the European Communities, 1992; FIZ and BMEL, 2011; Sacher et al., 1983).

Based on the rapid increase in the world population, the higher standard of living and the development of technology in the last century, the quantity of caught fish and shellfish increased from about 12.8 million tons in 1950 to over 80 million tons per year since 2000 (BfN, n.d.).
In Germany, this corresponds to a per capita consumption of 14.1kg (catch weight). Forecasts for the quantity of caught fish in 2025 and 2050 shows significant increases (Keller and Sandra Kess, 2016). As a result of this extensive consumption of fish, more and more percent of fish species are considered to be threatened or overfished. In the meantime, 31.4% of the world's fish stocks are over- and 58.1% maximum fished. Only 10.5% are considered to be moderate or sparsely fished (FAO, 2016). Furthermore, the large individuals, which are of great importance for reproduction as they bear many offspring, decrease by some species (FAO, 2016; Keller and Sandra Kess, 2016). With increasing fishing, often bycatch increases as well.

Bycatch is understood as the whole captured weight, which is not the target species. The bycatch can be animal, plant or non-living. The animal bycatch can be separated in 2 types, can be used for commercially purposes or cannot be used. Within the commercially usable species, there are once again classifications (Ehrich and Neudecker, 1996). It is not possible to estimate an exact number, because different facilities publish different numbers. For an example the Alverson assessment published in 1994 a discard of 27 million tons. In 1998 the FAO published results of 20 million tons. On that account the Alverson assessment indicated in 1998 that the 1994 assessment was an overestimate (Kelleher, 2005).

1.2 Demersal trawl fisheries

More than 80 million tons of fish and shellfish are captured every year (FAO, 2016). It is estimated, that from this 80 million tons approximately 16 million tons are caught with demersal trawls (Kieran Kelleher 2005). Most of the catches are from Northern Europe and Northern American continental shelf (Bensch et al., 2009). The demersal trawl fisheries target species living on or several meters above the seafloor (Valdemarsen et al., 2007), as for example cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and different flatfish species. In the Baltic Sea, 53.5 million tons of fish were fished from 9 littoral states in the years 1950-2007 (Zeller et al., 2010). Over 65% of which comes from the trawl fishery.

Demersal trawls are towed along the ground and catch anything that does not escape under the groundrope or through the meshes of the net (Suuronen, 2005; Valdemarsen et al., 2007). As a consequence, unwanted species and/ or size classes are usually caught beside the target catches. Too small individuals are also caught, when for an example the mesh openings are blocked by bigger fish or the meshes are too small. These unintended catches are considered as bycatches (Fischbestände Online, n.d.). Once onboard, it is estimated that a high fraction was thrown back to sea as discard. A global discard assessment from the FAO estimates a discard rate averaging 22% in shrimp and demersal finfish fisheries. This is very similar to what is estimated for all non-shrimp trawl fisheries with 19.1%, where only fish and bilateria were included (Kelleher, 2005). Discard can take place for various reasons. For an example discard can take place for economic interests or because of established legislations. A case for established legislations was species with *minimal landing size* (MLS) regulations. The MLS sets minimum sizes for fish species to be retained on board, transported or sold (European Commission, n.d.). Fish under this size had to be discarded. For example, the MLS of cod in the Baltic Sea was 35cm (Fischbestände Online, 2016) before 2015, were the landing obligation was introduced. Individuals that did not reach this size were illegal for landing and had to be discarded. A high percentage of the discarded fish was already dead or died directly as a result of the catch and discarding procedure (Suuronen, 2005). The mortality varies between the different species and the catching devices. Furthermore, abiotic factors such as water temperature affects the survival rates (Suuronen, 2005; Zimmermann et al., 2015). Therefore, discarding is considered a fishing practice which jeopardize fish stocks and thus whole marine ecosystems (Kelleher, 2005).

For this reason, the landing obligation was issued by the European Commission (European Commission, 2016, 2013). The aim of this reform is to ensure a sustainable management of fish stocks in European waters with the help of a gradual discard ban of quota species. Therefore, the MLS is substituted with the *minimum conservation reference size* (MCRS). Fish below the new MCRS have to be landed but cannot be sold for human consumption (European Commission, 2014). The Baltic Sea is the ideal water to implement the landing obligation and its control. Therefore, the Baltic Sea is the pilot project for the EU (Zimmermann et al., 2015). The landing obligation can have drastic consequences for Baltic Sea fisheries. Once the quota of one fish species has been achieved, the fishermen are not allowed to fish anymore, if they are not able to avoid the catch of this species (European Commission, 2016). This fish species can serve as a choke species. A choke species is a species for which the available quota is exhausted before the quotas of other species are caught and which limit the catch opportunities of other species (Zimmermann et al., 2015). Basically, no species is a choke species. Fish species can only become through certain factors to a possible choke species. Because of the quotation and reforms for the Baltic Sea species like Plaice (*Pleuronectes platessa)* or cod (*Gadus morhua)* can there function as potential choke species (Zimmermann et al., 2015). Due to the high bycatch rates in demersal trawl fisheries and low quotas, the quota is reached quickly. This is why fishermen are not allowed to go on the sea for the rest of the season. Therefore choke species can create not only economic existential fears among fishermen but also possible shortages on the market. That implies that fishermen using trawls register heavy losses.

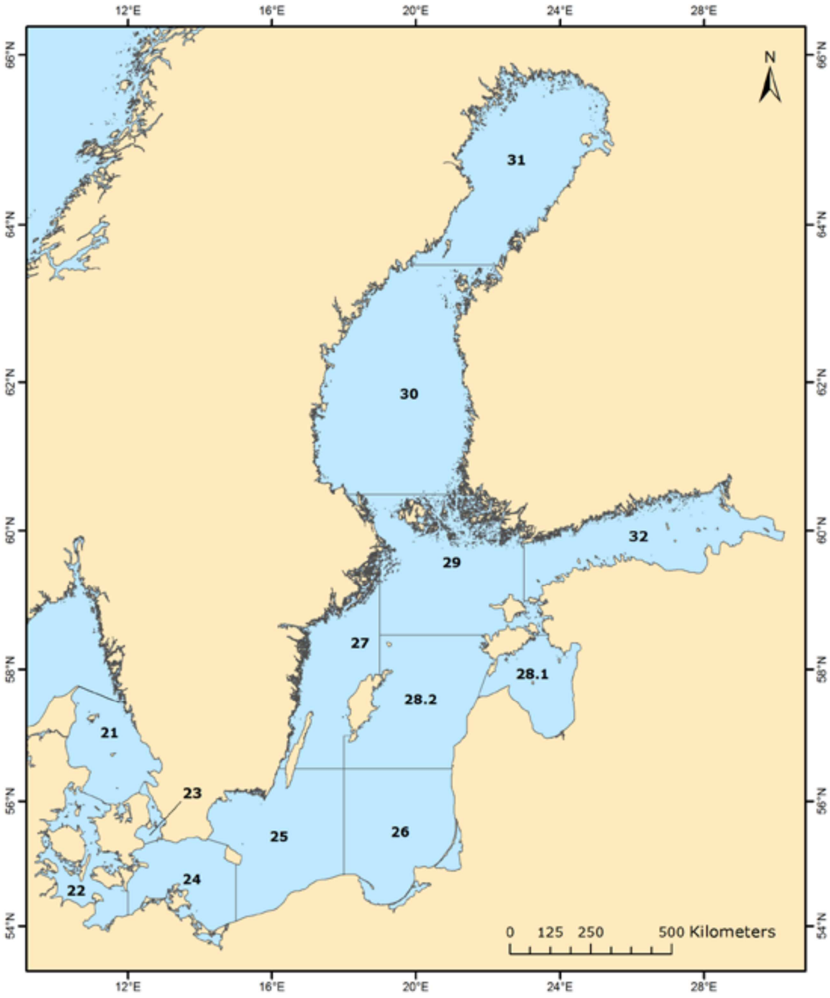
This gives the occasion to find new selective fishing methods which reduce the bycatch rate in order to ensure sustainable fishing. Furthermore, to integrate the economic branch, it has to be assured that there are no declines in the catch of the target species per fish catch (Glass et al., 2012).

1.3 Reduction of bycatch by means of natural behavior of the fish

There are different approaches to reduce the bycatch rates. On the one hand the technical aspect by using new or modified nets. On the other hand the adaption of fishing behavior. The aim is to avoid areas and periods in which fish with limited quotas increasingly occur. This has already been successfully tested in some parts of the world. For example, the accomplishment of a discard restraint in the British Columbia groundfish trawl fishery caused that fishermen avoided fishing grounds where fish with limited quotas were more abundant. Further there are examples were real-time catch and discard information from different areas are shared to encourage vessels to avoid areas with high bycatch. (Zimmermann et al., 2015)

Now this should also be looked at in the Baltic Sea by Thünen Institute of Baltic Sea fisheries. There, plaice accounts as a potential choke species especially in cod fishery. In the last five years, plaice catches of the cod-directed fisheries were between 100 and 170% of the plaice (landings) quota. Therefore, the cod-directed fisheries might have the highest interest in reducing unwanted plaice bycatch. Cod is the most valued demersal fish in the Baltic Sea but has also the highest bycatch of plaice because catches are in the same areas where the plaice abundance and catches are also high. The Baltic Sea is subdivided into different management areas (21-31). (Zimmermann et al., 2015)

Map 1: The Baltic Sea and adjacent waters with limits of ICES Sub- Divisions (SD) indicated



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Sources: ArcView and ICES

Therefore, it was to detect if there are areas or periods where the cod catch-rate remains nearly the same without the unwanted plaice bycatch.

In order to achieve this, the catch data of the last years by plaice and cod were analyzed. It was ascertained in which regions and during which periods most catches took place. Subsequently, a comparison took place.

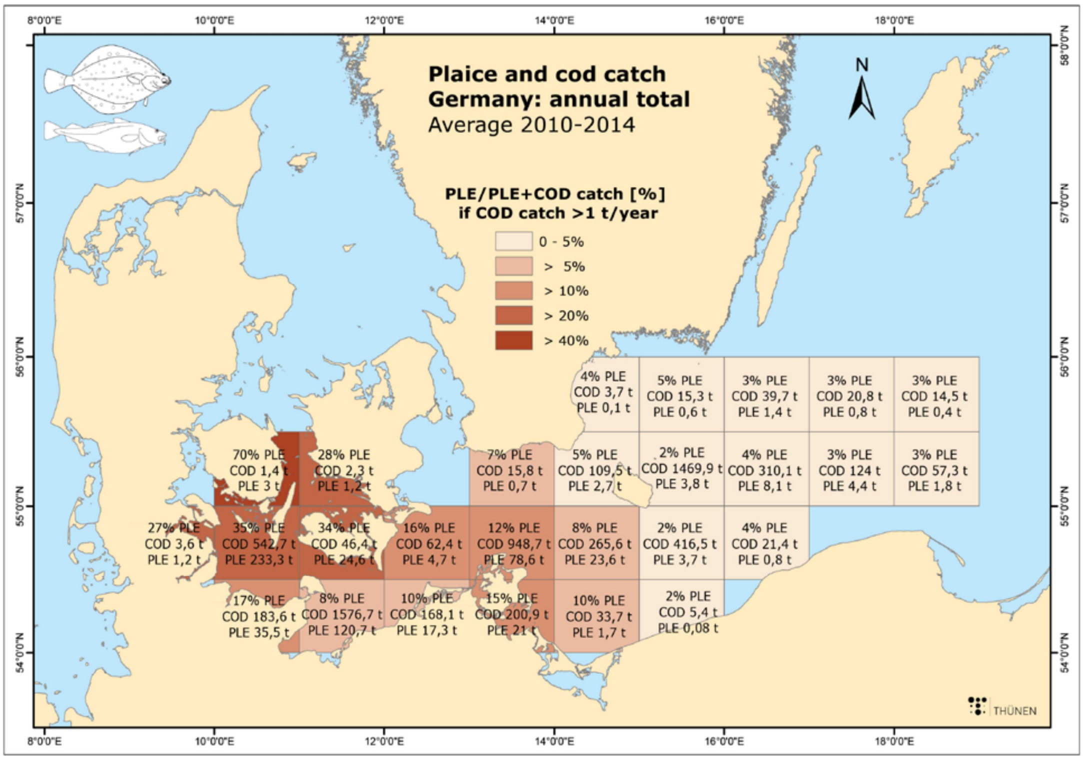


Figure 1: Average annual proportion of German plaice catches compared

Data source: Thünen Institute.

Figure 1: Average annual proportion of German plaice catches compared shows, that solely in Arkona (SD 24) are many areas where the plaice abundance is less but the cod stocks catches is high. Plaice depends on an adequate high salinity where cod is more tolerant to changing salinity. As a result, the plaice stocks decreased eastwards and the cod stocks remained high. Therefore, it is possible to reduce bycatch by changing the fishing behaviour in the Baltic Sea. However, not every fisherman is willing to change the areas or the periods in which he is fishing and also to catch maybe less than before (Zimmermann et al., 2015). On these grounds, the modification of nets is another important aspect to look at.

Two concepts have been tested for roundfish fishing, including Cod. On is the concept called “FRESWIND” and the other one is called “FLEX”.

The FRESWIND, which is the abbreviation for Flatfish Rigid Escape Windows, takes advantage of the differences in body morphology between roundfish and flatfish. Moreover FRESWIND influences the swimming direction to enhance flatfish size selection and to reduce flatfish bycatch (Santos et al., 2015; Zimmermann et al., 2015).

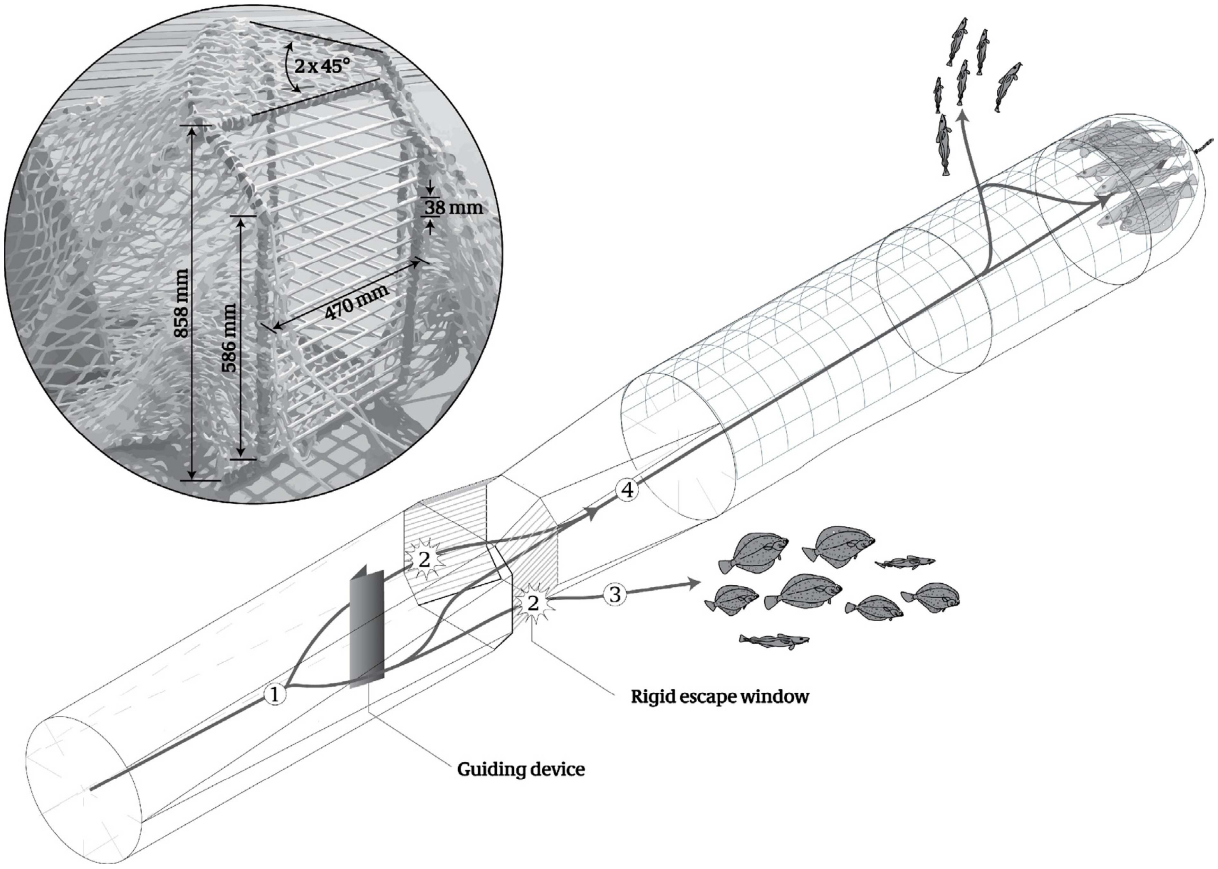


Figure 2: selection system with FRESWIND mounted in front of the BACOMA codend. The numbers represent the different events occurring when fish swim in to the FRESWIND enclosure. Fish entering the extension piece are guided sideways by the V-shaped canvas device (1). Fish escapements (3) after contacting the windows (2) depend on FRESWIND size selection, which is defined by the bar spacing. Fish not contacting the windows, or not able to escape through the rigid windows because of inefficient contact or size selection, retake the path towards the codend (4), where a successive, cod-directed selection process takes place. Steps 2 and 3 are parametrized in the alternative structural equation model (see Eqs. (3) and (4)). Topleft: FRESWIND picture showing design details of the windows.

Data source: Thünen Institut

The FLEX, which means Flatfish Excluder, is the newest development from the Thünen Institute for Baltic Sea fisheries. It is using differences of vertical swimming preferences between flatfish and roundfish species to exclude flatfish from catches. Therefore, underwater observations in commercial trawls were carried out. These observations showed that flatfish tend to swim very close or even along the net floor. Roundfish such as the cod, swim with water flow and avoid contact with the net (Zimmermann et al., 2015). Based on these differences in behaviour, a strategy to avoid flatfish bycatch would be to integrate an opening in the bottom of the trawl tunnel. The Opening is steel frame in the lower panel of the extension piece. Furthermore, there is a so called carpet at the lower end of the steel frame to prevent cod to escape and to help flatfish escaping. Weights and floats are necessary to guaranty the necessary shape (Mieske, 2016; Mieske et al., 2016).

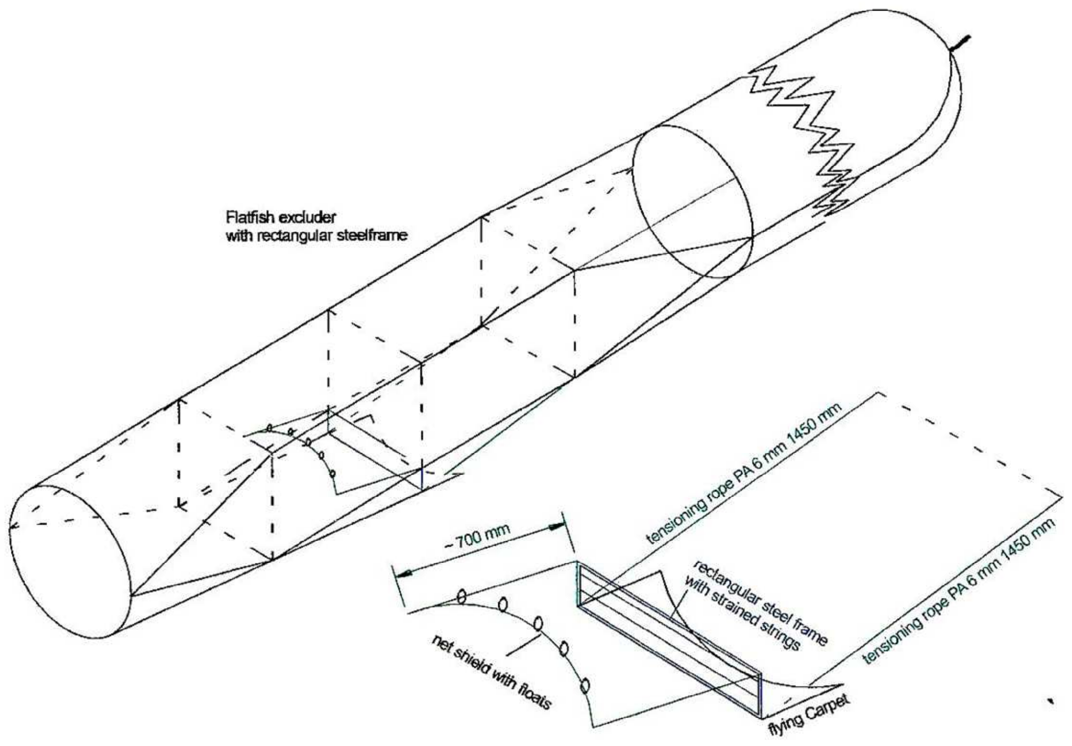


Figure 3: The principle of the four- selvedge- extension with the rectangular FLEX- mouth

Data source: Bernd Mieske Thünen- Institut für Ostseefischerei

To test the new concept, several research trips took place. For this, twin trawls were used whereby the second net was a control net. The FLEX was a success and bycatch of flatfish could be reduced by up to 65% and there were no significant losses in cod caught. (Mieske et al., 2016)

Figure 4: Integrated FLEX in a commercial demersal trawl

Data source: Thünen Institute.

1.4 New quota for cod in 2017 gives occasion for cod bycatch reduction

The cod equals 8% of the world fish consumption (Fischbestände Online, 2016). This corresponds to 80,000 tons annually. Cod is ranked 4th in the world's most important fish after herring (*Clupea harengus*), alaska- pollock (*Gadus chalcogrammus)* and tuna (*Thunnus)* fish. Approximately 51% originate from the Baltic Sea. For 2016-2017 42,400 tons cod originate from the eastern and 8400 tons from the western Baltic Sea (Fischbestände Online, 2016).

Due to poor population stocks and reproduction rates, Atlantic cod (*Gadus morhua)* is considered to be at risk. The EU Commission agreed to reduce the cod quota for the year 2017 in order to stabilize the population. Above all, this has drastic consequences for the western Baltic Sea. In 2016 German fishermen could fish 5597 tons of cod overall, while in 2017 the number decrease to 1194 tons (European Commission, 2017).

As a consequence cod can now function as a choke species in the flatfish fishery. For this reason, the focus is now on minimizing cod bycatch in flatfish fishery. Since the FLEX system achieved such good results, the question was whether it would work the same way when you turn it around. Is it possible to minimize cod bycatch in flatfish fisheries, when you let the excluder open and to put the BACOMA-codend with the aid of an adapter to the steel-frame opening (Mieske, 2017; Mieske et al., 2016).

2. Materials and Methods

2.1 Trawl description

2.1.1 Demersal Trawl

On the research trip demersal trawls were used because there are common used trawls in the Baltic flatfish fisherie. The trawler tows at the so-called “trawl warp” the demersal trawl. Which are used for the exposure, towage and reel of the net. At the trawl warp are “trawl boards” which are used for the stability and the sideways spread apart. Additionally, attached floats and weights give the trawl the desired shape (Commission of the European Communities, 1992).

A ground floor roller protects the net against damage from the ground. Through the extension the fish enter the BACOMA- codend, which is the end of the trawl. (Commission of the European Communities, 1992) A BACOMA- codend is used because it is the most common codend in the Baltic Sea fisheries.

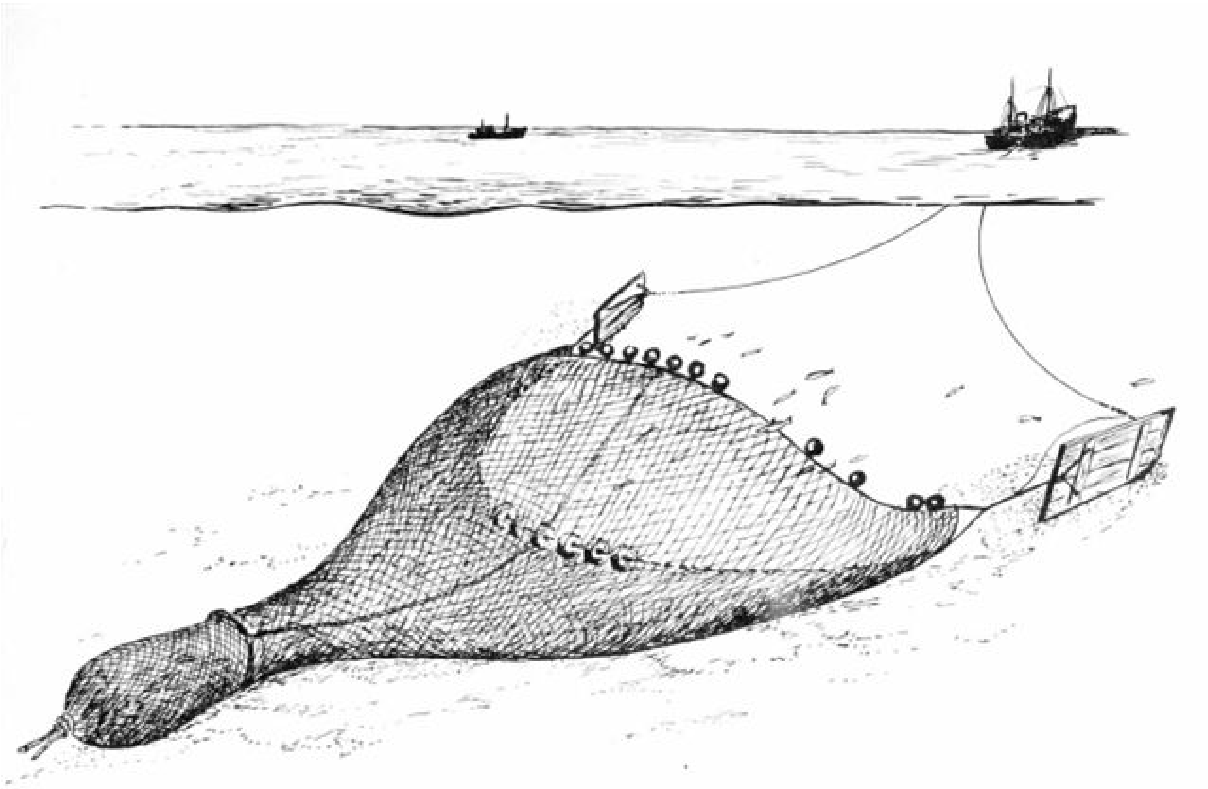


Figure 5: construction of a demersal trawl

2.1.2 iFlex

The iFLEX is based on the species selection facility FLEX which was developed on earlier trips and stands for inverted flatfish excluder. Like the FLEX, the iFLEX is made of a rectangular steel frame. In contrast to the FLEX system, the BACOMA- codend is placed on the escape opening with the aid of a codend- adapter. Furthermore iFLEX lacks the carpet because there is no opening to let flatfish escape anymore. The extension of the demersal trawl is in the iFLEX open to let cod escape. iFLEX can be integrated into any commercial demersal trawl (Mieske, 2017).

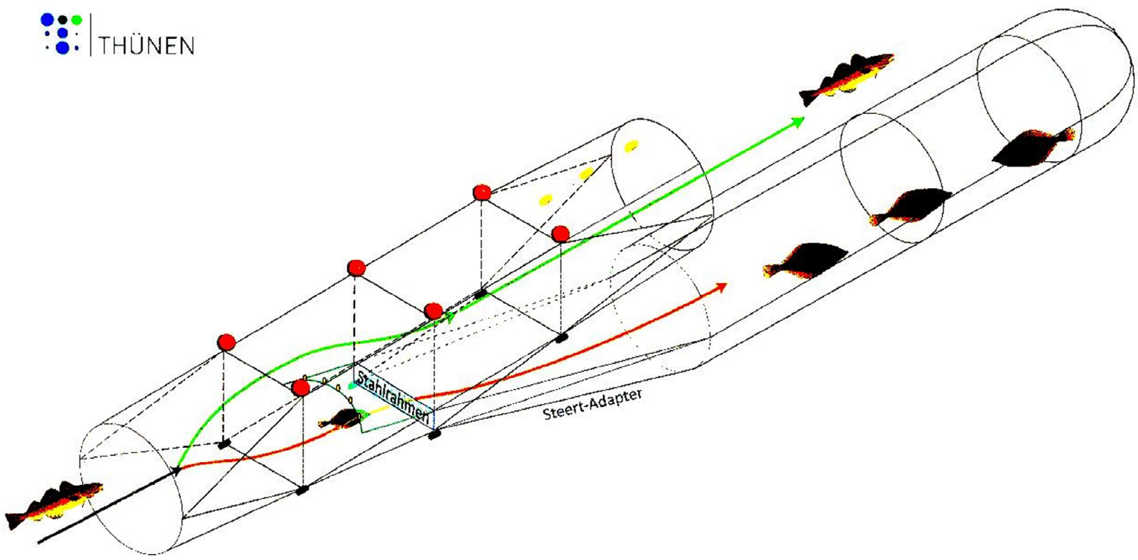


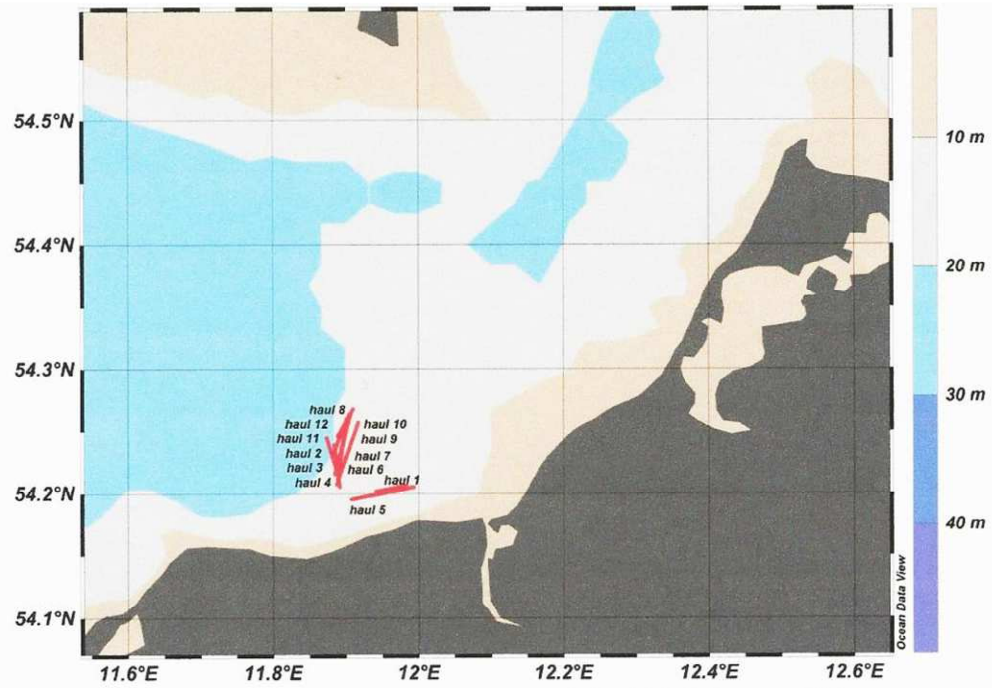
Figure 6: Setup of the iFLEX with codend- adapter

Data source: Thünen Institut für Ostseefischerei

2.2 Data collection

From 28Th November – 16Th December 2016 the experiment was carried out onboard the German Fishery Research Vessel (FRV) „Clupea" (28.8m LOA, 2.3m draught) with Bernd Mieske from the Thünen-Institute of Baltic Sea fisheries as cruise leader. The 308Th cruise of FRV "Clupea" started in the morning from Rostock Marienehe over the Warnow to the western Baltic Sea, which is near Warnemünde. This corresponds to the SD area 22.

Map 2: Investigation area for the trials during the 308. cruise of the FRV "Clupea"



Data source: Thünen Istitut für Ostseefischerei

The experiment was performed with the twin trawl method. Two trawls are towed simultaneously by a Trawler. (Wileman et al., 1996) This method is used to allow an accurate comparison, with the same conditions, between the control- net and iFlex.

Depending on the weather, 2 holes could be passed in one day. Due to bad weather conditions, 10 holes took place. For this each hole was towed between 30min and 1 hour. At some holes underwater cameras were installed in front of the iFlex.

After each hole there were two trawls (Lot1=iFlex, Lot2=control) with fish. Each Lot had to be classified according to the fish species. Afterwards they were weighed and measured. The collected Data lays the foundation for the following analysis in the statistic program R.

2.3 Underwater Observation

GoPro Hero 3 cameras were used for the underwater observation. These were installed in front of the iFlex to control whether the trawl opens and if the entire construction operates as intended. Furthermore, the cameras were used to observe if the fish behaves like anticipated. The videos were analysed directly onboard or afterwards on land to detect possible improvement.

3. Results

3.1 Setup and operational Information

Within the entire journey 4 different experiments took place. The iFLEX, SORTEX 2, assignment of MARPORT- trawl boards sensors and a trial for NKE- data loggers. The following results are only obtained from the iFLEX experiment.

Altogether, we conducted 10 hauls in the Mecklenburg Bay (ICES SD 22). Towing duration varied between 30min and 60min. Additional operational information are listed in Table 1.

Table 1: Operational information of the 10 hauls

Haul	Area	Date	Towing duration (min)	Phase	Latitude	Longtitude
1	Mecklenburger Bay	23.11.16	30	At the ground	54°12.352N	011°59.024E
1	Mecklenburger Bay	23.11.16		From the ground	54°12.086N	011°56.487E
2	Mecklenburger Bay	23.11.16	30	At the ground	54°12.802N	011°53.353E
2	Mecklenburger Bay	23.11.16		From the ground	54°14.323N	011°53.057E
3	Mecklenburger Bay	24.11.16	30	At the ground	54°13.135N	011°53.234E
3	Mecklenburger Bay	24.11.16		From the ground	54°14.650N	011°52.417E
4	Mecklenburger Bay	24.11.16	30	At the ground	54°13.802N	011°53.104E
4	Mecklenburger Bay	24.11.16		From the ground	54°12.305N	011°53.524E
5	Mecklenburger Bay	05.12.16	60	At the ground	54°12.290N	011°59.620E
5	Mecklenburger Bay	05.12.16		From the ground	54°11.714N	011°54.479E
6	Mecklenburger Bay	05.12.16	60	At the ground	54°12.413N	011°53.271E
6	Mecklenburger Bay	05.12.16		From the ground	54°15.406N	011°55.032E
7	Mecklenburger Bay	07.12.16	60	At the ground	54°12.896N	011°53.331E
7	Mecklenburger Bay	07.12.16		From the ground	54°15.818N	011°54.273E
8	Mecklenburger Bay	07.12.16	30	At the ground	54°16.063N	011°54.603E
8	Mecklenburger Bay	07.12.16		From the ground	54°14.734N	011°53.333E
9	Mecklenburger Bay	12.12.16	60	At the ground	54°15.584N	011°54.071E
9	Mecklenburger Bay	12.12.16		From the ground	54°12.649N	011°53.349E
10	Mecklenburger Bay	12.12.16	60	At the ground	54°12.905N	011°53.108E
10	Mecklenburger Bay	12.12.16		From the ground	54°15.858N	011°54.407E

3.2 Description of the catch

During the 308. Clupea cruise a total amount of 2578.69 Kg and 8418 individuals of fish were caught. Of this total amount, 1152.85 kg were caughted by iFLEX and therefrom 48.3kg cod. This equals to 16 cod individuals. With the reference trawl 142.7 kg cod were caughted which corresponds to 52 cod individuals. (Table 2-5)

Table 2: iFLEX: Caught species in kg seperated into the 10 hauls

species	haul 1	haul 2	haul 3	haul 4	haul 5	haul 6	haul 7	haul 8	haul 9	haul 10	total
Cod	3,2	0,12			36,52	3,28			5,18		48,3
Flounder	6,36	40,27	29,94	34,02	13,92	40,3	23,16	14,76	28,66	19,16	250,55
Plaice	14	16,02	15,32	9,42	8,36	14,94	15,92	10,28	11,52	13,36	129,14
Turbot	2,14	3,74	3	0,72	4,82	2,66	5,5	3,36	8,1	4	38,04
Dab	23,02	37,76	46,96	63,9	31,98	64,4	149,82	26,76	126,6	115,62	686,82
total	48,72	97,91	95,22	108,06	95,6	125,58	194,4	55,16	180,06	152,14	1152,85

Table 3: iFLEX: Caught species seperated into the 10 hauls

species	haul 1	haul 2	haul 3	haul 4	haul 5	haul 6	haul 7	haul 8	haul 9	haul 10	total
Cod	2	1			9	1			3		16
Flounder	18	108	81	82	31	97	56	39	66	46	624
Plaice	37	52	49	31	20	47	55	39	38	40	408
Turbot	5	8	8	2	12	7	11	6	13	8	80
Dab	93	157	181	237	130	272	592	112	494	430	2698
total	155	326	319	352	202	424	714	196	614	524	3826

Table 4: Reference trawl: Caught species in kg seperated into the 10 hauls

Species	haul 1	haul 2	haul 3	haul 4	haul 5	haul 6	haul 7	haul 8	haul 9	haul 10	total
Cod	10,06	6,7	0,78	12,36	25,58	17,46	15	4,6	17,22	32,94	142,7
Flounder	12,9	45,04	29,9	36,68	15,92	34,14	25,26	14,62	23,88	20,68	259,02
Plaice	13,66	15,82	14,36	14,48	11,92	26,8	17,1	10,28	23,62	14,6	162,64
Turbot	3,62	6,62	1,78	3,98	4,82	7,4	6,46	3,88	9,96	3,18	51,7
Dab	32	38,52	42,98	65,86	37,86	76,42	161,82	23,5	136,24	194,58	809,78
total	72,24	112,7	89,8	133,36	96,1	162,22	225,64	56,88	210,92	265,98	1425,84

Table 5: Reference trawl: Caught species seperated into the 10 hauls

species	haul 1	haul 2	haul 3	haul 4	haul 5	haul 6	haul 7	haul 8	haul 9	haul 10	total
Cod	3	3	3	4	10	4	4	1	8	12	52
Flounder	34	113	77	93	38	92	65	35	58	49	654
Plaice	36	51	49	49	33	80	66	38	71	40	513
Turbot	10	13	2	9	12	15	12	8	18	7	106
Dab	128	168	173	264	151	323	668	105	539	748	3267
total	211	348	304	419	244	514	815	187	694	856	4592

3.3 Comparison of the hauls

The following figures (7-11) show the captured fish seperated according to their species and if they were catched by iFLEX or by the reference trawl. The iFLEX catches are represented by the lower bars, the reference trawl catches by the upper bars. Furthermore, they are organized according to the length and divided to the respective haul.

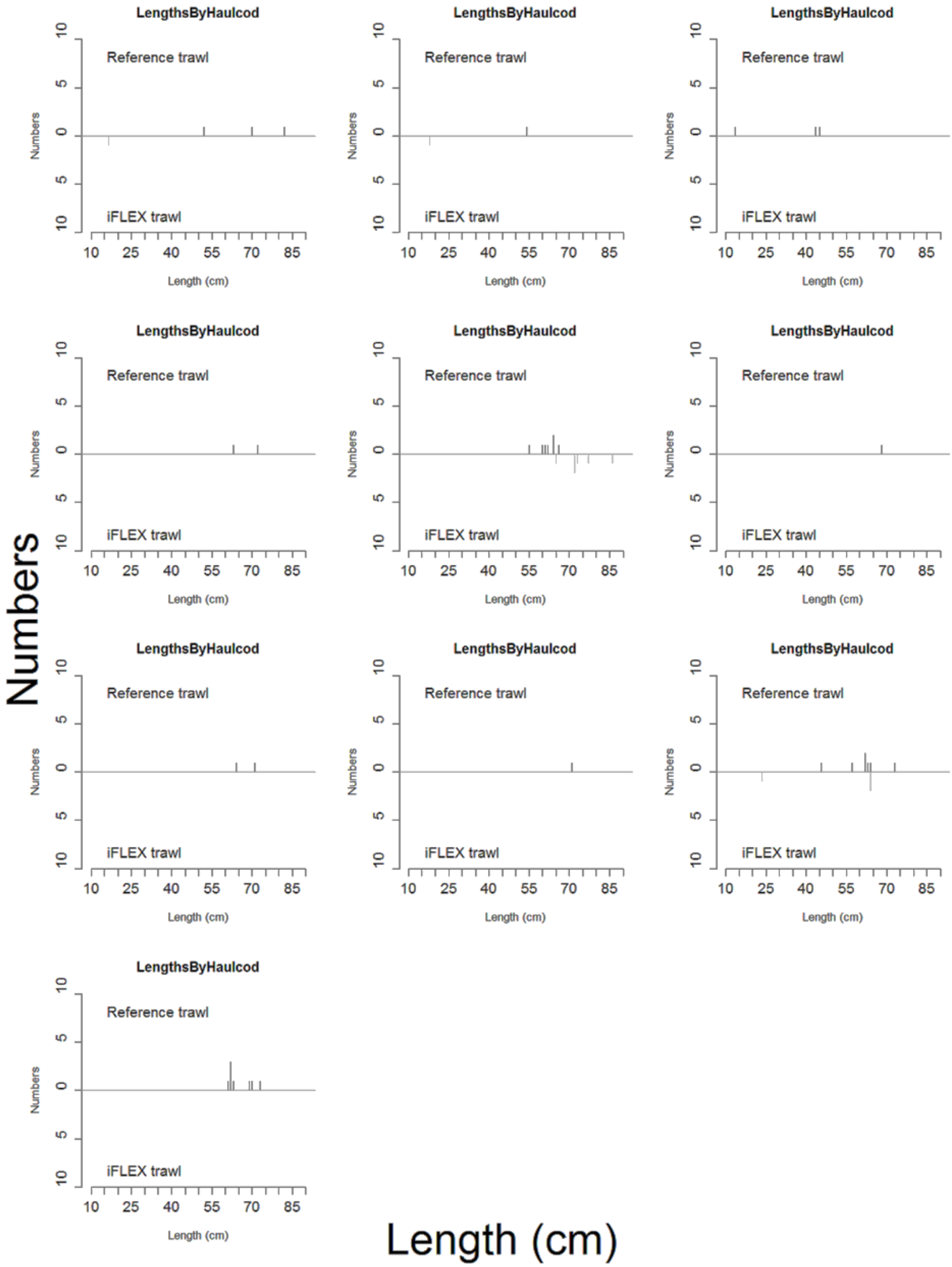


Figure 7: shows the length distribution by haul of cod in comparison between the iFLEX and the reference trawl

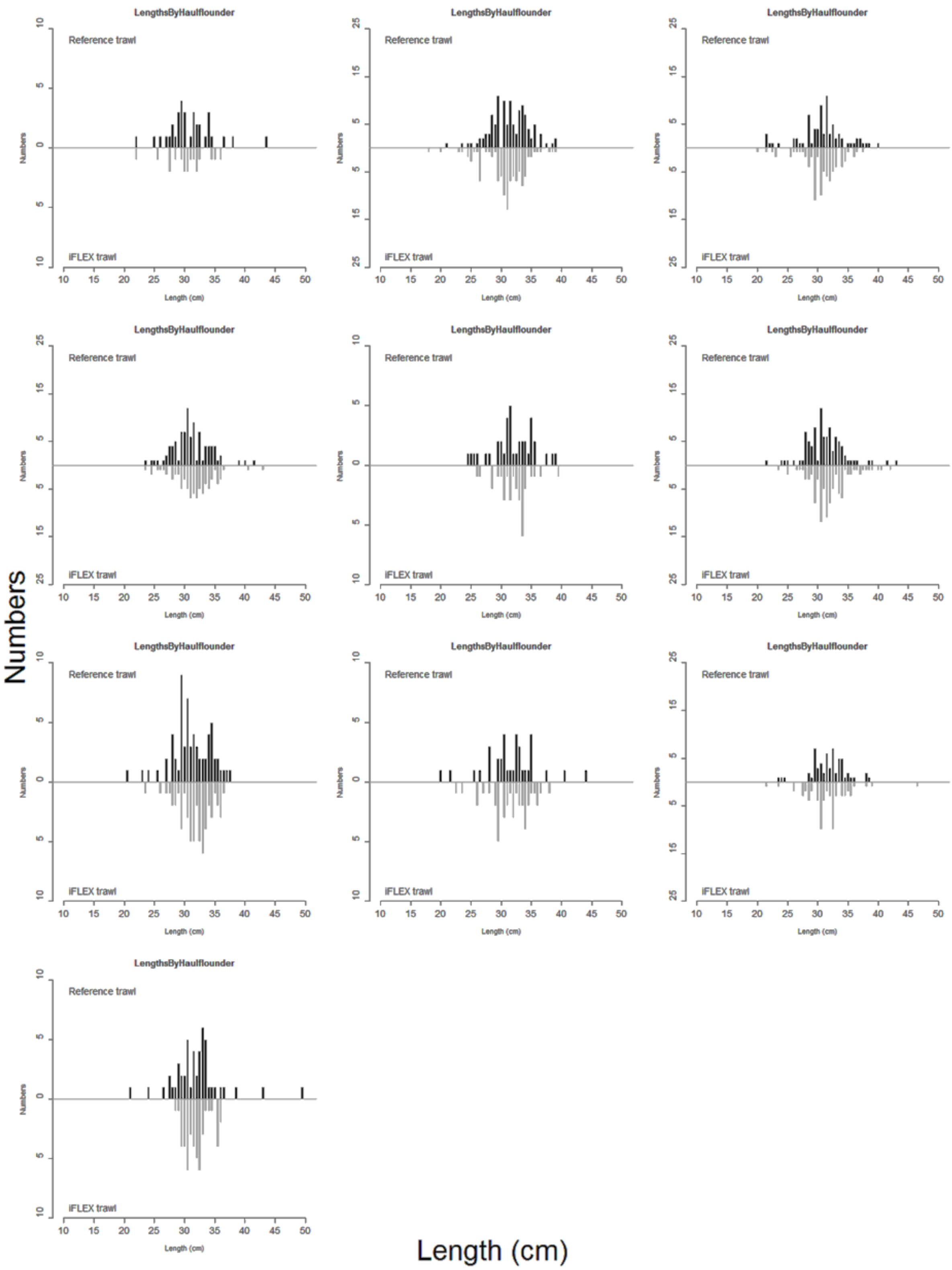


Figure 8: shows the length distribution by haul of flounder in comparison between the iFLEX and the reference trawl

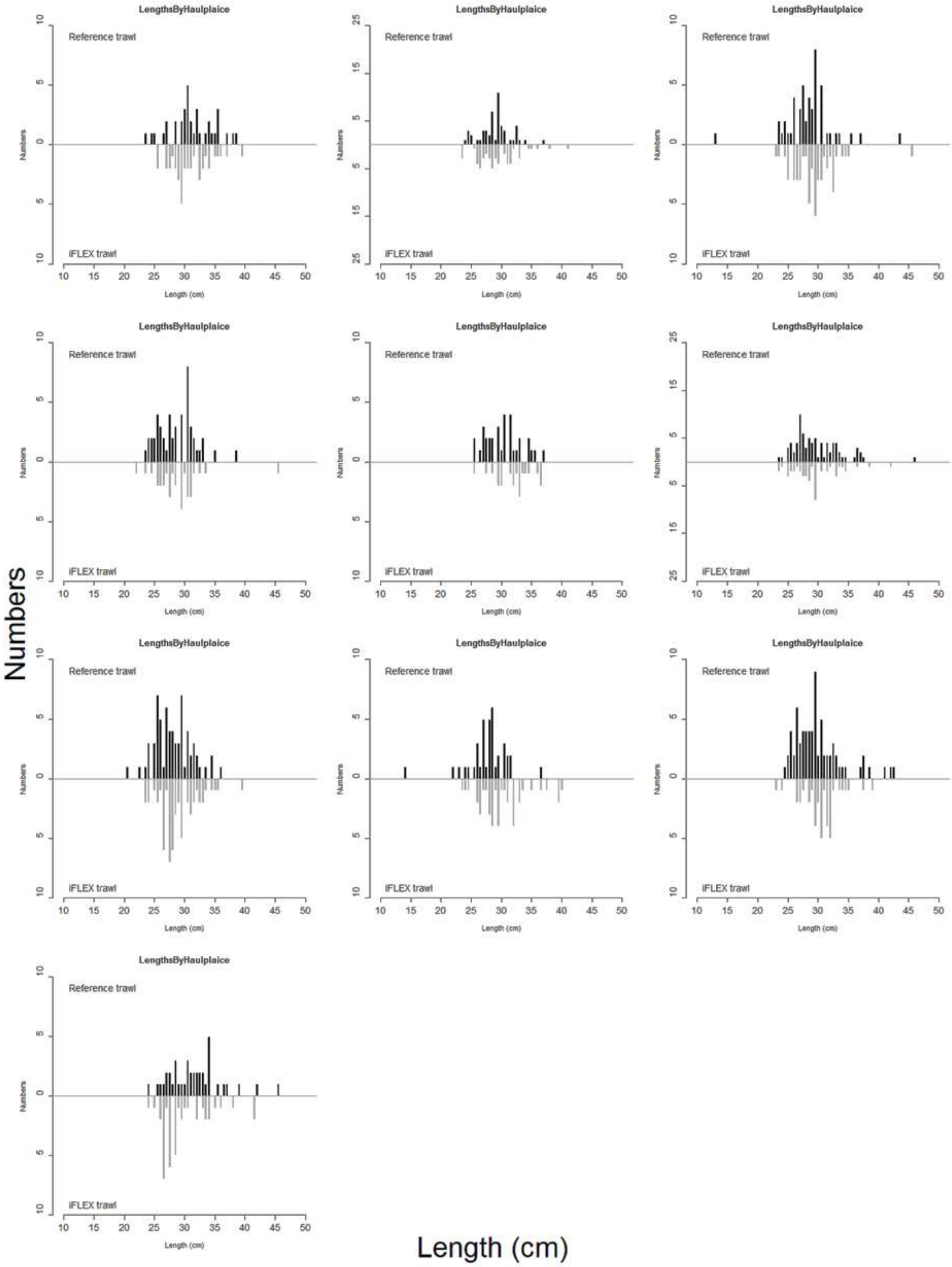


Figure 9: shows the length distribution by haul of plaice in comparison between the iFLEX and the reference trawl

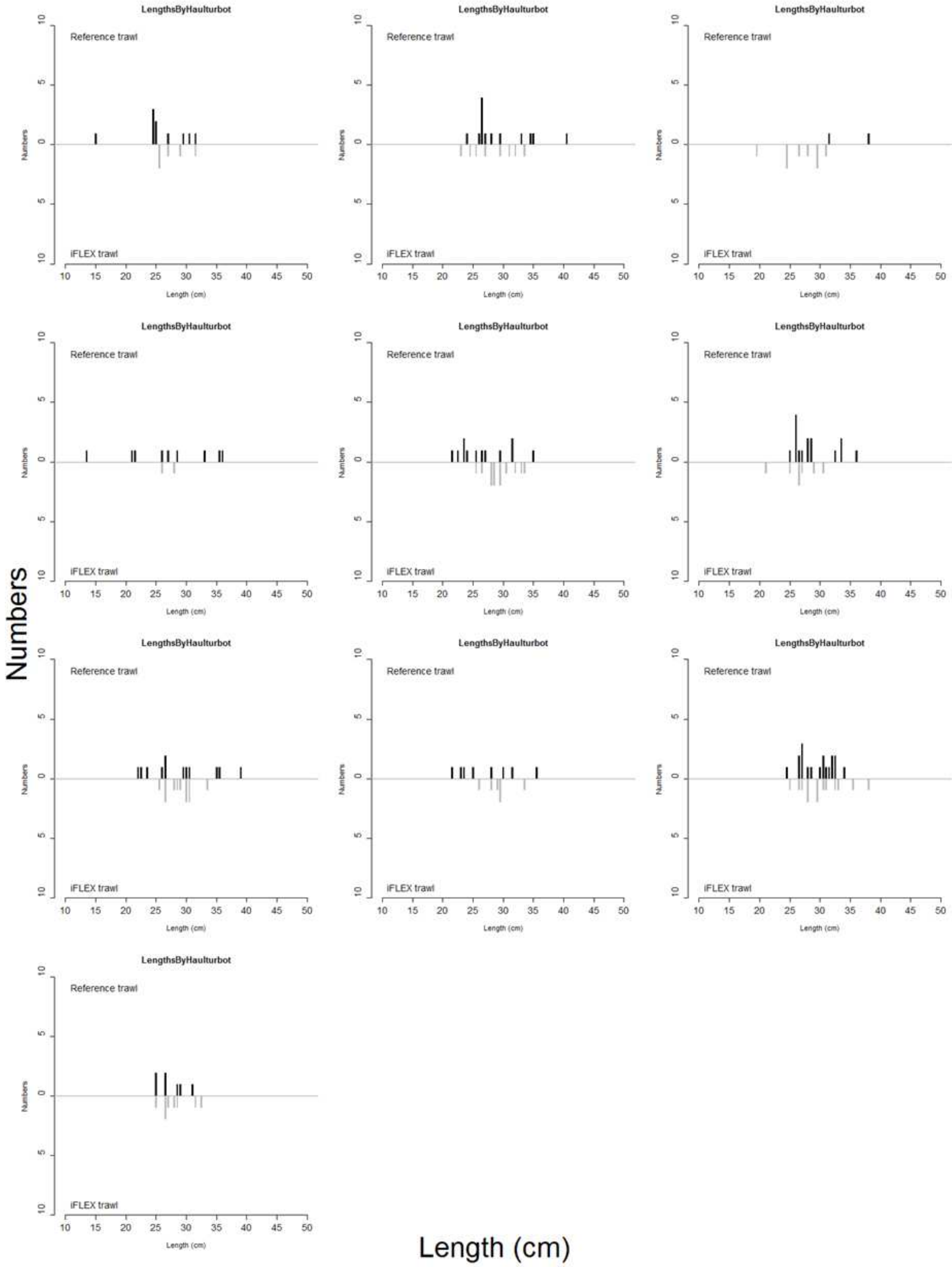


Figure 10: shows the length distribution by haul of turbot in comparison between the iFLEX and the reference trawl

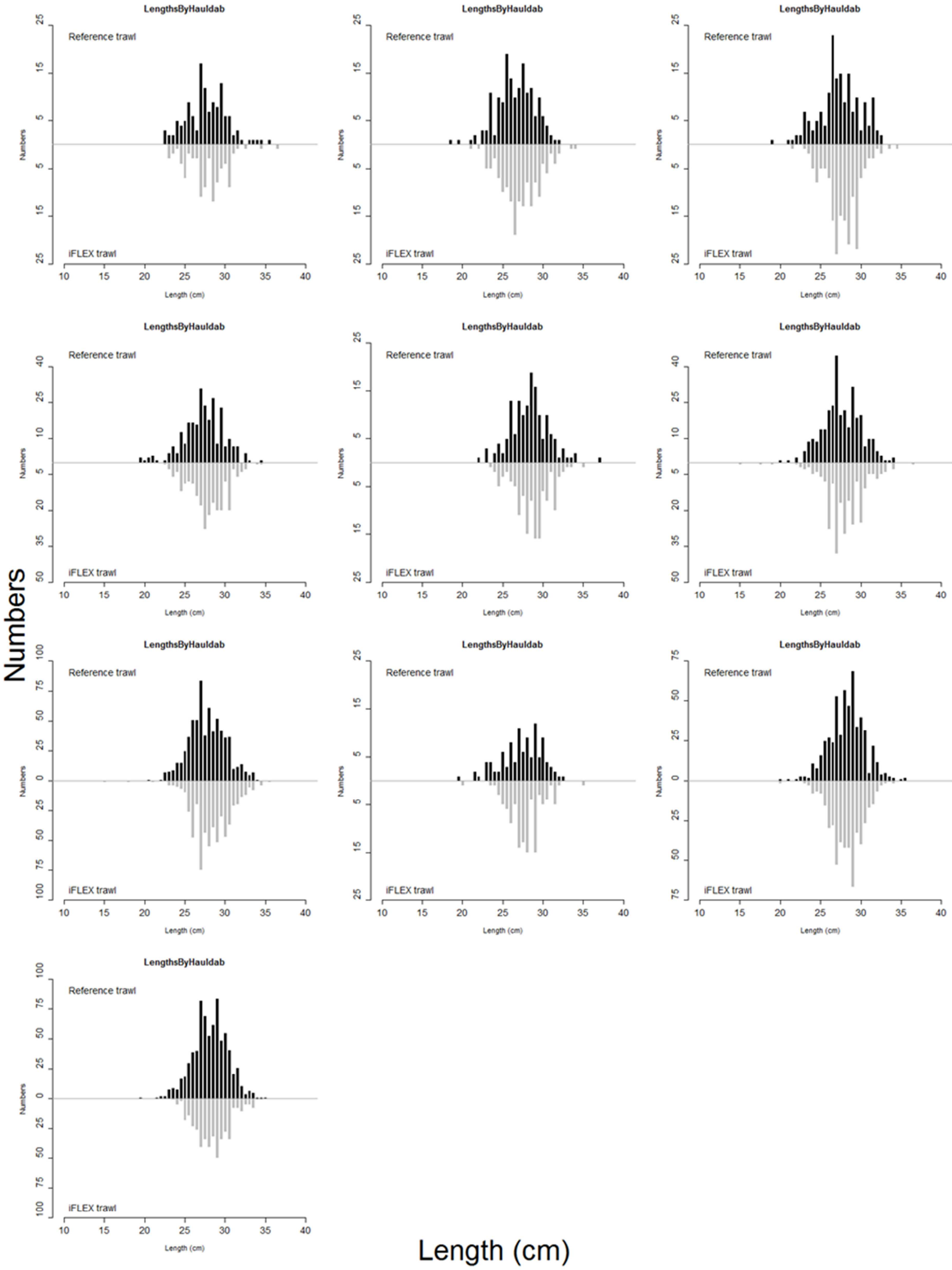


Figure 11: shows the length distribution by haul of dab in comparison between the iFLEX and the reference trawl

3.4 Comparison of the total values

The following figures show the total individuals distributed by length of the individual species catched by iFLEX or the reference trawl. The iFLEX catches are represented by the lower bars, the reference trawl catches by the upper bars.

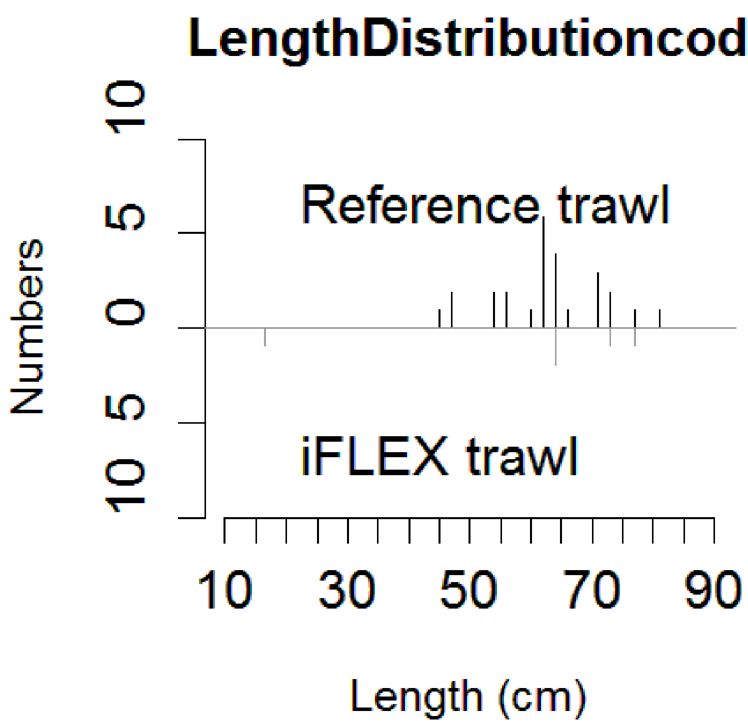


Figure 12: shows the total individual length distribution of cod with the iFLEX and the reference trawl. The fish had a length of 13.5 to 86cm. Altogether 68 individuals were caught, 16 by iFLEX.

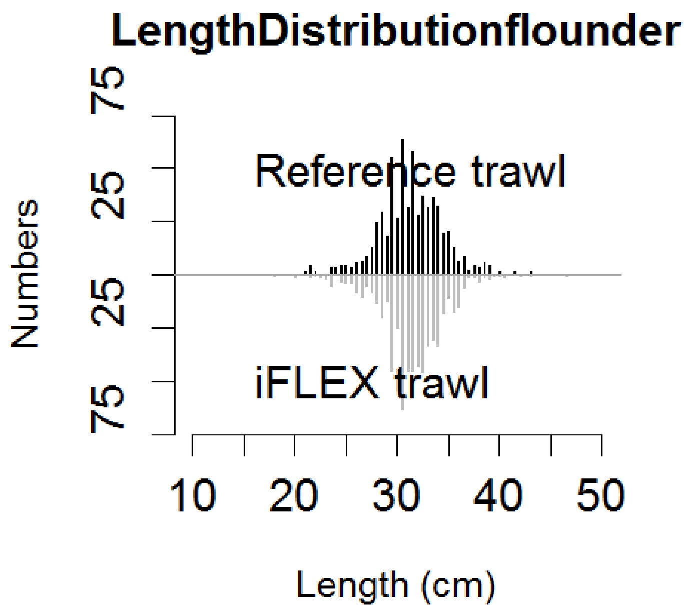


Figure 13: shows the individual length distribution of flounder with the iFLEX and the reference trawl. The fish had a length of 18 to 49.5cm. Altogether 1278 individuals were caught, 624 by iFLEX.

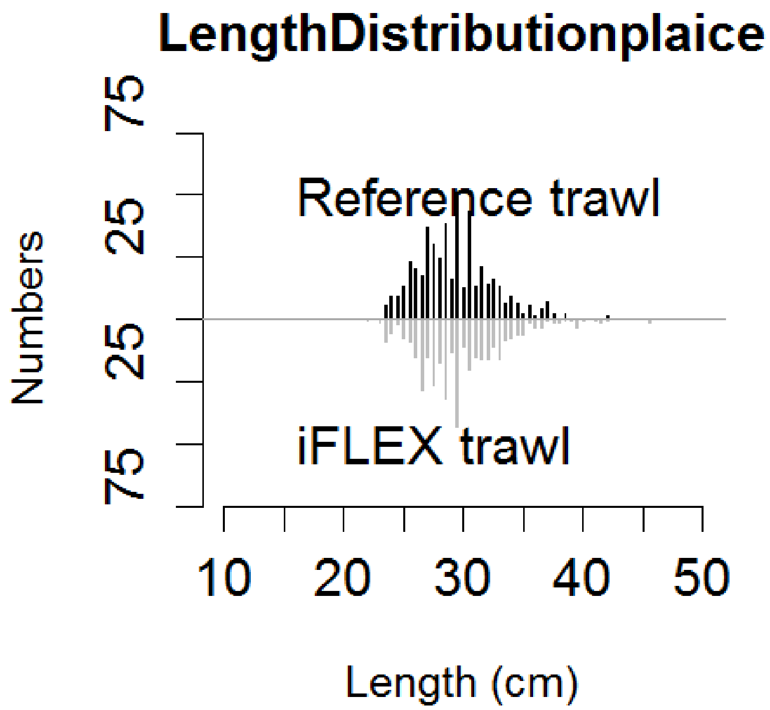


Figure 14: shows the individual length distribution of plaice with the iFLEX and the reference trawl. The fish had a length of 13 to 46cm. Altogether 921 individuals were caught, 408 by iFLEX.

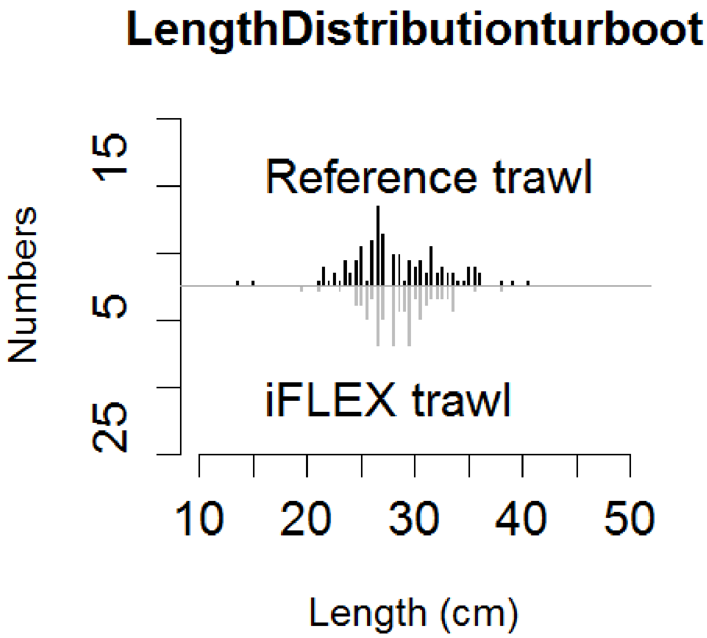


Figure 15: shows the individual length distribution of turbot with the iFLEX and the reference trawl. The fish had a length of 13.5 to 40.5cm. Altogether 180 individuals were caught, 80 by iFLEX.

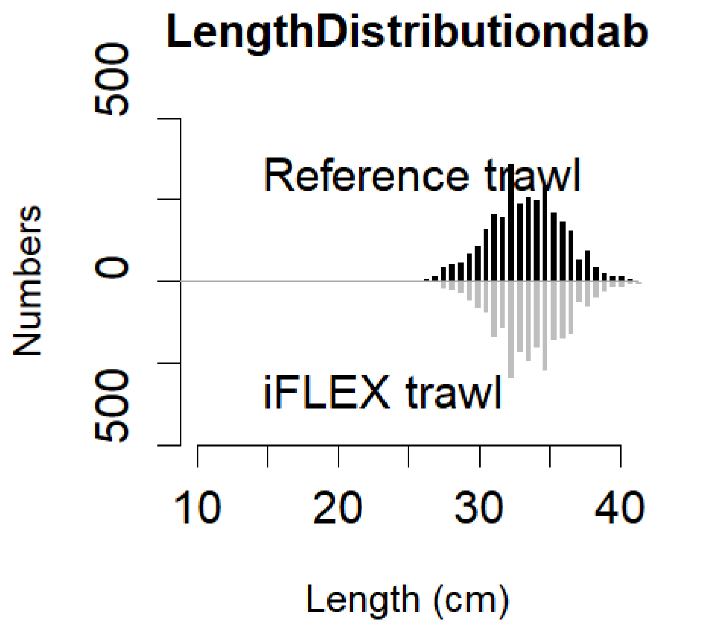
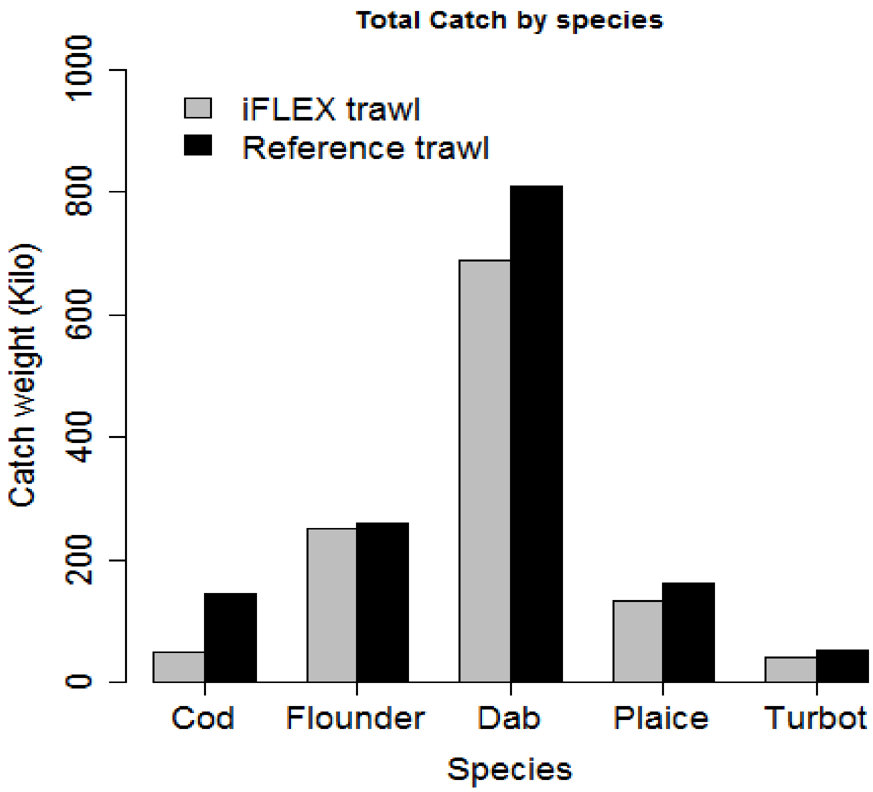


Figure 16: shows the individual length distribution of dab with the iFLEX and the reference trawl. The fish had a length of 15 to 37cm. Altogether 5964 individuals were caught, 2697 by iFLEX.



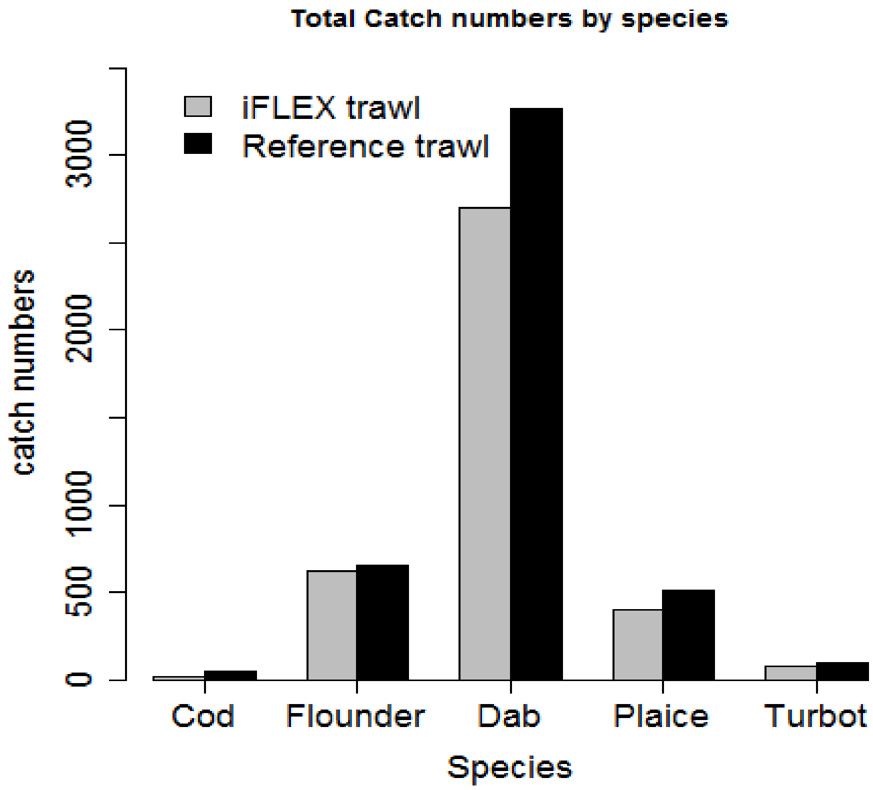
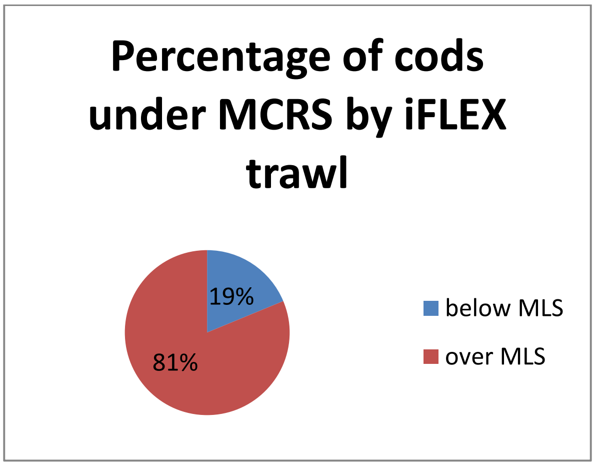


Figure 17: The upper graph shows the comparison between the iFLEX and the reference trawl in total catch rate by species in kilogram. By iFLEX 48.3 kg cod, 251kg flounder, 686.8kg dab, 133kg plaice and 39.5kg turbot were caught. By reference trawl 142.7kg cod, 259kg flounder, 810kg dab, 162kg plaice and 51.7kg turbot were caught. The bottom graph shows the comparison between the iFLEX and the reference trawl in total catch number by species. By iFLEX

16 individuals of cod, 624 flounders, 2698 dabs, 408 plaices and 80 turbots were caught. By reference trawl 55 individuals of cod, 654 flounders, 3267 dabs, 513 plaices and 100 turbots were caught.

3.5 Minimal conservation reference Size (MCRS)

The following figures (18-22) show the percentage of the fish that lay under the MCRS for each species in all hauls. It is illustrated by circular diagrams. The colour red represents the fish amount, which is above the MCRS. The fish amount, which is under the MCRS is represented by blue colour.



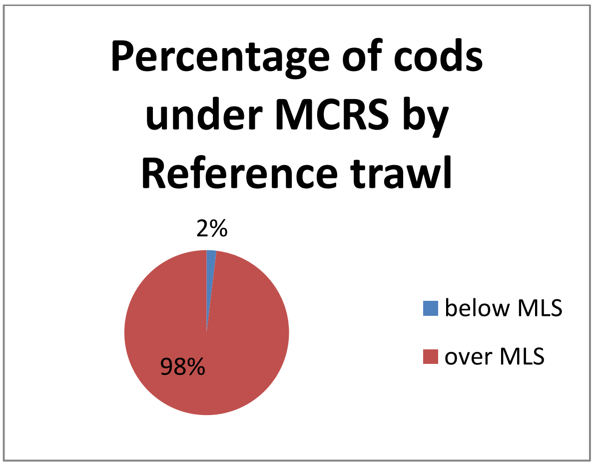
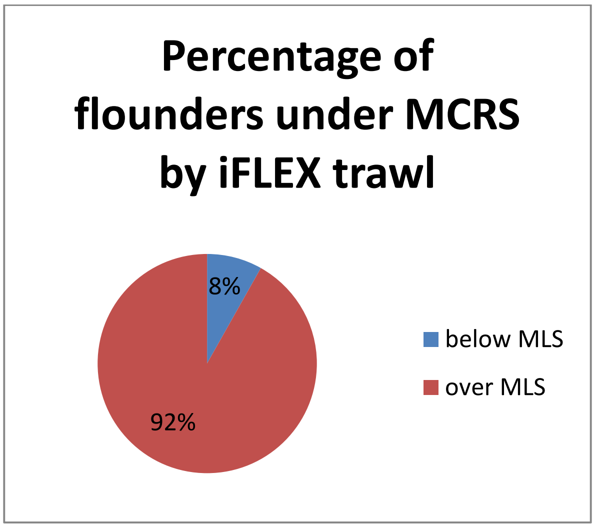


Figure 18: shows the percentage of cods under the MCRS (35cm) by iFLEX and the reference trawl for all 10 hauls together. By the iFLEX, a total of 16 cods were caught and 3 were under the MCRS. By the reference trawl, a total of 52 cod were caught and 1 was under the MCRS.



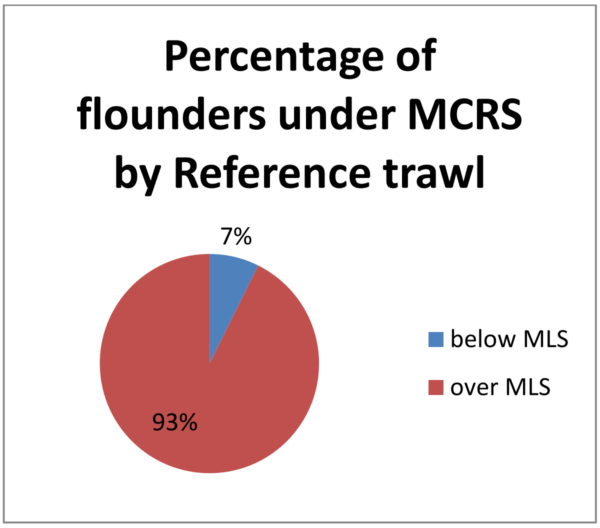
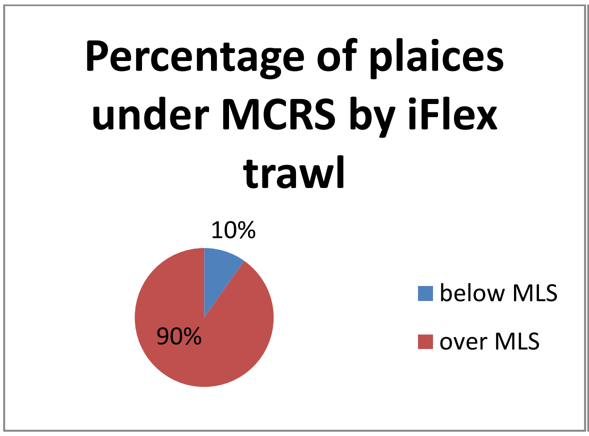


Figure 19: shows the percentage of flounder under the MCRS (27cm) by iFLEX and the reference trawl for all 10 hauls together. By iFLEX a total of 624 flounders were caught and 51 were under the MCRS. By the reference trawl a total of 654 flounders were caught and 48 were under the MCRS.



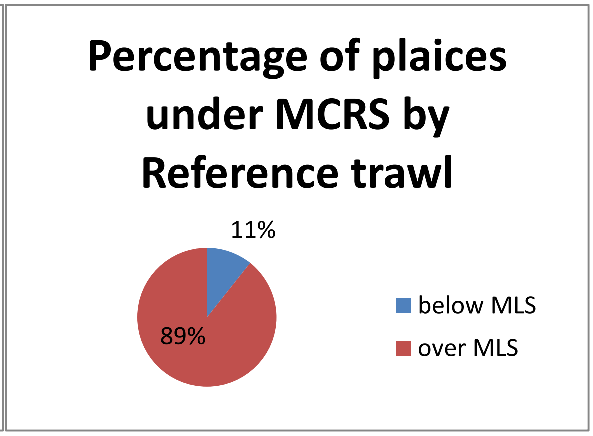
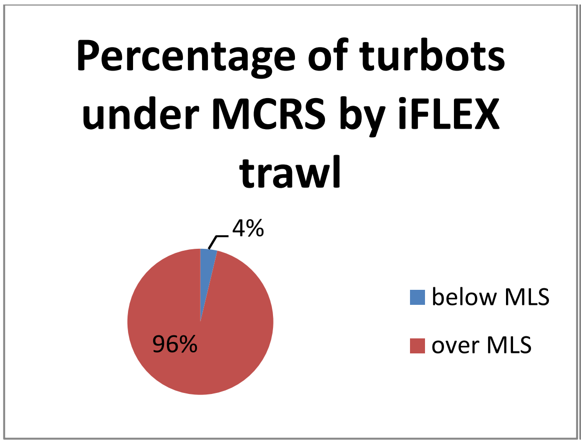


Figure 20: shows the percentage of plaice under the MCRS (27cm) by IFLEX and the reference trawl for all 10 hauls together. By the iFLEX a total of 408 plaices were caught and 40 were under the MCRS. By the reference trawl a total of 513 plaices were caught and 70 were under the MCRS.



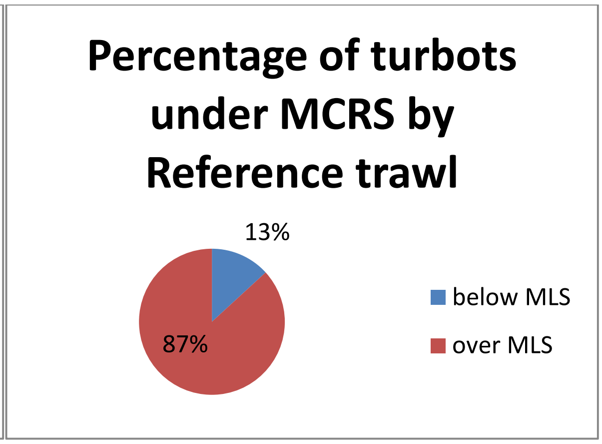
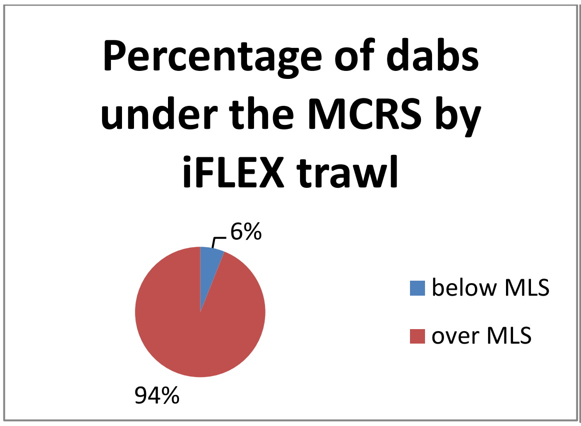


Figure 21: shows the percentage of turbots under the MCRS (24cm) by iFLEX and the reference trawl for all 10 hauls together. By the iFLEX a total of 80 turbots were caught and 3 were under the MCRS. By the reference trawl a total of 100 turbots were caught and 14 were under the MCRS.



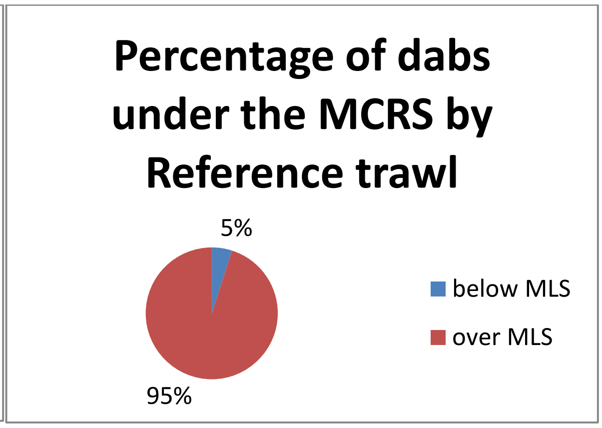


Figure 22: shows the percentage of dabs under the MCRS (24cm) by iFLEX and the reference trawl for all 10 hauls together. By the iFLEX a total of 2698 dabs were caught and 162 were under the MCRS. By the reference trawl a total of 3267 dabs were caught and 163 were under the MCRS.

3.6 Underwater observation

Altogether, 4 underwater videos with a total duration of 288.54 min were collected in 4 hauls. They were not used in all hauls because the observation was only random done. Since the cameras do not use artificial light, not to influence the natural behaviour of the fish, the quality of the videos was not optional. The sight induced by the rough sea was poor, in particular at the sea bottom.

The underwater videos allowed to control, whether the trawl opens and if the entire construction operates as intended. Furthermore, the different behaviour of roundfish and flatfish in their natural environment could be observed. Flatfish such as plaice and flounder, kept in contact or stayed near the trawl bottom. Most of the flatfish slided through the escape opening and the adapter, in to the codend.

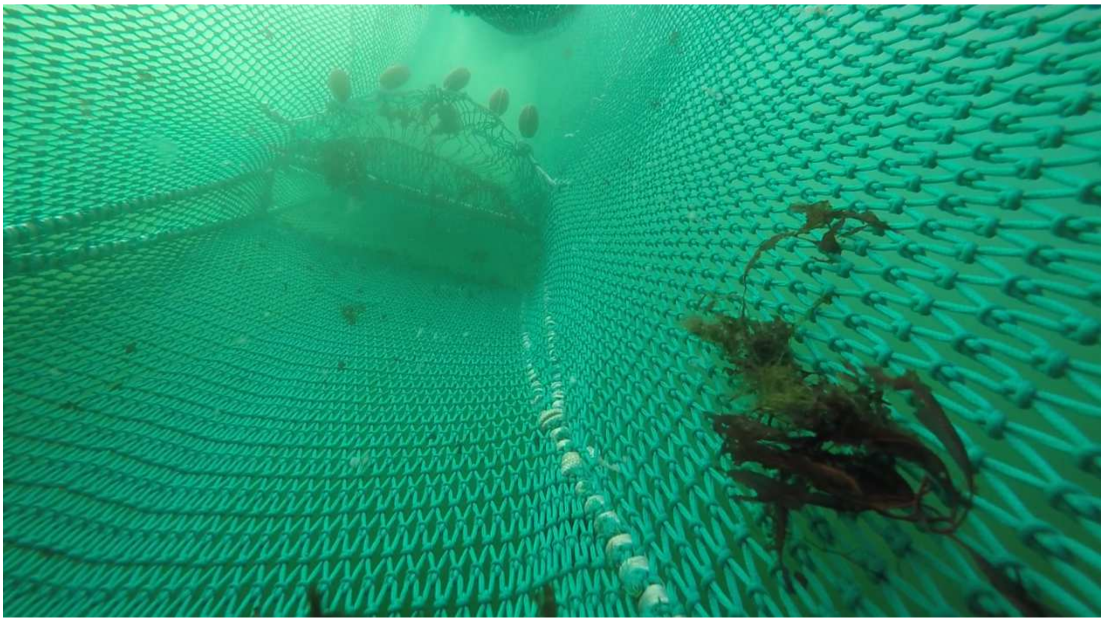


Figure 23: Sreenshot of an underwater video recording. The camera points from the inner trawl to the escape opening with the adapter and BACOMA-codend and the open excluder. Shows that the trawl opened as intended. (haul 3, during expsoing)

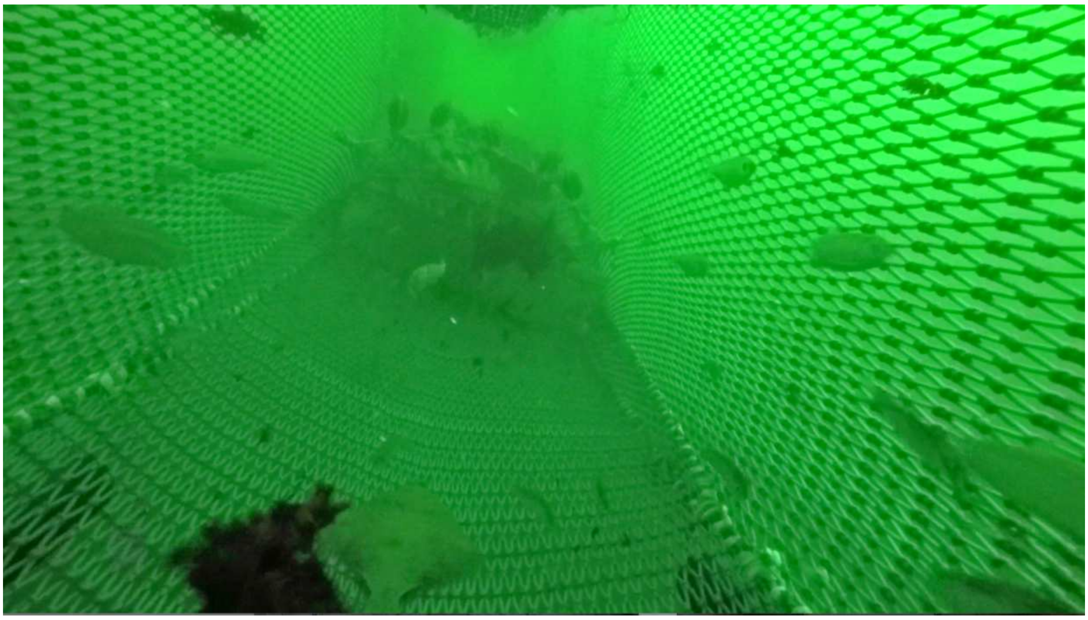


Figure 24: Screenshot of underwater video recording. Shows a flatfish staying in contact with the trawl bottom. (haul 3, during towing)

Figure 25: Screenshot of underwater video recording. Shows flatfish staying near the trawl bottom. (haul 7, during reeling)

Roundfish, here demonstrated by cod, avoided contact with the trawl and swam in the upper part of the trawl, where the excluder was open.

Figure 26: Screenshot of underwater video recording. Shows a cod avoiding contact with the trawl. (hole 5, during towing)

4. Discussion

4.1 Aim of the research trip

The aim of this research trip was to test, whether the iFLEX selective system can reduce the bycatch of cod in the directed flatfish fisheries.

For the year 2017, a new quota for the cod becomes effective. In 2016 German fishermen could fish 5597 tons of cod overall, in 2017 the number decrease in to 1194 tons (European Commission, 2017). As a consequence, cod can now function as a choke species in the flatfish fishery. To avoid this, the iFLEX is used. In addition, the reduction of captured cod should contribute to the conservation of the population stocks.

The foundation of the iFLEX is the FLEX. The FLEX System, to reduce flatfish bycatch in cod fisheries, was a success. There was a bycatch decrease up to 65% and no significant losses in cod caught (Mieske et al., 2016). For this reason, the assumption was if you invert the system similar results occur. Inverted means that the extension is open and the BACOMA-codend is placed on the escape opening with the aid of a codend- adapter. Due to the fact that flatfish stays in contact with the net bottom or swims near it, they get caught in the codend. Roundfish, such as the cod avoids the net and thus can escape through the open extension (Zimmermann et al., 2015).

To test this assumption, the iFLEX was integrated into a commercially used demersal trawl and a normal demersal trawl as a reference. Altogether 10 hauls took place (Mieske, 2017).

4.2 Comparison of the individual hauls

The analysis of the obtained data allowed the comparison of the individual hauls with each other. Based on Map 2 it is determined, that for every haul a different route was taken. The reason for this is, that the iFLEX should be tested as extensively as possible in the SD22 (Map 1). Additional, certain weather conditions or routes should be excluded as a success reason for the iFLEX. Another reason was to see if there was a difference in the fishing rates among the different routes. If this is the case, it would be possible to connect the iFLEX with the experiment by Zimmermann where regions are avoided in which the choke species occur more frequently (Zimmermann et al., 2015).

With the aid of Figure 7 it is clearly detected, that the cod catch by iFLEX is in every single haul less than in the reference trawl. To be more precise, only in 4 hauls cod was caught by iFLEX, while the reference trawl had in every haul cod. Furthermore, it is established that haul 5, 9 and 10 have the most cod caught. Out of the total of 68 caught cods, 42 were caught in these 3 hauls. 12 were from the iFLEX and the other 30 from the reference trawl. In addition, Table 1 features that 5 hauls (1-4 and8) had a towing duration of 30 minutes and the other 5 hauls (5-7 and 9-10) a towing duration of 60 minutes. Theoretically, it is assumed that with double towing duration the catch rate can double also. The data illustrate that 17 cods were caught after 30 minutes towing and 41 after 60minutes. This is more than a doubling.

Figure 8 shows the length distribution by haul of flounder. There are clear differences by each haul in the abundance numbers. The range reaches from 18 individuals in haul 1 by iFLEX up to 113 individuals in haul 2 by the reference trawl. In contrast to the cod hauls, flounder has not shown any significant increase in haul 5, 9 and 10. These have only moderate catches. Here is haul 2 noticeable since this is the only haul with more than 100 individuals each trawl. In addition Table 1 features that 5 hauls had a towing duration of 30 minutes and the other 5 hauls a towing duration of 60 minutes. However, the data illustrate that altogether 680 flounders were caught after 30 minutes towing and only 598 after 60minutes. Here, more fish were caught in a shorter time. This also applies to the comparison of the individual trawls.

The length distribution by haul of plaice is shown by Figure 9. It displays for each haul a different abundance numbers. The range reaches from 20 individuals in haul 5 by iFLEX to 80 in haul 6 by the reference trawl. As demonstrated with the flounders, there is not an increase of individuals in haul 5, 9 and 10. This figure does not feature a noticeable intemperance. Moreover, 5 hauls had a towing duration of 30 minutes and 5 of 60 minutes. After the towing duration of 30 minutes 431 plaices were caught and after 60 minutes 490. This is only 12% more of fish and not the theoretically expected 100% more.

Figure 10 shows the length distribution by haul of turbot. The Figure shows, as with the previous figures differences among the individual hauls. The range reaches from 2 individuals in haul 4 and 3 up to 18 in haul 9. The comparison between the catches from the iFLEX and the reference trawl features a huge gap not between each haul but amongst the difference in 1 haul by iFLEX and reference trawl. For example in haul 1 with iFLEX there were 5 turbots caught whereby with the reference trawl 10 were caught. Furthermore, a total of 71 turbots were caught after a 30 minutes towing duration and 115 after 60 minutes. With the iFLEX 43% more fish was caught after 60 minutes and 34% with the reference trawl.

The length distribution by haul of dab is shown by Figure 11. There are clear differences between the single hauls. The range reaches from 93 individuals in haul 1 by iFLEX up to 748 individuals in haul 10 by the reference trawl. It is established that haul 7, 9 and 10 show a significant increase in the catch rate of dab. Out of the total 5965 caught dabs, 3471 were caught in these 3 hauls. This corresponds to 58.2% of the total catch rate of dab. In addition, Table 1 features that 5 hauls had a towing duration of 30 minutes and the other 5 hauls a towing duration of 60 minutes. Altogether 1618 dabs were caught after 30 minutes towing and 4347 after 60minutes. Here the catch was not only doubled but almost tripled.

Only the cod catches features with the hauls 5, 9 and 10 a distinct increase of individuals in comparison to the other hauls. Within these 3 hauls, most codfish were caught with the iFLEX also. Further research trips should be made in order to see whether these were weather-related results or depending on the routes. If this is the case, it would be a benefit to avoid these routes to fish even less bycatch (Zimmermann et al., 2015).

The data of all 4 flatfish species together illustrate some interesting points. Altogether 8350 individuals of flatfish were caught. Of these 2800 were caught after 30 minutes towing duration and 5550 after 60 minutes. If the dab data is not included, because dab has no big economic impact, today there is only a different about 21 individuals and not over 2000 like before. With the iFLEX there were 565 flatfish individuals without dab after 30 minutes and only 547 individuals after 60 minutes. These results suggest that a longer towing duration does not promise higher catch rates. Further research trips would have to prove this assumption. Should other research trips be able to prove this, it would be appropriate to adjust the towing time accordingly in the commercial fishery.

4.3 Comparison of the total values

Altogether 68 individuals were caught, 16 with the iFLEX and 52 with the reference trawl. The 68 individuals had a total weight of 191kg, 48.3 by the iFLEX and 142.7kg by the reference trawl (Figure 17). This is a reduction of bycatch by 66%. Figure 12 shows the length distribution of cod from all 10 hauls together. Cod was caught from a length of 13.5 to

86 cm. Most of the fish were between 60-70cm, which are adults (Fischbestände Online, 2016).

Within the 10 hauls 1278 flounders were caught, 624 with the iFLEX and 654 with the reference trawl. The 1278 individuals had a total weight of 509.57kg, 250.55kg by iFLEX and 259.02kg by the reference trawl (Figure 17). This corresponds to a loss of 3%. On the basis of Figure 13, it can be seen that flounders were caught between a lengths of 18 to 49.5cm. Most of the fish were between 27 and 37cm. The ratio is similar for both trawls. Thus, no difference can be found within the length distribution between the iFLEX and the reference trawl.

In total 921 plaices were caught, 408 with the iFLEX and 513 with the reference trawl. The 921 plaices had a total weight of 291.78kg. Out of these 129.14kg are from the iFLEX and 162.64kg from the references trawl (Figure 17). This corresponds to a loss of 18%. Figure 14 features the length distribution of plaice from all hauls together. Plaices were caught between a length from 13cm to 46cm. The highest abundance resides between 23.5cm and 34cm.

Altogether 180 turbots were caught, 80 with the iFLEX and 100 with the reference trawl. The 180 turbots had a total weight of 89.74kg. 38.04kg came from the iFLEX catches and 51.7kg from the reference trawl catches (Figure 17). This corresponds to a loss of 23.7%. The length distribution of turbot by all 10 hauls together is shown in Figure 15. The length distribution is between 13.5m and 40.5cm. Most of the turbot individuals were between 24.5cm and 33.5cm.

Within the 10 hauls a total of 5965 dabs were caught. From these 2698 individuals were caught with the iFLEX and 3267 with the reference trawl. This corresponds to total weight of 1496.6kg. 686.82kg by iFLEX and 809.78kg by the reference trawl (Figure 17). Comparing both catches a loss of 15% is noted. Based on Figure 16 it is featured that the length distribution of dab is between 15cm and 37cm. The highest abundance is between 23cm and 32cm.

According to all 5 species, it can be seen that both trawls have similar length distributions. There is no significant difference. However, with the iFLEX a total of 3826 individuals and 1152.85kg were caught. Whereas, with the reference trawl a total amount of 4592 individuals and 1425.8kg were caught (Table 2-5). In percent, this means a catch loss of about 19%. Considered one look only at the cod catches, a reduction of 66% can be seen. This means for fishermen that the quota, established by the EU for the cod, is reached with less speed. On the downside there is also a decrease in the catch rates of flatfish. Approximately 15% of the flatfish is lost in the iFLEX system compared to the commercial demersal trawl. As a consequence, fishermen have to tow more often for the same catch rate as before. If they have to go out more frequently, the danger of catching cod is also increasing.

4.4 MCRS data

In 2013 the introduced landing obligation (European Commission, 2013), caused the MLS to be adapted to this new regulation. Therefore, the MLS is substituted with the MCRS. Fish below the MCRS have to be landed but cannot be sold at market for human consumption (European Comission, 2014). This means losses for the fisherman, since the market for human consumption brings the most income. For this reason, some systems have already been developed, for example the adjustment of the mesh size, to avoid fish under the MCRS.

Now, it is to be examined whether the iFLEX system has an influence on the catch rate of fish under the MCRS.

Figure 18 shows the percentage of cods under the MCRS by iFLEX and the reference trawl. Cod has a MCRS of 35cm, which is a fixed size. By the iFLEX 19% are under the MCRS, which means 3 of 16 cods. By the reference trawl only 1 of 52 cods are smaller than 35cm, corresponding to 2%. Here the iFLEX did not have a positive effect on the catch rate but rather a degradation.

The percentage of flounders under the minimum conservation reference size is features in Figure 19. The MCRS is by 27cm. This size has been used since flounders of this size are regarded as being mature. By the iFLEX a total of 624 flounders were caught and of these 51 are under the MCRS. In percentage this means 8%. Altogether 654 flounders were caught with the reference trawl and 48 are under 27cm. This corresponds to a percentage of 7%. As already noted by cod, more fish under the minimum size were caught with the iFLEX.

Figure 20 depicts the percentage of plaice under the MCRS. The MCRS is by 27cm, which is a fixed size (ICES, 2010). It is noticeable that, unlike by cod and flounder, here the iFLEX caught less fish under the MCRS than with the reference trawl. With the iFLEX a total amount of 408 plaices were caught. Out of these 40 plaices are under the minimum size, which means in percentage 10%. 11% of the total catch rate is under 27cm by the reference trawl. In numbers this means that of the 513 caught plaices, 70 are under the MCRS.

Figure 21 features the percentage of turbots under the minimum conservation references size. The MCRS for turbots is by 24cm. With the iFLEX altogether 80 turbots were caught and 3 are under 24cm. This means 4% of the total catch. 100 Turbots were caught with the reference trawl and from these 24 are under the MCRS, corresponding to 13%. Here there is a significant difference between the iFLEX and the reference, whereby iFLEX less fish under the MCRS were caught.

The percentage of dab under the MCRS is shown with Figure 22. Dab has a minimum conservation reference size of 24cm. Here, the difference between iFLEX and the reference trawl is by 1%. With the iFLEX a total amount of 2698 dabs were caught and of these 162 are under the MCRS. With the reference trawl a total amount of 3267 dabs were caught and of these 163 are under the MCRS.

In summary, it can be concluded that no specific effect on size has taken place. Since no consistent trend can be identified, the cases with fewer fish under the MCRS have to be considered as random.

4.5 Underwater observation

The underwater camera were installed in front of the iFLEX to control whether the trawl opens and if the entire construction operates as intended. Furthermore, the cameras were used to observe if flatfish and roundfish behave like anticipated.

The cameras did not use additional light to influence the behaviour of the fish. Due to the lack of the additional light and rough sea, the quality of the videos is poor. This means, that the videos were partly too dark and by other sequences the view was blocked because of ground swirls. As a consequence, an evaluation of the video material was only sequentially possible.

Figure 23 shows the correct opening of the trawl and that the entire construction operates as intended. No malfunction was detected. Thus, the trawl construction can be excluded as an error source.

Figure 24 and 25 features the behaviour of flatfish like it is anticipated. In Figure 24 is a flatfish, probably a flounder, staying in contact with the trawl bottom. Figure 25 shows 2 dabs, which swim towards the iFLEX and remain close to the trawl. Both screenshots show the natural behaviour of flatfish, as it is anticipated.

Figure 26 features a cod avoiding contact with the trawl. Looking at the following seconds, it can be observed how the cod get carried away from the current through the open extension into freedom. This scene proves the expected behaviour of cod.

However, there are other scenes where the cod strives against the current to sink exhausted to the bottom of the trawl and entering the codend. Another sequence shows a codfish lurking at the side of the trawl and devouring passing prey fish. These examples show that not every fish has the same behaviour, so that bycatch occurs despite the open extension.

With the help of the underwater observation, it is not possible to determine why less flatfish are caught with the iFLEX system. Scenes showing the reasons for this cannot be analysed, for example due to the poor quality. In addition, only videos were made in haul 1, 3, 5 and 7. Therefore, it is possible that other hauls would have given reasons for this problem.

4.6 Conclusion

This study showed that it is possible to decrease the cod bycatch up to 66% with the iFLEX system. At the same time, no deterioration in the length distribution could be observed. However, a loss of flatfish had to be booked. Compared to the reference trawl, it was up to 24% of the weight less.

The underwater videos exclude a source of error in the construction, but cannot show why flatfish escaped through the extension. More test series with underwater observation in every haul and better quality would have to display exactly where the problems is.

Furthermore, only 68 cods were caught during the entire research journey. This small number can be seen as a reflection of the state of the cod population. At the same time, due to this small number, the reduction rate of 66% can only be appreciate with caution.

Research trips with the iFLEX in other waters or regions of the Baltic Sea would have to provide further data to support the results obtained here.

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Appendix

List of Abbreviations

BfN: Bundesministerium für Naturschutz

BMEL: Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz

FAO: Food and Agriculture Organization of the United Nations

ICES: International Council for the Exploration of the Sea

MCRS: Minimum conservation reference size

MLS: Minimum Landing Size

SD: Sub-division

Selbständigkeitserklärung

Hiermit versichere ich, dass ich diese Arbeit selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe. Außerdem versichere ich, dass ich die allgemeinen Prinzipien wissenschaftlicher Arbeit und Veröffentlichung, wie sie in den Leitlinien guter wissenschaftlicher Praxis der Universität Rostock festgelegt sind, befolgt habe.

Ort, Datum Unterschrift