Institut Für Ostseefischerei

Alter Hafen Süd 2, 18069 Rostock Telefon 0381 8116122 Telefax 0381 8116-199 juan.santos@ti.bund.de

Bericht

über die 696. Reise des FFS Solea
vom 12.11. **bis** 21.11.2014

Fahrtleitung: Juan Santos

Das Wichtigste in Kürze

Während der Reise SO696 wurde eine neuartige Plattfisch-Selektionseinrichtung getestet. Während die auf vorigen entwickelte und getestete Plattfischselektionseinrichtung, FRESWIND (Flatfish Rigid EScape WINDows) Unterschiede in der Morphologie von Plattfischen und Rundfischen (z.B. Dorsch) nutzt um die Arten zu trennen, nutzt neue FLEX-Design (FLatfish EXcluder) Unterschiede im Schwimmverhalten. Trotz des sehr einfachen Aufbaus der Selektionseinrichtung (inkl. der sich daraus ergebenden Vorteile für den Einsatz in der Fischerei) ist es möglich den Plattfischbeifang um ca. 80% zu reduzieren bei gleichzeitigem nahezu unverändertem Fang von Rundfischen. Damit steht eine weitere Möglichkeit zur Anpassung der Fischereiaktivität z.B. im Rahmen der Einführung eines Anlandegebots in der Ostsee zur Verfügung.

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Euro-Baltic Mukran

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Testing FLEX, a FLatfish EXcluder device for trawl fisheries

Juan Santos, Bernd Mieske and Daniel Stepputtis

Thünen Institut for Baltic Sea Fisheries

1 Introduction

The former EU policy allowed fishermen to perform a *take the best, leave the rest* fishing strategy. As a result, those fish not intended to be caught for legal restrictions (e.g. quota exhaustion or minimum landing size), market value or any other reason [7] could be subsequently discarded. Discarding is an ethically and ecologically undesirable fishing practice of global concern. It wastes natural resources and severely challenges the sustainability of fisheries [4]. It decreases the efficiency of fishing operations and changes the trophic flows in food-webs and entire ecosystems [1, 3].

The Landing Obligation adopted in the reformed European common fisheries policy (CFP), is a step forward to phase out discards in commercial fisheries. To be implemented progressively, the rule forces the fishermen to land all catches from quoted species, and count the catch volumes against the quotas. One of the biggest issues to be addressed in mixed fisheries under the current scenario is the presence in catches of species with limited quota. Exhausting the quota allocated for such species can alter (or even stop) the normal fishing strategy of the fleets, even if there is still quota available for other species caught besides the choke species (choke species can be defined as "species for which the available quota is exhausted (long) before the quotas of (some) other species that are caught together in a (mixed) fishery are exhausted").

A recent desktop study identified plaice (*Pleuronectes platessa*) as a potential choke species for the German Baltic cod (*Gadus morhua*) trawl fishery. In addition, other unquoted flatfish species are by-caught in this fishery and subsequently discarded because of their low market value. This represents an ethical problem to be addressed besides the economical problem it may involve for the fishery to exhaust plaice quota before the cod quota.

With the aim of providing tools for the Baltic fishermen to address the mentioned bycatch problem, the Thünen Institute of Baltic Sea Fisheries (TI-OF) started in 2013 to develope technological solutions to avoid flatfish catches in cod-directed trawl fisheries. The initial efforts resulted in the development of the so-called FRESWIND (Flatfish Rigid EScape WINDows), a concept which uses the special morphology of flatfish to optimize selectivity (i.e., to largely avoid flatfish catches) without compromising the catchability of marketable sizes of cod [8].

Further research efforts have been invested into a second flatfish bycatch reduction device. FLEX (FLatfish EXcluder) has been developed and tested for the first time in 2014 by the TI-OF. The new device has been designed as a simple, cheap, handy and reversible adaptation of the net, which aims to exclude flatfish before entering in the codend. Unlike FRESWIND, the functioning of FLEX relies on observed differences in vertical swimming preferences between flatfish and roundfish to achieve the desired species selection.

The development of the FLEX concept from the earliest stages of design to the first testable setup was carried out during the research cruise `Clupea 287`, while the experimental fishing involving quantitative data collection was carried out during the present research cruise `Solea 696`. The cruise was conducted in Baltic fishing grounds located at ICES Subdivisions 22 and 24. The experimental design was based on paired gear method. It is the objective of this report to quantify the effectiveness of FLEX to avoid flatfish catches, and the effect on the catch efficiency on the targeted cod.

2 Material and Methods

2.1 FLEX concept

Underwater video recordings collected in previous sea trials (`Clupea 271`, `Clupea 275`) showed clear trends in the vertical preferences of fish when swimming towards the codend; while cod generally tend to swim in the water column staying clear of the netting, flatfish tend to swim very close to or even contacting the floor of the net. Considering these behavioral differences, an obvious strategy to reduce flatfish catches would be to open an escapement zone in the lower panel of the net tunnel. FLEX therefore is basically an excluder-slot, which is kept open regardless of the mechanical forces acting on the net by utilizing a simple frame made of rigid wire and fiber glass. Small weights are attached to the lower net panel to create a funnel shape to drive the flatfish towards the excluder. On the other hand, a rectangular piece of net with small floats on top is connected to the upper side of the FLEX frame, with the aim of deflecting roundfish upwards to prevent losses of targeted fish (Figure 1). As in the case of FRESWIND, by mounting FLEX in the extension piece of the net, a sequential selection system is established as it follows:

- Flatfish should escape through FLEX before they enter the codend.
- Roundfish should not use the FLEX escapement opening, therefore they end in the codend, being available for size selection.

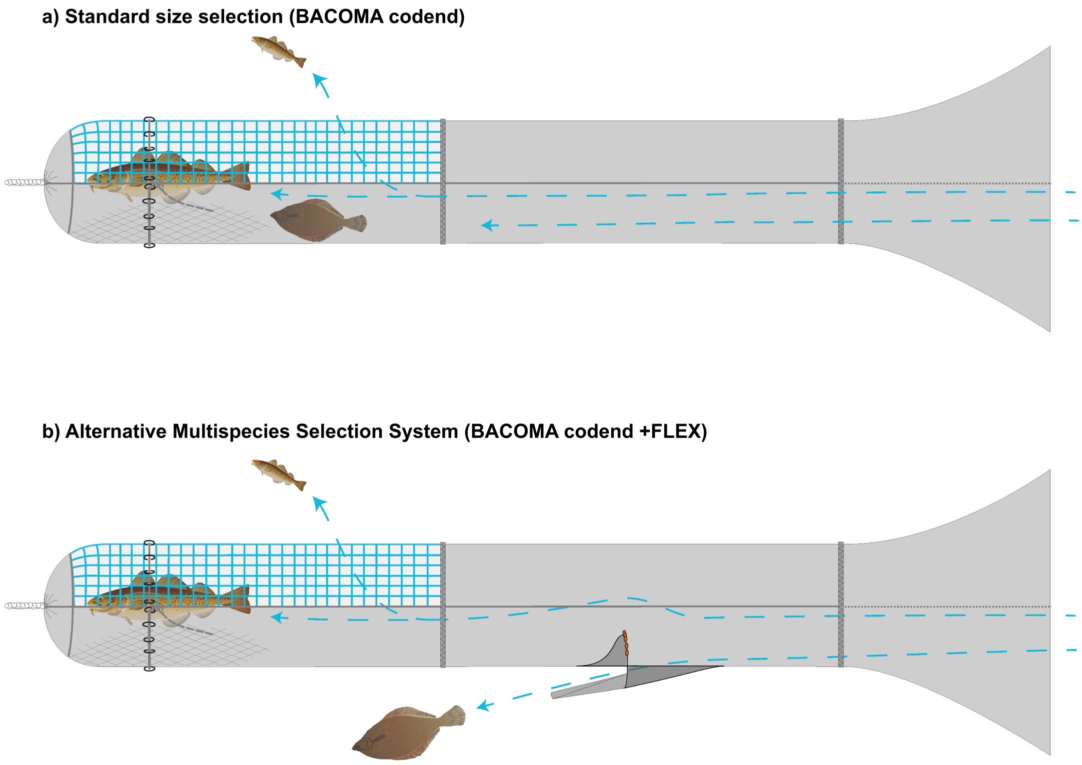

Figure 1: Top: Functioning of the standard BACOMA codend, designed to optimize the selectivity of Baltic cod. Blue arrows represent differences in swimming paths between cod and flatfish species, based on underwater observations collected in previous research cruises. Bottom: Intended multi-species size selection system, with FLEX mounted ahead of the codend to provide escapement possibilities for flatfish species. The figure show the funnel shape of the net panel in front of the FLEX opening, and the upper flapper to discourage cod from using FLEX to escape.

2.2 Experimental design

The experiment was based on the paired gear method [9], used here to directly compare catches from a reference gear and a test gear. The reference gear combined a small mesh codend ($60mm$) and an extension piece with the same netting. On the other hand, the only difference between the reference and the test gear was the insertion of FLEX device in the lower panel of the extension piece. With this configuration, it was assumed that all fish entering in the reference gear would be finally caught, while the only change for a fish to escape from the test gear would be by using FLEX.

Both the test (FLEX extension + unselective codend) and reference (unselective extension and unselective codend) gears where used simultaneously and in parallel. This was possible due to the usage of the SOLEA-DBT (Double Belly Trawl), developed by Bernd Mieske (TI-OF) and used for first time during the `SO693` cruise. The DBT allow us to perform a paired gear experiment (reference and test were attached separately on each belly) while keeping the single trawl rigging normally used in the research vessel. Thyborön type 11 (450 kg) doors were used to spread the experimental trawl.

The data collection was carried out onboard FRV `SOLEA`, a 42,40 m, 1780 kW German research vessel, and the experimental fishing was conducted on fishing grounds in ICES subdivisions 22 and 24. All fish caught at haul level were sorted by species, weighted using an electronic scale, and subsequently measured to the half centimeter below using electronic measuring boards. Operational information were automatically gathered using the bridge facilities.

Let $n_{l,h,t}$ be the number of fish with length l caught in the test gear t during haul h, $n_{l,h,r}$ the number of individuals caught in the reference gear, and $n_{+,h,l}$ the global catch of the haul. Then

$$CC_{l,h} = \frac{n_{l,h,t}}{n_{+,h,l}} \tag{1}$$

is the calculation of the catch proportion in the test gear. $CC_{l,h}$ is normally used for catch comparison to assess the catch efficiency of the test gear relative to the reference gear. Catch comparison analysis are not directly focused on investigating the size selection properties of a given selection device, but on estimating the relative gain/loss of catchability of the test system in relation to the reference system [5], assuming that the observed trend in $CC_{l,h}$ is caused by the introduction of the selection device. Coming back to the present study, values of $CC_{l,h} < 0.5$ would indicate that fish of length l used FLEX to escape during haul h, while values of $CC_{l,h} \sim 0.5$ would mean no FLEX effect in fish catchability.

2.3 Data analysis

2.3.1 Catch comparison model

It is assumed that the number of fish observed in the *test* gear is a random variable from the binomial distribution,

$$n_{l,t} \sim Binom(n_{+,l}, CC(l)) \tag{2}$$

The objective in catch comparison studies is to estimate the catch comparison curve ($\hat{CC}(l)$) most likely associated to the experimental data. This is addressed by applying regression tools with the form:

$$\mathbf{Y} = \mathbf{X}\beta + \epsilon \tag{3}$$

where $\mathbf{Y}$ is the *logit* transformation of the catch proportion in test codend ($\mathbf{Y} = \log(\frac{CC_l}{1-CC_l})$), $\mathbf{X}$ is the model matrix, β the vector of fixed effects used as predictors in the model, and ϵ the model error. The most applied models only use two fixed effects $\beta = \binom{\beta_0}{\beta_1}$, where β_0 is the model intercept, and β_1 is the effect of fish length (l). With this structure it is expected to obtain indirect information about the mechanical size selection of the tested device. Since FLEX is not developed to mechanically sort fish by size, a significant effect of length in the catch comparison analysis would be related with behavioral differences on the way they interact with the excluder. For example, a positive trend along the length range would mean a positive trend to avoid FLEX with length size.

The experimental fishing data obtained along the cruise consist on repeated measurements (hauls) of the variable of interest ($CC_{l,h}$ 1, $h = 1, \ldots, H$), taken over length classes from the measured species. It is well known that the performance of a fishing trawl can vary significantly from haul to haul even if the gear was not altered (as in the present case). This between-haul variation is usually related with uncontrolled factors acting on the gear during fishing [2], and it must be taken into account in the models to avoid misleading final predictions. It is therefore of interest to define a model structure able to account for such between haul variation affecting the individual hauls, to obtain a better estimation of the "population" catch comparison curve. Following these argumentation equation 3 is extended to the form;

$$\mathbf{Y} = \mathbf{X}\beta + \mathbf{Z}b + \epsilon \tag{4}$$

Model 4 accounts for the potential between haul variation implicit in the data, by including a random structure, $\mathbf{Z}b$, with two different random effects $b = \binom{b_0}{b_1}$. b_0 allows the intercept to vary over hauls ($\beta_0 + u_{0,h}$, random intercept). To increase the degree of flexibility of the model, a second random effect (b_1) is used, allowing the effect of fish length to vary between hauls ($(\beta_1 + u_{1,h}) * l$, random slope). Finally, the structure of $\mathbf{X}\beta$ in model 4 is further generalized by considering other fixed effects which might influence the performance of FLEX:

- *Side (s)*= Side where the test codend was mounted (two levels: str or bb).
- *Fishing ground (fg)*= Considering ICES statistical rectangles
- *Towing duration (t)*
- *Total catch test (w)*

2.3.2 Model selection and predictions

A two stage model selection procedure was implemented to find the best candidate model from (4) and sub-models, which are defined by leaving out one or more effects from the full model structure.

The first stage comprises the definition of the random structure of the model. Three different structures were tested:

- Correlated random intercept and random slope.
- Uncorrelated random intercept and random slope.
- Random intercept

The fixed effects structure in this stage was simplified, and only the intercept was included in the estimation. The best random structure candidate was chosen based on the assessment of AIC and BIC values.

A full model was defined by combining the fixed effects (l, s, fg, t and w), and the random structure chosen in the first stage.

The second stage comprised an automatic model selection of the fixed effects. Considering all combinations of the fixed effect included in the starting full model, a total of 32 different competing models were estimated and ranked according to models AIC value. Therefore, the model with the lowest AIC value was chosen as the most appropriate model for each of he studied species.

The best model obtained in the model selection was used to predict the catch comparison curve at haul level ($\hat{CC_h}(\mathbf{X})$). This conditional predictions are used to assess the goodness of fit of the model to the experimental data. Because we are mostly interested on the length effect, the predictions were plotted conditioned by fish length.

The unconditional catch comparison curve ($\hat{CC}(\mathbf{X})$) is also calculated to provide population-level predictions. The catch comparison curve cannot directly express the rate of fish of length l that would be retained in the test codend, relative to the reference codend. Experimentally, such a question can be answered by deriving $\hat{CC}(\mathbf{X})$ into a catch ratio curve $\hat{CR}(\mathbf{X})$. This is done as follows:

$$\hat{CR}(\mathbf{X}) = \frac{\hat{CC}(\mathbf{X})}{1 - \hat{CC}(\mathbf{X})} \tag{5}$$

equation 5 is used here to assess the length-specific exclusion rates provided by FLEX. For the marketable sizes of cod (sizes above MLS), the value of $\hat{CR}(\mathbf{X})$ should preferably be close to 1.0. In contrast, $\hat{CR}(\mathbf{X})$ values closer to 0 are desirable for flatfish species. For example, a value of $\hat{CR}(\mathbf{X}) = 0.4$ would imply a catch efficiency of 40% for length class l relative to the reference gear. This value would represent a reduction in the catch by 60%.

Confidence intervals associated to the catch ratio curve were estimated by parametric bootstrapping. All analysis were conducted using R [6], a free software for statistical computing.

3 Results

3.1 Operational information and catch data

A total of 40 valid hauls were conducted from 12.11 to 21.11.2014 in fishing grounds of Fehrmarn, Mecklenburger Bucht, Kühlungsborn, Warnemünde and north of Rügen. Hauls 1 to 36 were conducted under the experimental design described in Section 2.2, while hauls 37 to 40 (21.11.2014) mounted BACOMA codend in the test codend, therefore these hauls are not used in this report for further descriptions or analysis. The observed catch profile differed between fishing grounds, with flatfish dominating the catches near Fehmarn and Mecklenburger Bucht, while cod and withing (*Merlangus merlangus*) were the most abundant species off Warnemünde during the last days of the cruise. Catch information from hauls 20 to 22 are not available due to problems with the data collection protocol. Dab (*Limanda limanda*) was the most abundant species in catches (pooled hauls 1 to 36) (10339 individuals), followed by cod (8848 individuals), whiting (3219 individuals) and flounder (*Platichthys flesus*) (2718 individuals). Only 410 plaice individuals were caught (Table 2).

Table 1 show the catch volume (kg) of the most important species after pooling the catches over hauls (hauls 1 to 36). The comparison of catch weight in the test and the reference gears shows a clear trend in the performance of the test gear. The catches of the roundfish species (cod, whiting and herring) are similar in both gears (catch ratio in test codend over 95%, while the catches of flatfish species (dab, flounder, plaice and turbot) are noticeably lower in the test gear, with catch ratios in the range of 18.4-24.5%. Figure 2 indicates that there is not a strong differences in the length distributions of cod, whiting, dab and flounder in the test and the reference gears.

	Catches (kg)		
species	test	reference	CR Test
cod	2084.51	2251.92	95 (66.2-144.3)
dab	240.09	1137.32	21.2 (16.4-26.8)
flounder	111.40	607.04	18.4 (15.3-21.3)
herring	338.11	348.06	97.6 (81.3-115.9)
whiting	239.64	244.57	99.2 (67.9-132.4)
plaice	25.23	106.31	24.5 (17-35.9)
horse mackerel	24.10	37.91	69.8 (33.3-114.7)
turbot	4.02	18.78	24.5 (6.9-65.1)

Table 1: Catch volume (kg) by species in test and reference gear (pooled data from haul 1 to haul 36). CR Test = bootstrap bias corrected catch ratio in test codend (Confidence Intervals in brackets).

date	station	haul	fishing ground	start	end	latitude	longitude	towing speed (kts)	mouth opening (m)	doors spread (m)	Observed catches (n)				
											Cod	Flounder	Dab	Plaice	Whiting
12.11.14	771	1	SD 22 N-lich Warnemünde	9:53:24	11:53:24	54° 12,253N	011° 58,002E	2.60	6.10	38.90			2		
12.11.14	772	2	SD 22 N-lich Warnemünde	12:44:10	13:14:11	54° 12,823N	011° 45,772E	2.40	5.40	34.50		6	4		8
12.11.14	773	3	SD 22 N-lich Warnemünde	14:06:30	14:36:30	54° 11,954N	011° 50,760E	2.70		32.80	1	2	1		
12.11.14	774	4	SD 22 N-lich Warnemünde	16:01:26	17:01:38	54° 11,768N	011° 56,047E	2.80		49.40	2		2		
13.11.14	775	5	SD 22 E-lich Fehmarn	7:13:02	8:13:03	54° 26,611N	011° 25,508E	2.70	4.90	46.80	17	198	850	13	84
13.11.14	776	6	SD 22 E-lich Fehmarn	9:11:52	11:11:52	54° 26,687N	011° 25,458E	3.20	4.80	46.30	19	566	1883	37	121
13.11.14	777	7	SD 22 E-lich Fehmarn	12:43:41	14:43:43	54° 21,715N	011° 24,420E	3.30		45.10	10	380	1646	34	74
13.11.14	778	8	SD 22 E-lich Fehmarn	15:22:04	16:22:06	54° 27,450N	011° 25,047E	3.00		48.70	5	152	914	12	67
14.11.14	779	9	SD 22 N-lich Kühlungsborn	7:09:32	8:09:32	54° 10,686N	011° 49,771E	3.60	5.30		1195	184	203	58	258
14.11.14	780	10	SD 22 N-lich Kühlungsborn	9:12:51	10:42:58	54° 11,303N	011° 50,243E	2.90	4.90	50.40	163	41	23	5	224
14.11.14	781	11	SD 22 N-lich Kühlungsborn	12:07:38	13:37:39	54° 10,656N	011° 51,317E	3.50	4.90	34.70	75	11	8		36
14.11.14	782	12	SD 22 N-lich Kühlungsborn	14:07:35	15:37:36	54° 10,752N	011° 43,342E	2.60		40.30	309	92	211	38	50
15.11.14	783	13	SD 24 N-lich Rügen	7:08:35	8:38:36	54° 42,570N	013° 08,890E	2.80	5.60	41.60	146	28	5	3	5
15.11.14	784	14	SD 24 N-lich Rügen	9:42:48	11:42:47	54° 42,533N	013° 07,684E	3.20	5.40	44.60	322	10		3	2
15.11.14	785	15	SD 24 N-lich Rügen	12:40:30	14:40:30	54° 42,534N	013° 07,920E	3.20	5.80		156	13	1	3	4
16.11.14	787	16	SD 22 N-lich Kühlungsborn	7:07:29	8:07:30	54° 13,124N	011° 33,560E	3.10	5.80	27.40		1	1	3	14
16.11.14	788	17	SD 22 N-lich Kühlungsborn	8:57:55	10:27:56	54° 10,782N	011° 42,758E	3.40		27.30	8	18	22	1	61
16.11.14	789	18	SD 22 N-lich Kühlungsborn	11:13:47	13:13:47	54° 12,202N	011° 48,751E	3.50		42.90	3	4	7		4
16.11.14	790	19	SD 22 N-lich Kühlungsborn	14:26:03	14:34:42	54° 17,132N	011° 55,144E	3.10		40.60			71		6
17.11.14	791	20	SD 22 E-lich Fehmarn	7:06:12	8:36:13	54° 20,232N	011° 23,498E	3.70	6.30	39.50					
17.11.14	792	21	SD 22 E-lich Fehmarn	9:28:19	11:17:31	54° 26,858N	011° 25,290E	2.20		53.00					
17.11.14	793	22	SD 22 E-lich Fehmarn	11:54:07	13:24:08	54° 20,994N	011° 24,141E	3.80	5.90	35.40					
17.11.14	794	23	SD 22 E-lich Fehmarn	14:07:55	15:07:55	54° 26,203N	011° 25,759E	3.40	4.50	46.90	8	112	588	7	65
17.11.14	795	24	SD 22 E-lich Fehmarn	15:47:43	16:47:45	54° 23,384N	011° 24,974E	3.10	5.70		16	37	216	8	65
18.11.14	796	25	SD 22 Mecklenburger Bucht	7:35:00	9:05:00	54° 16,756N	011° 39,406E	3.60		52.50	27	24	117	7	79
18.11.14	797	26	SD 22 Mecklenburger Bucht	10:11:35	12:05:00	54° 20,308N	011° 23,560E	2.10		49.20	23	388	1363	31	199
18.11.14	798	27	SD 22 Mecklenburger Bucht	13:15:52	14:15:53	54° 31,219N	011° 19,570E	3.60	4.80	50.30	9	157	879	39	109
18.11.14	799	28	SD 22 Mecklenburger Bucht	15:05:59	16:06:00	54° 31,303N	011° 19,446E	3.80	5.20	49.90	9	114	824	30	97
19.11.14	800	29	SD 22 N-lich Warnemünde	7:04:10	9:04:10	54° 12,239N	012° 00,673E	4.00	5.60		705	28	71	17	367
19.11.14	801	30	SD 22 N-lich Warnemünde	9:41:17	11:41:18	54° 11,323N	011° 51,236E	3.20	5.10	55.50	1826	97	185	31	293
19.11.14	802	31	SD 22 N-lich Warnemünde	13:19:30	14:49:31	54° 12,256N	012° 00,717E	3.30	4.90	33.50	656	5	26	2	111
19.11.14	803	32	SD 22 N-lich Warnemünde	15:25:53	16:40:55	54° 11,386N	011° 53,113E	3.50	4.90	30.20	1381	7	39	3	573
20.11.14	804	33	SD 22 N-lich Warnemünde	7:03:42	8:33:42	54° 12,249N	012° 00,792E	2.90	6.00	28.60	702	14	44	10	23
20.11.14	805	34	SD 22 N-lich Warnemünde	9:21:53	11:21:54	54° 11,299N	011° 50,739E	2.90	4.50		537	20	66	7	190
20.11.14	806	35	SD 22 N-lich Warnemünde	12:41:12	14:11:13	54° 12,269N	012° 00,856E	2.70	5.80	91.60	301	3	32	5	11
20.11.14	807	36	SD 22 N-lich Warnemünde	14:48:57	16:18:58	54° 11,826N	011° 53,418E	3.10	6.40	33.10	217	6	35	3	19
21.11.14	808	37	SD 22 N-lich Warnemünde	7:05:01	8:35:02	54° 12,256N	012° 01,106E	3.20	6.30	29.90	90	14	46	5	
21.11.14	809	38	SD 22 N-lich Warnemünde	9:13:38	10:43:40	54° 10,664N	011° 51,553E	3.20	5.30		167	107	60	59	
21.11.14	810	39	SD 22 N-lich Kühlungsborn	11:25:15	12:55:18	54° 10,741N	011° 44,182E	2.40	4.90	44.20	147	34	61	18	1
21.11.14	811	40	SD 22 N-lich Kühlungsborn	13:33:17	15:03:18	54° 11,296N	011° 50,678E	3.50		18.10	142	18	133	5	1

Table 2: Operational information and observed numbers of fish in catches (cod, flounder, plaice and whiting). Hauls 37 to 40 used a different gear setup and therefore they are not used for further analysis.

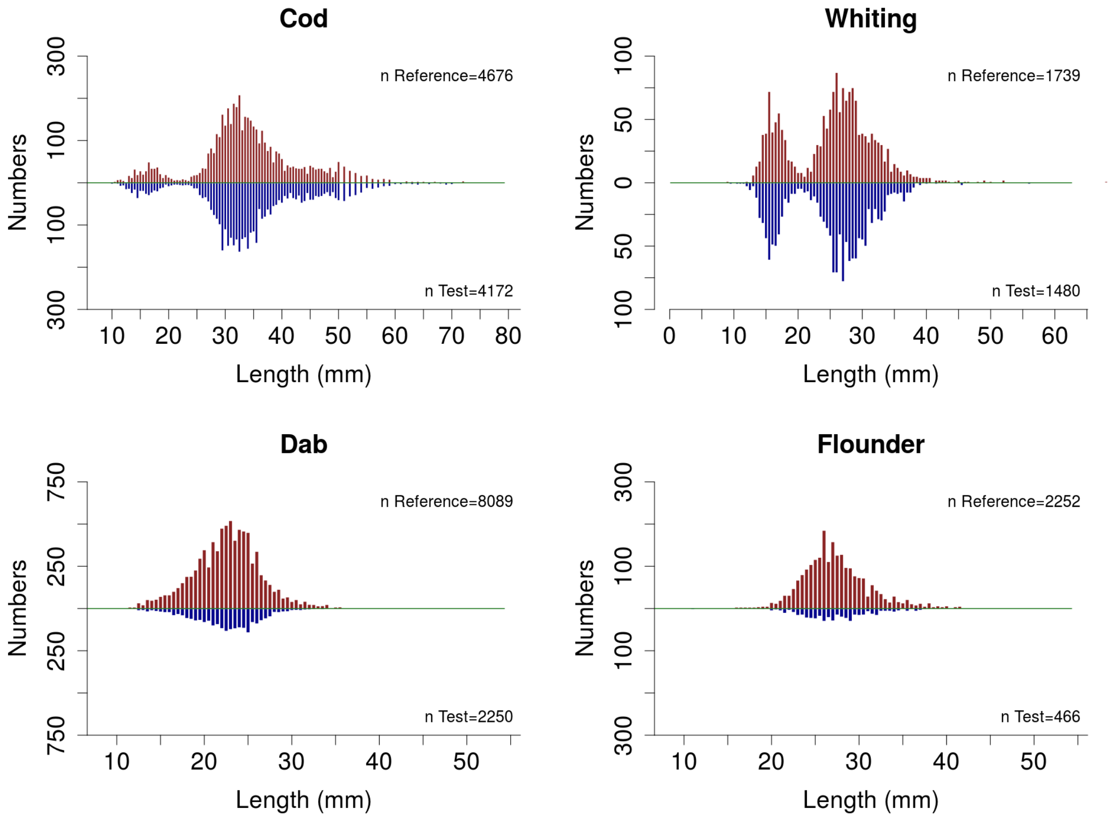

Figure 2: Length distributions of cod, whiting, dab and flounder in the reference gear (red bars) and the gear mounting FLEX (blue bars). Noticeable catch reduction are achieved for flatfish species, while catches remain similar for the roundfish species

3.2 Data analysis

The estimations and predictions of the best model candidates for dab and cod are presented. Only hauls with at least 60 fish from the species under study were used. A total of 16 (cod) and 15 (dab) hauls presented sufficient catches to be used in the catch comparison. Conditional predictions for the 4 hauls with most abundant catches are plotted together with the empirical catch proportions, in order to assess the goodness of fit of the models. Finally, the population catch rate curve and bootstrap confidence intervals are plotted to show what would be the expected effect of FLEX in the fishery.

Dab model

Information on the best model candidate for dab data is showed below. The selected model only includes the intercept and the effect of length as influential factors for the catch comparison, removing all the other factors. This indicates that FLEX worked similarly among fishing grounds, with different catch volumes and independent of the side where the test gear was mounted. Applying the inverse logit transformation on the model intercept results in a value close to 0, indicating the good performance of the device. On the other hand, the effect of length is weak but significantly positive, indicating that the bigger the fish, the lower the probability it uses FLEX to escape (compared to the probability estimated for smaller fish).

On the other hand the random structure used by the best model candidate includes uncorrelated random intercept and random slope. In other words, the intercept and slope of the catch comparison curve vary independently among hauls.

The conditional catch comparison curves predicted for the four hauls with large dab catches, indicate that the selected model is sufficient flexible to successfully model the between haul variation of the empirical catch data. The population catch rate curve predict a large reduction in dab catches over the available length range. For example, it is expected that only $\sim 17\%$ of dabs with body length of $20cm$ would enter in the codend $(0.17(0.06 - 0.36))$, or in other words, by mounting the FLEX in the gear it is expected that $\sim 83\%$ less dab with $20cm$ body length will enter in the codend. Based on the Confidence Intervals associated to the expected Catch Rate Curve, it can be said that the catch reduction is significant up to $40cm$ length (Figure 3).

```
Random effects:
 Groups Name        Variance Std.Dev.
 h      (Intercept) 2.828143 1.68171
 h.1    l           0.001682 0.04102
Number of obs: 609, groups:  h, 16

Fixed effects:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -2.58447    0.49459  -5.225 1.74e-07 ***
l            0.03411    0.01454   2.346    0.019 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
  (Intr)
l -0.356
```

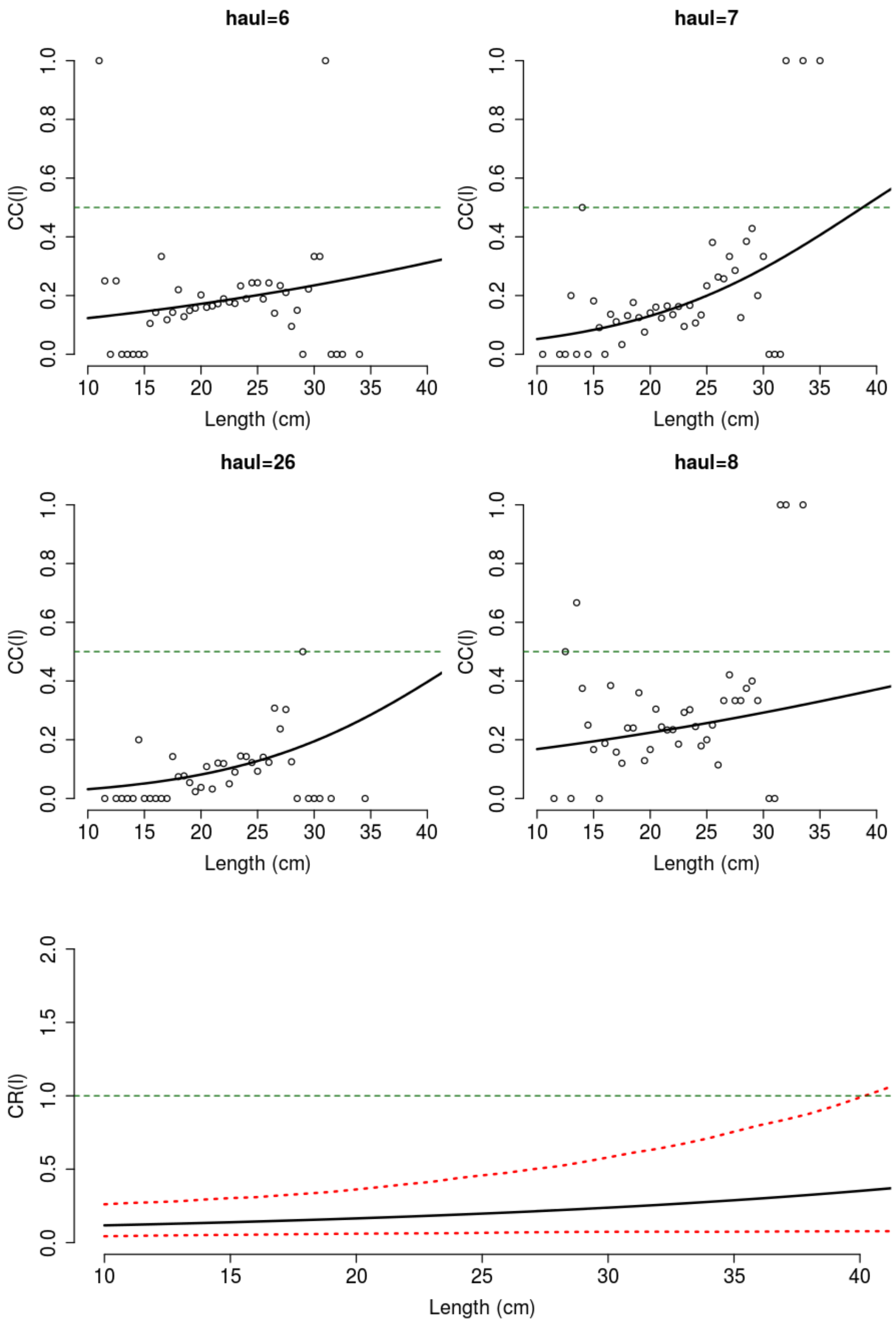

Figure 3: Top: Conditional catch comparison curves estimated for hauls 6, 7, 28 and 8 by the best candidate model for dab. Empirical catch proportions (points) plotted besides the curves to check the goodness of fit achieved. Green dotted lines represent equal catch proportion ($CC(l) = 0.5$). Bottom: "Population" Catch rate curve (solid line) and associated Confidence Intervals (red dotted lines). Green dotted line represent equal catch efficiency for the test and reference gears ($CR(l) = 1$)

Cod model

As in the previous case, the best model applied on cod data only includes the intercept and fish length as influential factors in the catch comparison, removing all the other factors, indicating once again that the effect of FLEX was neither influenced by the fishing ground, nor by different catch volumes, and also independent of the side where the test gear was mounted.

The random structure used by the best model candidate also includes both random intercept and random slope, but in contrast to the dab model, these are negatively correlated; in other words, the higher the intercept estimated in a given haul, the lower the slope associated to fish length.

The catch proportions observed in hauls 30, 32, 9 and 29 (hauls with highest abundance) show no clear trend in relation with fish size. Contrary, the points distributed as clouds centered in the reference line ($CC(l) = 0.5$) (Figure 4), which supports the results mentioned above. The conditional catch comparison curves estimated for each haul show the negative correlation of the intercept and the slope predicted by the random structure: the higher the intercept value, the lower the slope of the curve, reaching in the case of haul 32 a negative value. The population catch rate curve show a positive but non-significant trend, since the associated confidence intervals overlaps the reference line ($CR(l) = 1$, equal catch efficiency) (Figure 4).

```
Random effects:
 Groups Name        Variance Std.Dev. Corr
 h      (Intercept) 2.009228 1.41747
        l           0.000586 0.02421  -0.85
Number of obs: 1076, groups:  h, 15

Fixed effects:
             Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.552503   0.393353  -1.405   0.1601
l            0.013015   0.007178   1.813   0.0698 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
  (Intr)
l -0.859
```

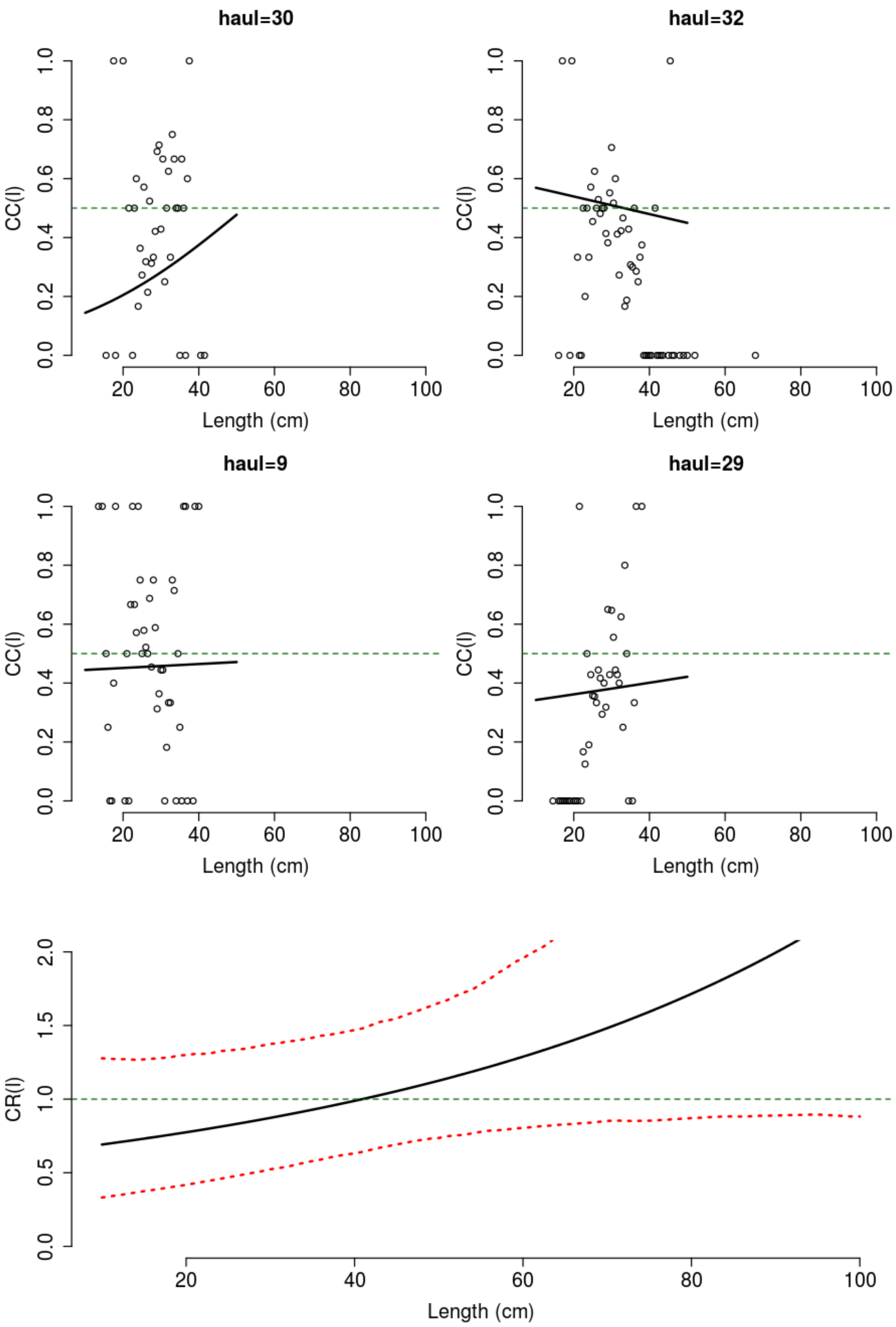

Figure 4: Top: Conditional catch comparison curves estimated for hauls 30, 32, 9 and 29 (hauls with highest abbundance of cod) by the best candidate model for cod. Empirical catch proportions (points) plotted besides the curves to check the goodness of fit achieved. Green dotted line represent equal catch proportion ($CC(l) = 0.5$). Bottom: "Population" Catch rate curve (solid line) and associated Confidence Intervals (red dotted lines). Green dotted line represent equal catch efficiency from test and reference gears ($CR(l) = 1$)

4 Discussion

This report presents the first experimental fishing results with FLEX, a new device for flatfish catch reduction in roundfish fisheries. Both, the catch data and the subsequent modeling show large catch reduction of flatfish species ($\sim 80\%$) with no significant losses of roundfish. These results improve those obtained with FRESWIND. The key goal of reducing flatfish catches by using differences in swimming behavior along the path towards the codend has been achieved.

Tests have been carried out with a double belly trawl specifically designed to perform catch comparison studies. Two non-selective codends were used to quantitatively estimate the escapement rates through the exclusion zone. Contrary to the experimental setup used for FRESWIND [8], we used small mesh codends instead of the mandatory BACOMA codend. This shift in the experimental design was necessary to retain the smallest length classes from the available population, which should help to identify potential length dependency and the usability of FLEX. Because FLEX is mounted ahead of the codend, we assume that the reduction of flatfish entering in the codend is independent from the codend used.

Best candidate models presented in section 3.2 show simple structure in the fixed effects part; only the intercept and fish length were included in both models. The lack of influence of other fixed effects considered in the study (side of the net FLEX was mounted, fishing ground used, towing direction or total catch in test gear) is a positive outcome, since FLEX worked consistently over the different fixing scenarios described. However, using swimming behavioral differences to sort fish by species is a riskier strategy compared to the standard mechanical sorting devices, since the earlier can be influenced by a wider range of variables. Additional experimental fishing trials testing FLEX in a wider range of fishing scenarios are recommended. New experiments should be planned to test, for example, the influence of fishing depth, fishing grounds, and season.

A significant, positive effect of fish length has been estimated by the Dab model. Although the trend is weak, the model predicts that the effectiveness of FLEX to exclude flatfish is reduced with fish length. Since the FLEX opening is sufficient big to avoid any mechanical size selection on any of the available fish species, we argue that such loss in efficiency might be related with length-dependent differences in swimming/avoidance behavior.

In contrast to the dab model, both the intercept and fish length in the cod model were found non-significant. This result indicates that the predicted catch comparison curve is not significantly different to 0.5 over the length classes available. In other words, based on the current data set, the model predicts that having caught a fish, it is equally likely that it was observed either in the reference or the test gear independently of the fish length. By using underwater video recordings collected during the cruise, it has been observed cod individuals swimming forward from the codend and escaping through FLEX during the last part haul-back process. Although these escapes were not systematic, further research efforts should be invested in the future to prevent such events.

FLEX is a very inexpensive device. Fishermen might be able to built their own FLEX version by using the material available onboard and in a short time. No extra handling effort is required to manipulate the device during the fishing operations.

Mounting FLEX in the net add flexibility to the fishing efficiency characteristics of the net, supporting shifts in the fishing strategy of the vessel. Since FLEX can be opened/closed onboard in few minutes, such flexibility is available even between hauls, making possible for the fishermen to decide what to fish from haul to haul.

5 Research crew members

Juan Santos	Cruise Leader	TI-OF
Kerstin Schöps	Technician	TI-OF
Peter Schael	Technician	TI-OF
Gokhan Göçke	Guess Researcher	Çukurova University (Turkei)
Jan Göbel	Volunteer	NA
Lisa Spotowitz	Volunteer	Rostock University
Stephan Lehmann	Volunteer	NA

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