Technical approaches to avoid cod catches in Baltic Sea trawl fisheries

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2 Summary

In the last few years, the Thünen Institute of Baltic Sea Fisheries developed and tested several selectivity devices for demersal trawls with the aim to reduce the unwanted bycatch of Baltic cod, while maintaining the high catchability of flatfish. This research is a direct response

- to the poor status of both Baltic cod stocks (ICES, 2019a, 2019b), resulting in reduced catch opportunities (Western Baltic cod) or a closure of the directed fishery (Eastern Baltic cod), respectively.
- to ad-hoc measures to alleviate a serious threat to the conservation of eastern Baltic cod, implemented by the European Commission by July 22, 2019 (EU 2019/1248)

The presented work updates and complements the ICES report on 'Technical strategies to avoid catches in the Baltic Sea trawl fisheries' (ICES, 2019c). There is now (April 2020) much knowledge gained compared to the state of play in the ICES report. This can now be considered state-of-the-art technology.

Since September 2019, two different approaches and a combination of the two were investigated: **1. modifications of the extensions and 2. modifications of the codend.**

For **approach 1.**, the following selectivity devices were (further) developed and tested (Figure 1):

(1) CODEX (COD EXcluder): A guiding panel in the extension of a trawl guides cod towards an escape opening.

(2) ROOFLESS (in various configurations): The top panel of the trawl extension was removed to build a large escape opening (175 cm, or 330 cm long). Additionally, configurations with stimulation ropes (STIPED) were tested.

Both devices were mounted in a standardized 4-panel extension of the trawl, developed at the Thünen Institute (NEMOS, NEt Enabling MOdular Selectivity, Figure 3) to ensure a firm shape of the extension and hence reduce variability in the efficiency of the selection process.

The experimental work was conducted during four cruises between September 2019 and February 2020. For CODEX, it was shown that cod catches could be reduced significantly, but also flatfish catches were reduced largely. The different ROOFLESS-configurations have also shown very good capabilities to reduce the bycatch of cod, while the catch efficiency was higher for flatfish species compared to CODEX.

An optimal compromise between a sufficient catch reduction of cod (75%), no statistically significant effect on the catch efficiency of flatfish, and the simplicity of construction was found for the ROOFLESS-175 selectivity device (escape opening 175 cm long). The results were confirmed on two research cruises, where day time fishing was conducted.

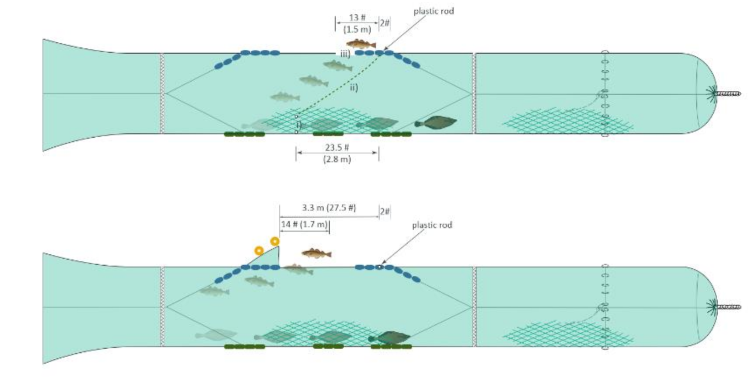

Figure 1: Selectivity devices CODEX (top) and ROOFLESS (below). Side view of the extension with codend. Additional information provided in this project report.

In a second research **approach (2.),** it was investigated whether the unwanted bycatch of cod could also be reduced by codend modifications, while keeping the catch efficiency for flatfish species high. **It does not appear to be an optimal cod avoidance strategy to fish with codends optimised for catching sized cod (Bacoma 120 mm and T90 120 mm).** This analysis is based on previous field selectivity experiments, as well as on theoretical investigations (modelling and simulation). The following codend types and mesh openings (MO) were investigated (Figure 2):

(1) Bacoma-codend with different mesh opening in Bacoma/square mesh panel (MO: 132 mm, 146 mm)
(2) Codend made solely of square mesh netting (MO: 120 mm, 127 mm, 130 mm, 140 mm)
(3) Codend made of T90-netting (T90-codend) (MO: 120 mm, 127 mm, 130 mm, 140 mm)

The results were promising: With an increase in mesh size, it is possible to reduce the catchability of cod for all codend types. **Even small increases in mesh size (e.g. to 130 mm) result in a relatively large reduction of cod catches. The highest reduction of catches of cod has been calculated for a T90 codend with 140 mm mesh size, where the reduction of catches is 99% for undersized cod and 79% for sized cod.**

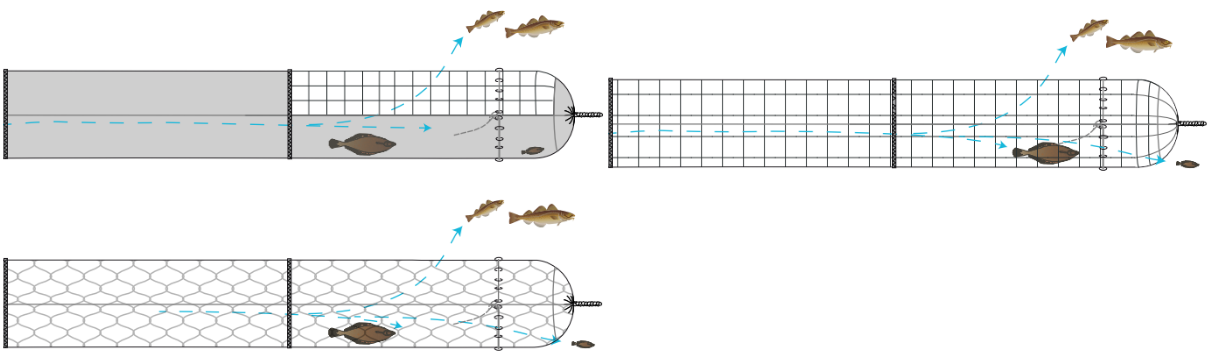

Figure 2: Codend types investigated as potential modification to reduce the catch of cod. Top: Bacoma-codend; Mid: Square mesh codend; Below: T90-codend. Schematic drawings.

Some of the cod-ends may also result in a relatively high loss of catch of flatfish (plaice was the species studied). Taking into account the current reference size for plaice (MCRS = 25 cm), the above mentioned T90 140mm codend results in a catch loss for sized plaice of 68%. This loss of catch would be reduced to 10%, for example, if the reference size is increased to 30 cm. Alternatively, it is also possible to select a codend with a lower bycatch reduction for cod, but with a higher catch retention for flatfish. One possibility here is to use the standard T90 codend (127 mm was tested), which reduces the cod bycatch by about 50%, but the flatfish catch by only 14%.

Which of the codends should be recommend for use in the fishery is a matter of balancing trade-offs (reduction of cod fishing, loss of flatfish catches, cost of codend). A modification of the codend would be a comparatively inexpensive solution for the fishery, with the T90 codend being by far the cheapest codend type.

A validation of these theoretical investigations in the field was planned during a research cruise in March 2020. This trip had to be cancelled as part of the measures to combat the Covid-19 pandemic.

3. Combination of approaches 1. and 2: The maximum catch reduction of cod could be achieved when combining a selection device in the extension of the trawl (ROOFLESS-175) and a modified codend.

Comments on the conformity of the selection approaches developed with applicable regulations:

Codends

The increase of the mesh size for Bacoma- and T90 codends to mesh openings larger than 120 mm is covered by the current EU regulation (EU, 2019), as this regulation defines minimum mesh sizes.

It seems necessary to prepare for the legalisation of other codend concepts currently under development for a flatfish fishery with the lowest possible bycatches of cod. These include, for example, 4-panel codends with lastridge ropes to achieve a more stable mesh shape.

Other selectivity devices, such as CODEX; ROOFLESS

Art 8 of EU (2019) states that regional technical regulations (here Annex VIII for the Baltic) “shall not apply to netting devices … used in conjunction with fish and turtle excluder devices”. Although CODEX and ROOFLESS-concepts can be clearly categorized as ‘fish excluder’, control authorities adopted a different interpretation. It was therefore difficult and time-consuming to obtain the relevant approvals. This is one of the reasons why the ROOFLESS concept has not yet been tested intensively on commercial fishing vessels.

To avoid such barriers for the test and use of gear adaptations with direct benefit for Baltic cod stocks and for Baltic fishery, **it is necessary to implement a legal framework for CODEX and ROOFLESS – even if they are not made mandatory.** This legalisation should also apply for the western Baltic Sea, where there is a risk that the very limiting cod quota will choke flatfish fishing, or that cod will be illegally discarded. A general clarification on the interpretation of Art. 8 EU2019/1241 would be highly desirable in order to avoid such discussion in future fishing gear developments.

3 Background

By July 22nd, 2019, the European Commission has implemented emergency measures (2019/1248) to protect the eastern Baltic cod stock. These measures had enormous impact on all Baltic fisheries. The measures included a closure of all directed cod fisheries in SD24-26. Fisheries were not closed completely, but all bycatch of cod in the fisheries now targeting flatfish had to be discarded. This rule is clearly in conflict with the intention of the landing obligation put down in the basic regulation of the reformed common fisheries policy (1380/2013). Even worse, instead of protecting the Eastern Baltic cod stock, the rule could have led to an increase of the fishing mortality on this stock, because the quotas were now not limiting the fishing activity any longer. Increased discards, specifically if not properly documented, will lead to an increased uncertainty of ICES' annual stock assessment. Also, vessels without cod quota were now allowed to start fishing for flatfish, as they could simply discard unwanted bycatches of cod. The increased fishing mortality in SD24, where the strong 2016 year class of Western Baltic cod dominated, was not only the opposite of what was intended by the emergency measure for Eastern cod, but was also detrimental for Western cod. In addition, the measure led to a loss of confidence of fishers in the EU legislation.

This status was neither satisfactory for the cod stocks nor for the fishers. The Thünen Institute of Baltic Fisheries (OF) therefore discussed technical solutions with the fishery in July 2019. The starting point for these discussions were the existing selectivity approaches for trawls SORTEX (SORTing Extension, Figure 4), which successfully sorts cod and flatfish in two separate codends. The concept CODEX (COD Excluder, Figure 5) was developed on the basis of SORTEX. The concept aims at utilizing the good sorting properties of SORTEX but then releasing the by-caught cod immediately instead of catching them in a separate codend. This should allow for the continued catch of flatfish while reducing the bycatch of cod as far as possible. As the concept is newly developed, the functioning of the approach was not verified during field tests at this time. Therefore, the project "CODEX" was initiated to test and further develop the CODEX-selectivity device, or to develop alternative solutions. The project was partly funded through the EMFF and the federal state of Mecklenburg-Western Pomerania.

Compared to the second half of 2019, the framework has been altered in 2020. The discard obligation for cod was discontinued, but there are still massive catch reductions in 2020: Cod can only be caught as bycatch and in very limited amounts. As these catches have to be landed again, there's a real risk that fishing for flatfish is choked by the limited cod bycatch quota. It is therefore still pivotal that the cod catch is reduced as much as possible, and technical developments are one important solution.

4 State of knowledge

For the development of selectivity devices (Bycatch Reduction Devices; BRD) several strategies could be applied, which can be categorized based on their working principle:

(1) Selectivity devices that make use of differences in fish behaviour to sort and exclude species.
(2) Mechanical size selectivity devices that make use of morphological differences between sizes or species (such as differences in body cross section between cod and flatfish). Example: the use of different nettings in codends.
(3) Selectivity devices that combine the two previous strategy (1 and 2) in a sequential process.

The Thünen Institute of Baltic Sea Fisheries has spent large efforts over the last years to develop and test a number of different multi-species selectivity devices (e.g. FRESWIND; FLEX; SORTEX[1]). The working principle of these devices is mainly based on the knowledge and usage of the behaviour of the different species. For optimal performance, it is advisable to modify the extension piece of the trawl (the cylindrical part of the trawl between the trawl body and the codend), as it is possible to separate the different species on their way to the codend. Thereby, it is possible to achieve a complementary possibility for selectivity in addition to the codend. Ideally, the selectivity properties of the selection device in the extension piece and the codend add together to achieve the desired overall selectivity/catch composition. A more detailed description of the different strategies to achieve desired selectivity properties of fishing gears can be found in ICES (ICES, 2019a).

One of the previously developed concepts is SORTEX (Figure 4), which separates cod and flatfish species into two codends. After separation, it is possible to choose an optimal selectivity strategy, i.e. codend configuration, for both catch fractions separately. SORTEX was tested on several research cruises in different configurations. The separation efficiency of cod and flatfish species for the best SORTEX-configuration was 80-90% (only 15% of total catch of cod were found in the lower codend, while only 10% of flatfish were found in the upper codend). Therefore, this selectivity device was considered as potential option to reduce the catch of cod in the Baltic demersal trawl fishery.

When this concept was discussed with German fishers in July 2019, they stated that in areas SD24 and SD25-SD32 it was not the aim in 2019 to find an optimal selection for cod, but rather to avoid catching cod as much as possible. Consequently, it is not necessary to guide cod into a second codend. Therefore, a modification of SORTEX was proposed. This modification should guide flatfish into the single codend, while guiding cod upwards towards an escape opening (Figure 5). As this concept was intended to reduce the catch of cod, it is called CODEX (COD EXcluder). CODEX is mounted in the NEMOS-extension (NEMOS: NEt Enabling MOdular Selectivity, Figure 3), developed at the Thünen Institute. This 4-panel construction ensures a firm shape of the extension and hence reduces variability in the efficiency of the selection process. Additionally, the special design of NEMOS enables easy installation of the different selection devices. Such flexibility might be attractive for fishers interested in adapting the selectivity of their trawls without major changes of the trawl body.

The CODEX-device was introduced as a theoretical concept (ICES, 2019c), while a practical test was missing at this time.

Technical drawings (net drawings) were available for SORTEX and CODEX (Figure 20 in Annex I: Technical drawings). For CODEX, specifications/drawings for two sizes are available to account for different sizes of vessels and trawl.

[1] https://www.thuenen.de/en/of/fields-of-activity/research/fisheries-and-survey-technology/reduction-of-unwanted-bycatch/

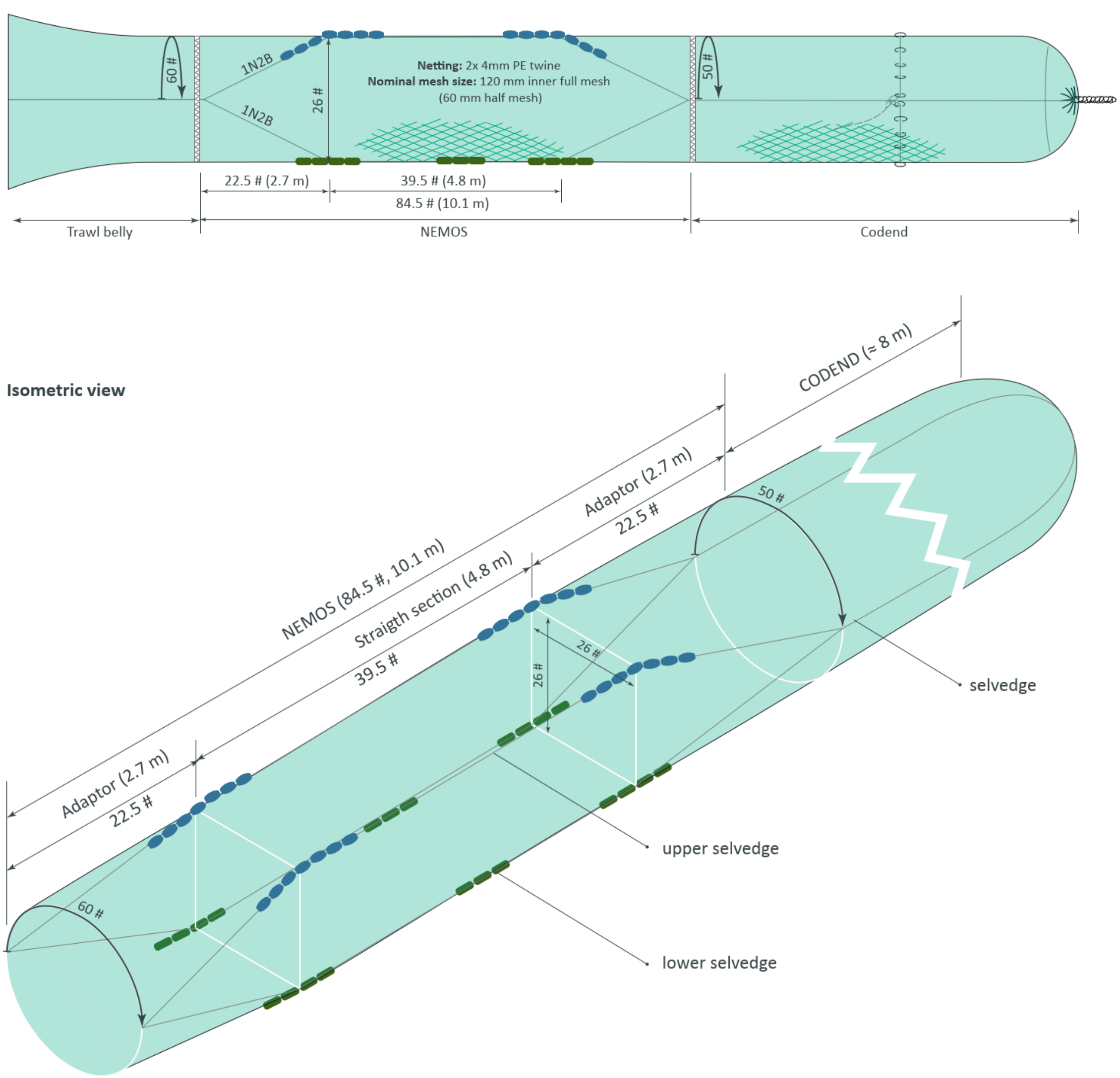

Figure 3: NEMOS (NEt Enabling MOdular Selectivity) device: A multi-purpose 2-4-2-panel net section located between the codend and the trawl body. NEMOS can be used for easy installation and removal of the selection devices in the trawl

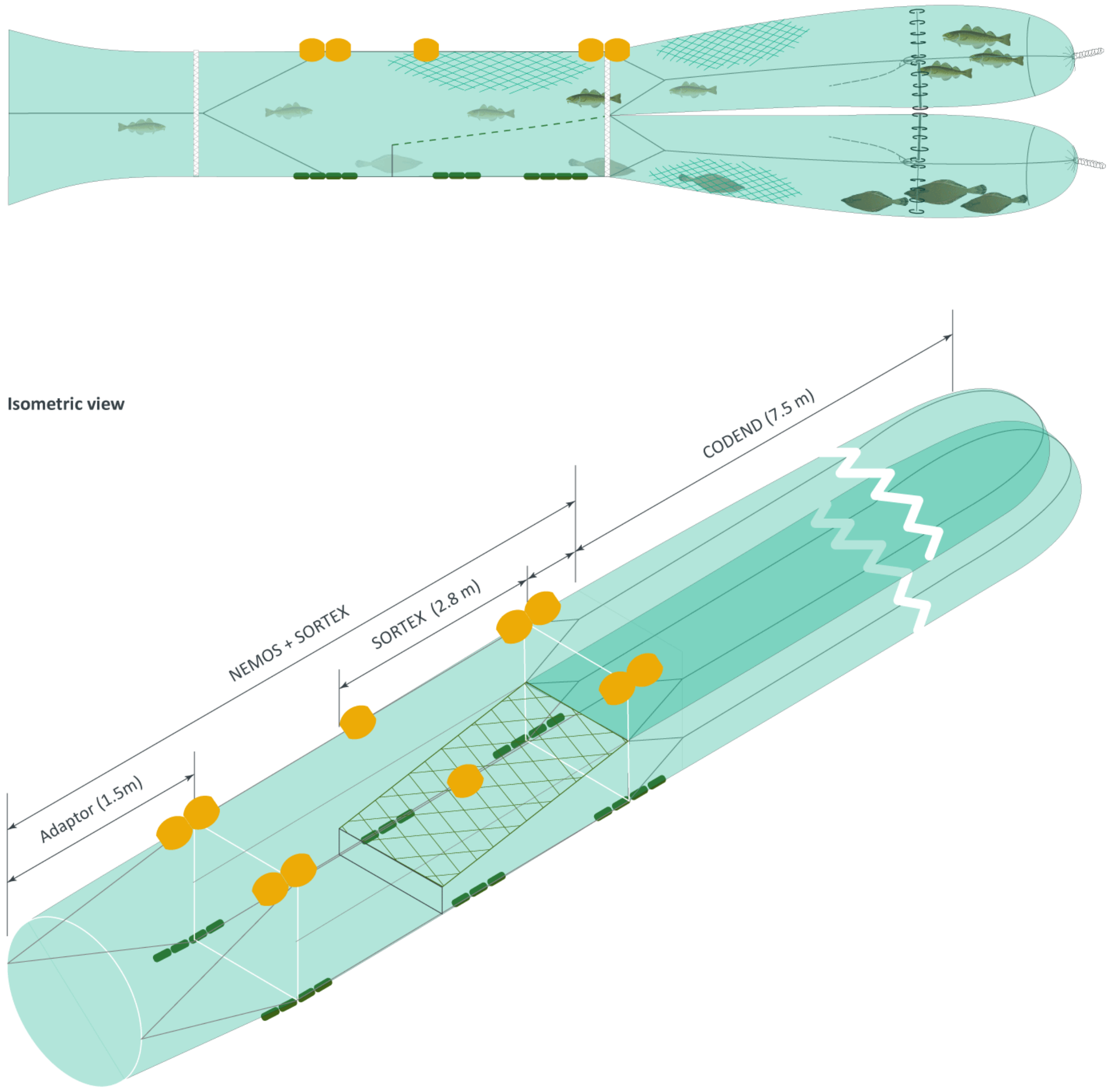

Figure 4: SORTEX (SORting EXtension) device to sort cod and flatfish into two codends. Top: side view of the device showing the intended species selective principle. Bottom: Isometric view showing assembly details of the device.

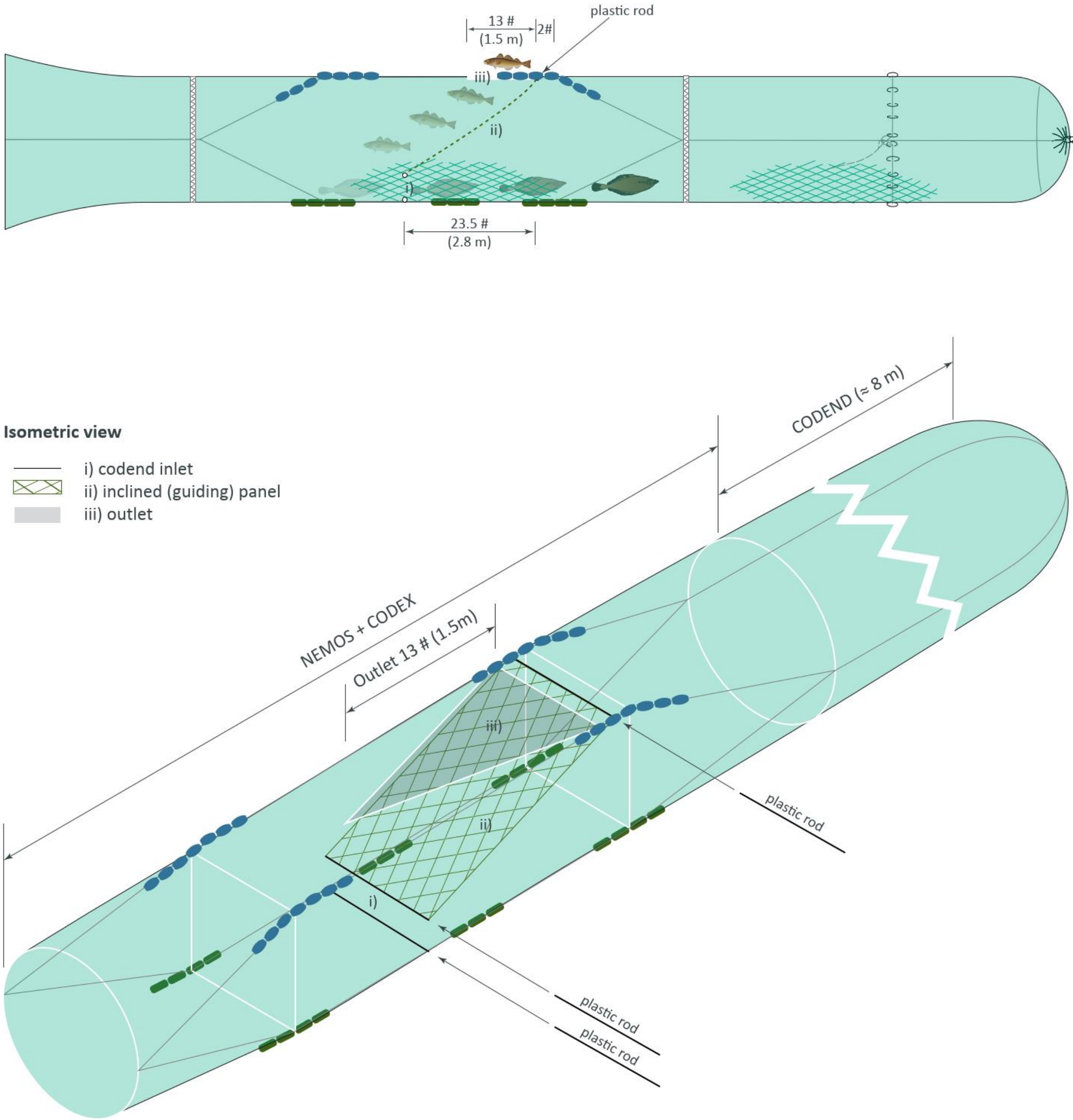

Figure 5: NEMOS + CODEX (COD EXcluder) device to separate cod and flatfish. A guiding panel in the extension of a trawl guides cod towards an escape opening. i) codend inlet, ii) inclined (guiding) panel and iii) outlet. Top: side view of the device showing the intended species selective principle. Bottom: Isometric view showing assembly details of the device.

5 Approach 1: CODEX and ROOFLESS

The first trial of the CODEX-concept was conducted onboard the commercial fishing vessel SAS107 „Crampas“ in September 2019 (18.09.-23.09.2019). During this cruise, the device was modified based on underwater video observations. Nevertheless, these first experiments have shown that the desired catch reduction of cod and the low catch loss of flatfish was not achieved with the first configurations tested. Additionally, several fishers raised the concern that the narrow entrance to the codend may be blocked or damaged easily.

Therefore, additional options to achieve the desired selectivity were evaluated. The basic idea behind this new development was to give cod as much escapement possibility as possible. Previous studies have shown that cod has a tendency to escape upwards and - at the same time - try to avoid contact with netting. During a previous research cruise (CLU275, 2013), it was shown that even very large meshes in the top panel of an extension (400 mm stretched mesh opening) can hamper the escapement possibilities with only around 25% of all cod escaping.

Consequently, it was decided to avoid this netting “barrier” and to entirely remove a large part of the top panel of the NEMOS-extension. This concept was called NEMOS + ROOFLESS (Figure 7). An additional modification was the use of stimulating ropes (STIPED), since their effectiveness was shown for Baltic cod by Herrmann et al. (2015).

Three research cruises were conducted to develop and test the gears (Table 1). More details about the cruises (logistics, methods, gears, results) can be found in related cruise reports[2][3][4].

Table 1: Research cruises (overview) used for development and test of cod catch reduction devices. See cruise reports for more details.

Cruise	Vessel	Dates	Area	objectives
CLU338	FRV “Clupea”	24.10-30.10.2019	SD22/SD24	Iterative development and optimization of new selectivity concepts using underwater video recording: NEMOS + ROOFLESS NEMOS + ROOFLESS + STIPED
CLU340	FRV “Clupea”	28.11.-19.12.2019	SD22/SD24	Catch comparison experiments to estimate the selective properties of the different devices and their configurations NEMOS + CODEX NEMOS + ROOFLESS-330 NEMOS + ROOFLESS-175
SO773	FRV “Solea”	02.02.-09.02.2020	SD24+SD25	Catch comparison experiments to estimate the selective properties of the different devices and their configurations NEMOS + ROOFLESS-175 NEMOS + ROOFLESS-175 + STIPED

[2] https://www.thuenen.de/de/infrastruktur/forschungsschiffe/clupea/reisen-2019/338/
[3] https://www.thuenen.de/de/infrastruktur/forschungsschiffe/clupea/reisen-2019/340/
[4] https://www.thuenen.de/de/infrastruktur/forschungsschiffe/solea/reisen-2020/773/

5.1 Experimental design

During cruises CLU340 and SO773 the performances of the different BRDs were assessed using the paired gear method (Wileman et al., 1996), where a test gear (mounting NEMOS with one of the BRDs) fished in parallel with a control gear (mounting NEMOS with no BRD) (Figure 5).

Standard T90 codends made with approx. 125 mm measured inner mesh size (Fonteyne et al., 2007), 50 meshes in circumference and approx. 8 m long were mounted in the test and the control gear, providing the same codend selectivity in both gears. The only difference between both gears was the presence of the BRDs in the test gear. Therefore, it can be assumed that differences in catches between the test and control gear were caused by fish escaping through the tested BRDs.

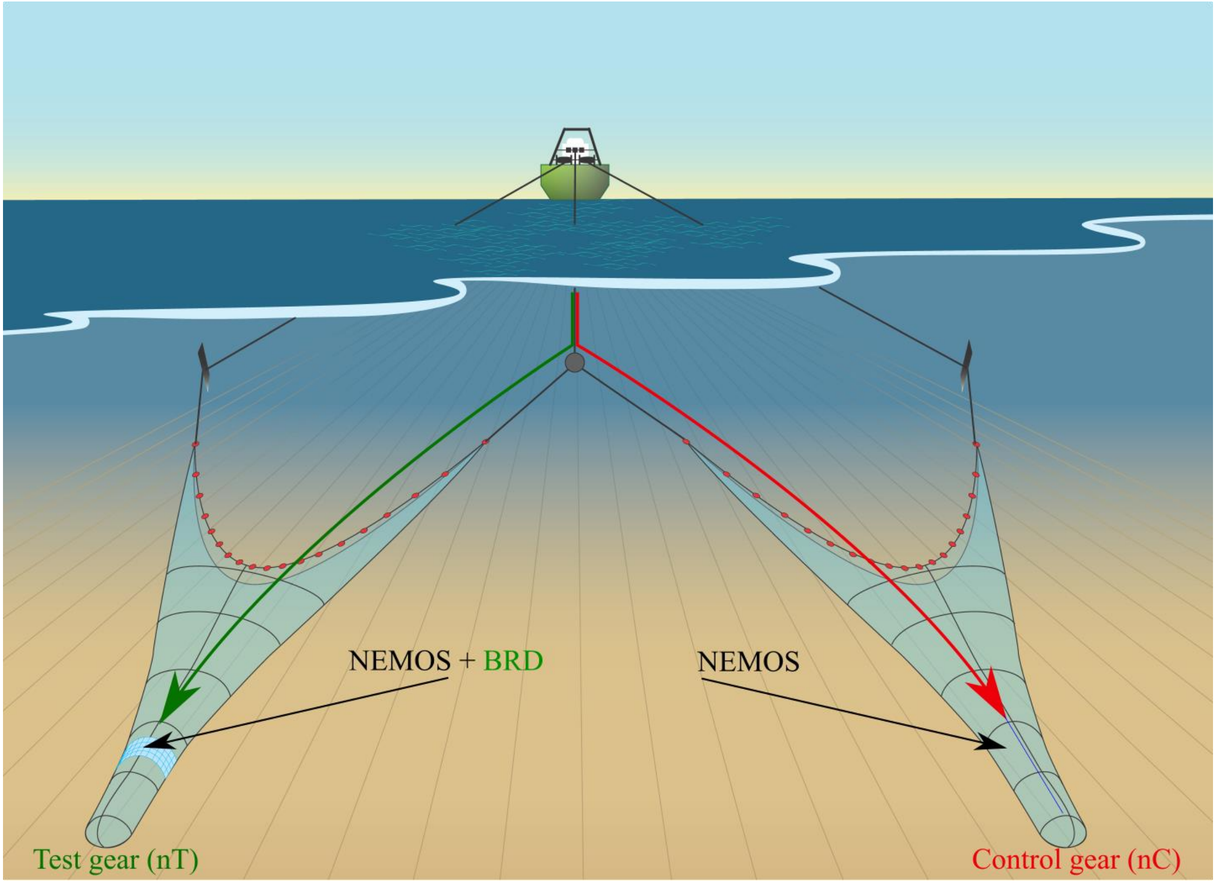

Figure 6: Schematic illustration of the paired gear method (Wileman et al., 1996), where a test gear (mounting NEMOS with one of the BRDs installed) fished in parallel with a control gear (mounting NEMOS with no BRD installed). Although this illustration shows a test-set up for a twin trawler (CLU340), the general concepts also applies for studies using double-belly trawls/trouser trawls studies (SO773).

5.2 Catch data analysis

Catch sampling involved a separate catch handling of the test and control gear for each haul. The biomass of each species was documented for each codend, before individual total length was measured to the half centimeter below by using Scantrol electronic measuring boards.

Catch reduction in the test gear relative to the control gear was evaluated by the following release efficiency indicators. Calculations are based on the ratio of catches (numbers) in the test gear (*nT*) compared to the control gear (*nC*):

$$nR+ = 100 \times \left(1.0 - \frac{\sum_i \{\sum_{l \geq ref} nT_{il}\}}{\sum_i \{\sum_{l \geq ref} nC_{il}\}}\right)$$
$$nR\text{-} = 100 \times \left(1.0 - \frac{\sum_i \{\sum_{l < ref} nT_{il}\}}{\sum_i \{\sum_{l < ref} nC_{il}\}}\right) \quad (1)$$
$$nR = 100 \times \left(1.0 - \frac{\sum_i \{\sum_l nT_{il}\}}{\sum_i \{\sum_l nC_{il}\}}\right)$$

where the summation of *i* is over hauls and *l* is over length classes. Release efficiency indicators (catch reduction in the test gear in relation to the reference gear; equal catch = 0% catch reduction) are calculated for species for the total catch (*nR*), and for the fractions below (*nR*-) and above (*nR+*) a given reference fish size (*ref*). If available, the used reference length was the species specific Minimum Conservation Reference Size (MCRS). In general, high values of the three indicators for flatfish (low catch reduction) and low values for roundfish (high catch reduction) would indicate that the intended species-selection was achieved. Any length-dependency in the release efficiency would be expressed by differences in the values of *nR*- and *nR+*.

The reference sizes (MCRS) for the different species were as follows:

- Cod (COD) = 35 cm
- Plaice (PLE) = 25 cm
- Turbot (TUR) = 30 cm
- Flounder (FLE) and dab (DAB) = 25 cm (MCRS for plaice applied here)

Potential length-dependency in the efficiency obtained from the different BRDs tested was further evaluated by modelling the length-dependent, catch-comparison data:

$$CC_l = \frac{\sum_{i=1}^{h} nT_{il}}{\sum_{i=1}^{h} (nC_{il} + nT_{il})} \quad (2)$$

where nT_{il} and nC_{il} are the numbers of fish in length class *l* caught in haul *i* in the codend of the test gear and the codend of the control gear, respectively. CC_l represents the catch share among test gear and control gear, by fish length. Analysis of the catch-comparison data (Equation 2) was conducted separately, species by species, following the procedure described in Annex II.

Specific details of the experiment design applied on each cruise are described in their respective sections in the document.

5.3 Assessment of fish behaviour interacting with BRDs

To supplement the described catch-data analysis, we analysed video footage and assessed flatfish and cod behavioural responses during the fishing process with the different BRDs. Video footage was recorded with GoPro cameras mounted in a protective structure and placed on the upper panel and/or side panel and/or bottom panel of NEMOS, either in front or behind the tested BRD.

No further analysis are available at the time of writing this report, however it is planned to disseminate such assessment in a scientific paper in the near future.

A selection of the video recordings showing the physical performance of the gear and the interaction of fish with the different devices will be available soon at

https://www.thuenen.de/en/of/fields-of-activity/research/fisheries-and-survey-technology/ and

https://vimeo.com/407563910

5.4 Results

Development and optimization – During the cruise CLU338, the concepts ROOFLESS (Figure 7) and ROOFLESS + STIPED (Figure 8) were developed and optimized. Sufficient underwater video footage was recorded (Figure 9 and Figure 10) to be able to evaluate the mechanical properties of the devices itself, as well as the behaviour of different fish species in relation to the selectivity device.

Catch comparison – The direct catch comparison between a standard/control-trawl and a trawl with selectivity device installed allowed the estimation of selectivity properties of the tested selection devices using the „paired gear method“ (Wileman et al., 1996). Selectivity properties were estimated for cod, plaice, flounder, dab and turbot. Figure 11 shows the catch weights per species shared in test trawls in relation to the combined catch of test trawl and control trawl (test + control = 100%). If the catch of control and test trawl are identical (no effect of selectivity device), the value is 50% (catch share in test trawl = 0.5). If the value is below 0.5, the catch in the test trawl was lower, i.e. the catch was reduced. Additionally, the size of the catch per haul is illustrated.

Results for CODEX indicate a strong catch reduction for cod, but also a considerable catch reduction for all flatfish species (Figure 11 left).

The cod catch reduction of ROOFLESS-330 (length of escape window = 330cm) was also rather high and stable over all hauls. As for CODEX, the catch of flatfish was reduced – even if the reduction was less pronounced.

Shortening the escape window of the ROOFLESS-device (ROOFLESS-175) reduced the escapement probability of cod slightly, but caught more flatfish than ROOFLESS-330. The results for ROOFLESS-175 were similar during both cruises (CLU340 and SO772), which indicate relative stable selectivity properties.

The selection device ROOFLESS-175 + STIPED was tested during cruise SO773. The installed stimulating ropes (STIPED) slightly increased the escapement probability of cod but resulted in slightly lower catches of flatfish. A length-based catch comparison is shown for ROOFLESS-330 and ROOFLESS-175 (CLU340; Figure 12), and ROOFLESS-175 and ROOFLESS-175+STIPED (SO773; Figure 13). No strong length dependency was found for any of the selectivity devices.

An overview about the catch composition of test trawl (with selectivity device) and control trawl, as well as resulting catch reduction is shown in Table 2.

5.5 Conclusions

Four selectivity devices/configurations were tested successfully. The experimental data basis allows for a sound statistical comparison of CODEX, ROOFLESS-330, ROOFLESS-175 und ROOFLESS-175+STI-PED. ROOFLESS-175 has shown very stable selectivity performance during two cruises.

All tested selectivity devices can significantly reduce the catch of cod. Highest cod catch reduction efficiency was found for CODEX, but at the price of high catch loss for all flatfish species.

A good compromise between maximum catch reduction of cod and minimum catch loss of flatfish is the selection device ROOFLESS-175. ROOFLESS-175 caught almost the same amount of flatfish as the control gear, while reducing catches of cod significantly (-75%). Another positive aspect for ROOFLESS-175 is its simple construction, which makes it easy and cheap to build and repair. It was also shown that this device can be handled on larger vessels, as well as smaller fishing vessels (one day trips on smaller fishing boats conducted, not described in this report).

It is important to note that the experimental fishing was solely conducted during day time. Therefore, it cannot be excluded that the selectivity performance is different during night (e.g. due to diurnal behavioural differences).

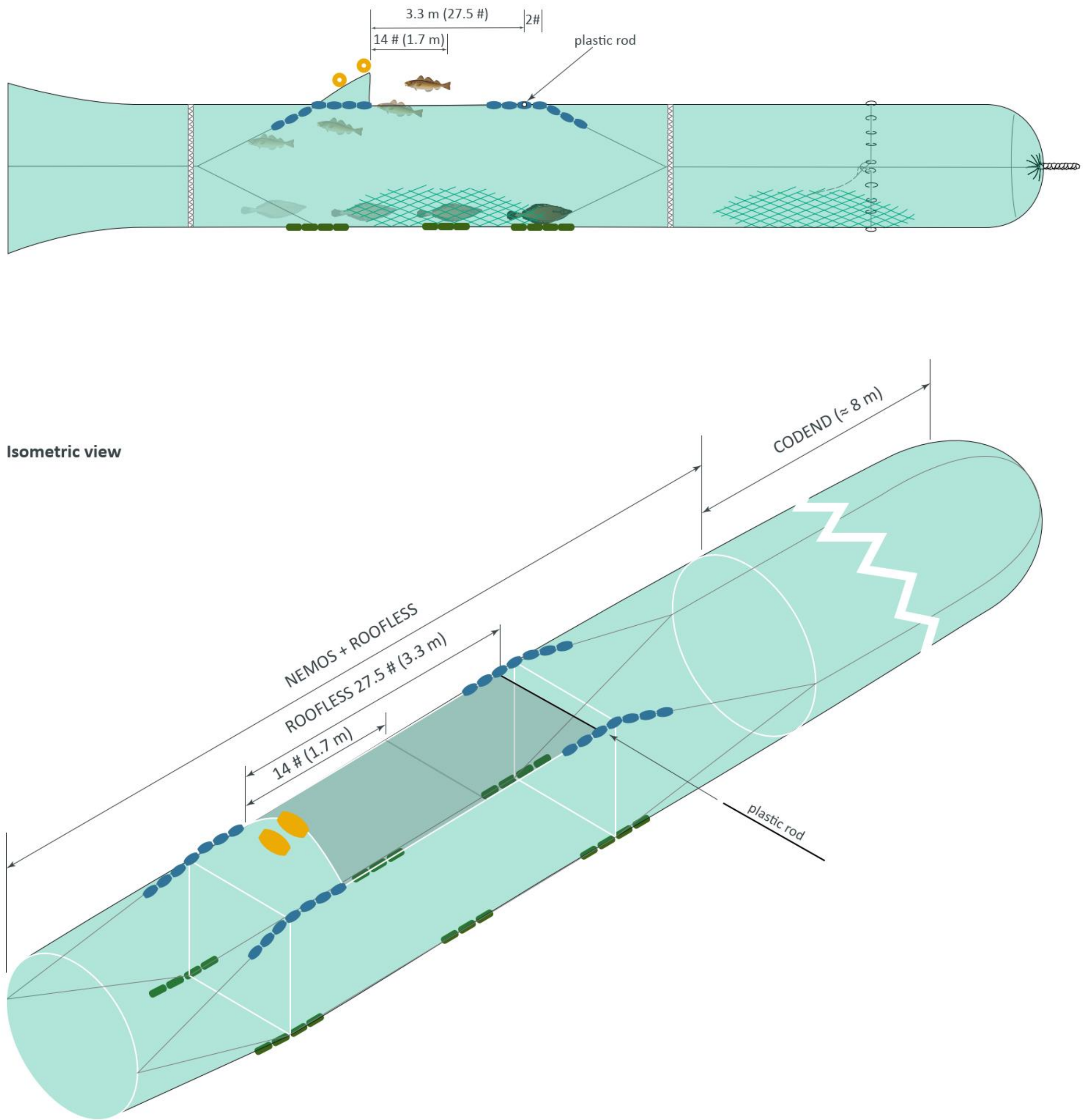

Figure 7: NEMOS + ROOFLESS Bycatch reduction device to reduce the catch of cod in flatfish fisheries. This adaption of the NEMOS (Figure 3) device includes a removed section of the top panel of NEMOS, as well as a lifted top panel section in front of the open window. The device provides a wide, net-free open window that could be used to escape by cod in its way to the codend. ROOFLESS was tested in two configurations with window length of 330cm (ROOFLESS-330) and 175cm (ROOFLESS-175), Top: side view of the device showing the intended species selective principle. Bottom: Isometric view showing assembly details of the device.

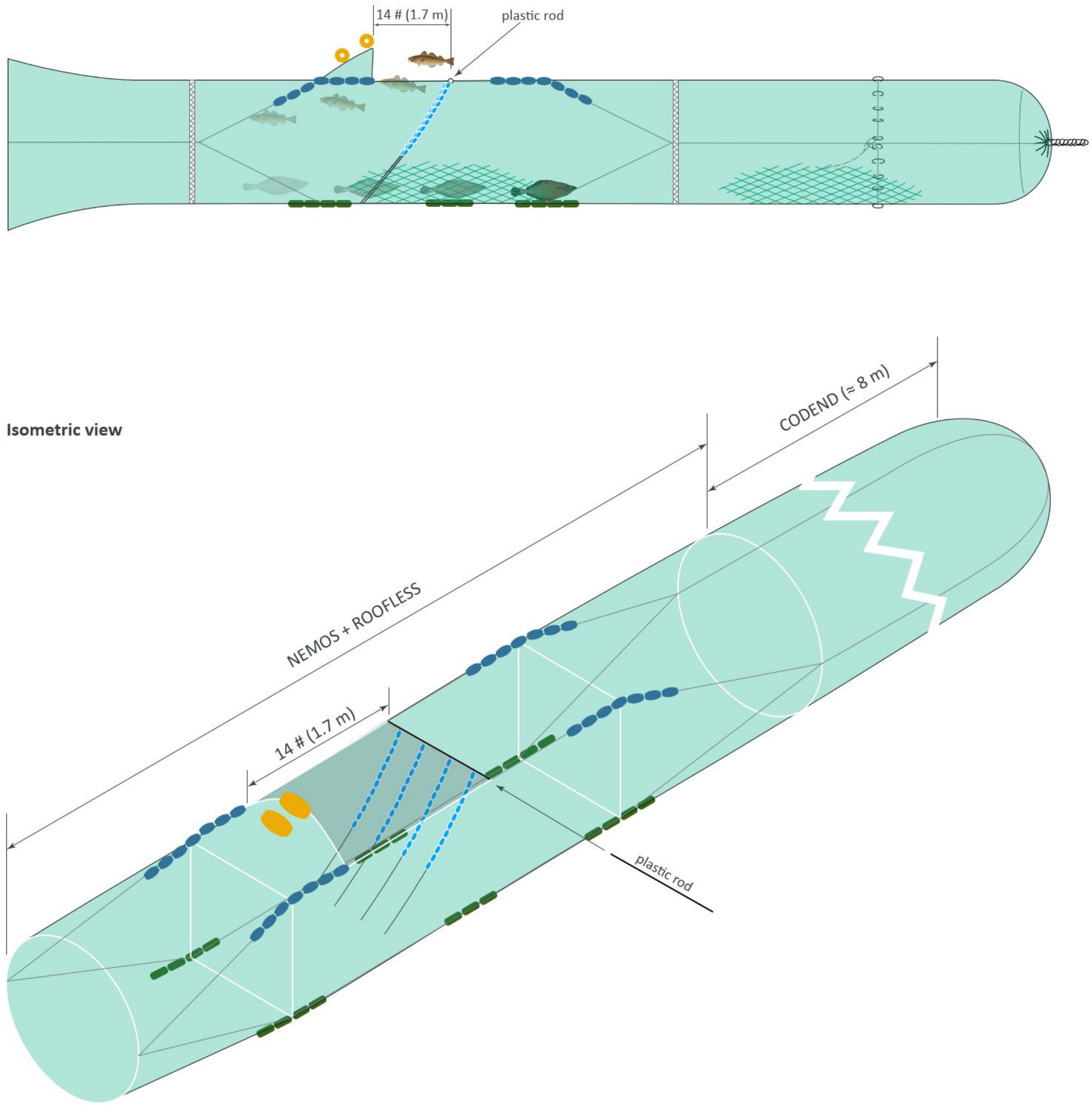

Figure 8: NEMOS + ROOFLESS+STIPED device: Bycatch reduction device to reduce the catch of cod in flatfish fisheries. This adaption of the NEMOS (Figure 3) device includes i) a removed section of the top panel of NEMOS (tested in configuration with window length of 175cm), ii) a lifted top panel section in front of the open window and iii) STIPED stimulating ropes. Top: side view of the device showing the intended species selective principle. Bottom: Isometric view showing assembly details of the device.

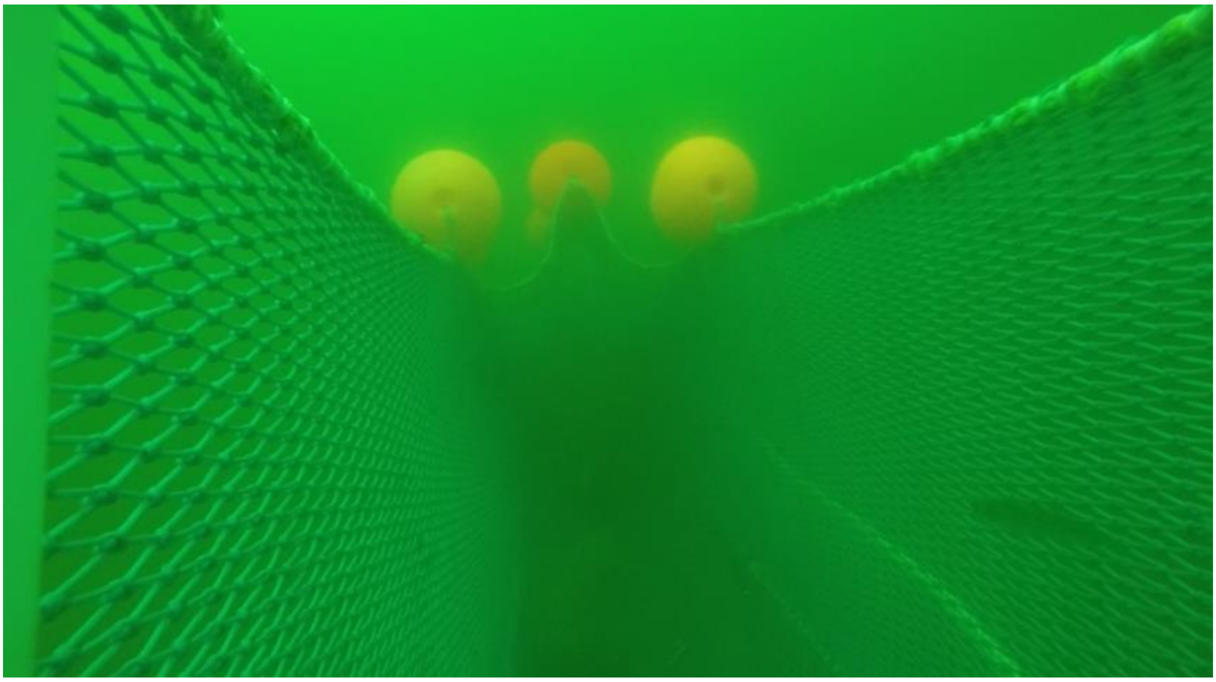

Figure 9: NEMOS + ROOFLESS device. Underwater footage (viewing direction: towards the vessel); front part of the escapement window in the top panel, including floats to lift the netting up. This lifted top panel helps to guide cod upwards.

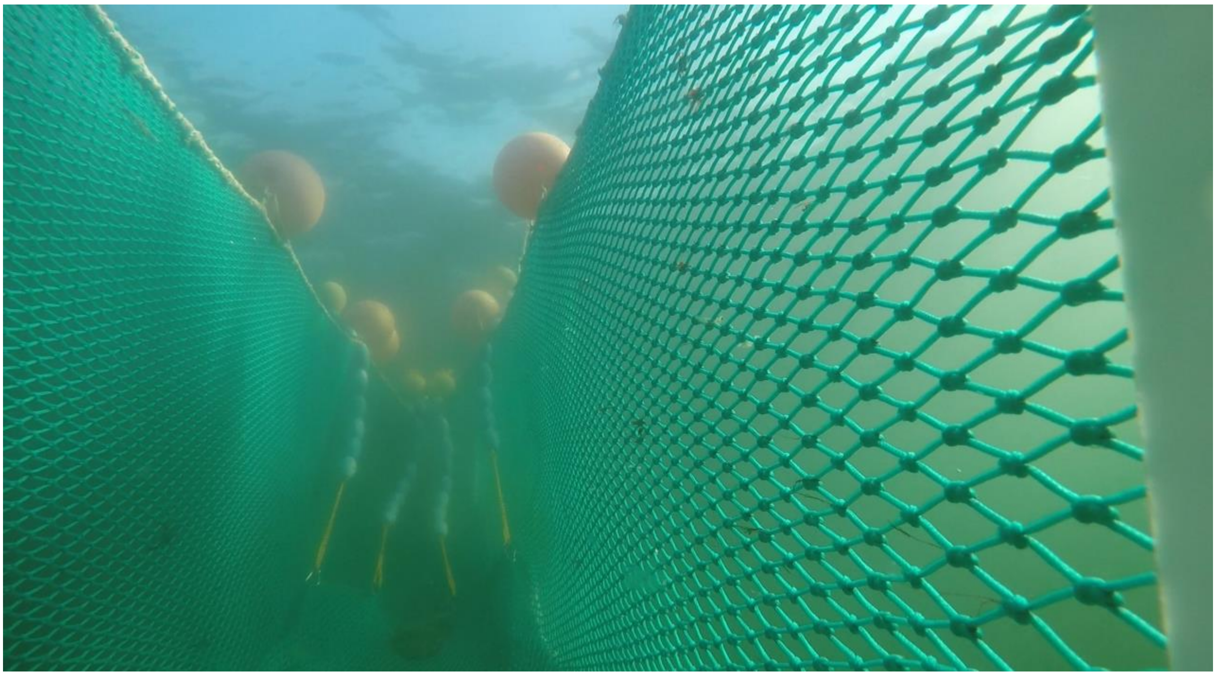

Figure 10: NEMOS + ROOFLESS + STIPED device. Underwater footage (viewing direction: towards the codend); rear part of the escapement window in the top panel, including stimulating ropes (STIPED) attached to the lower panel (not final configuration)

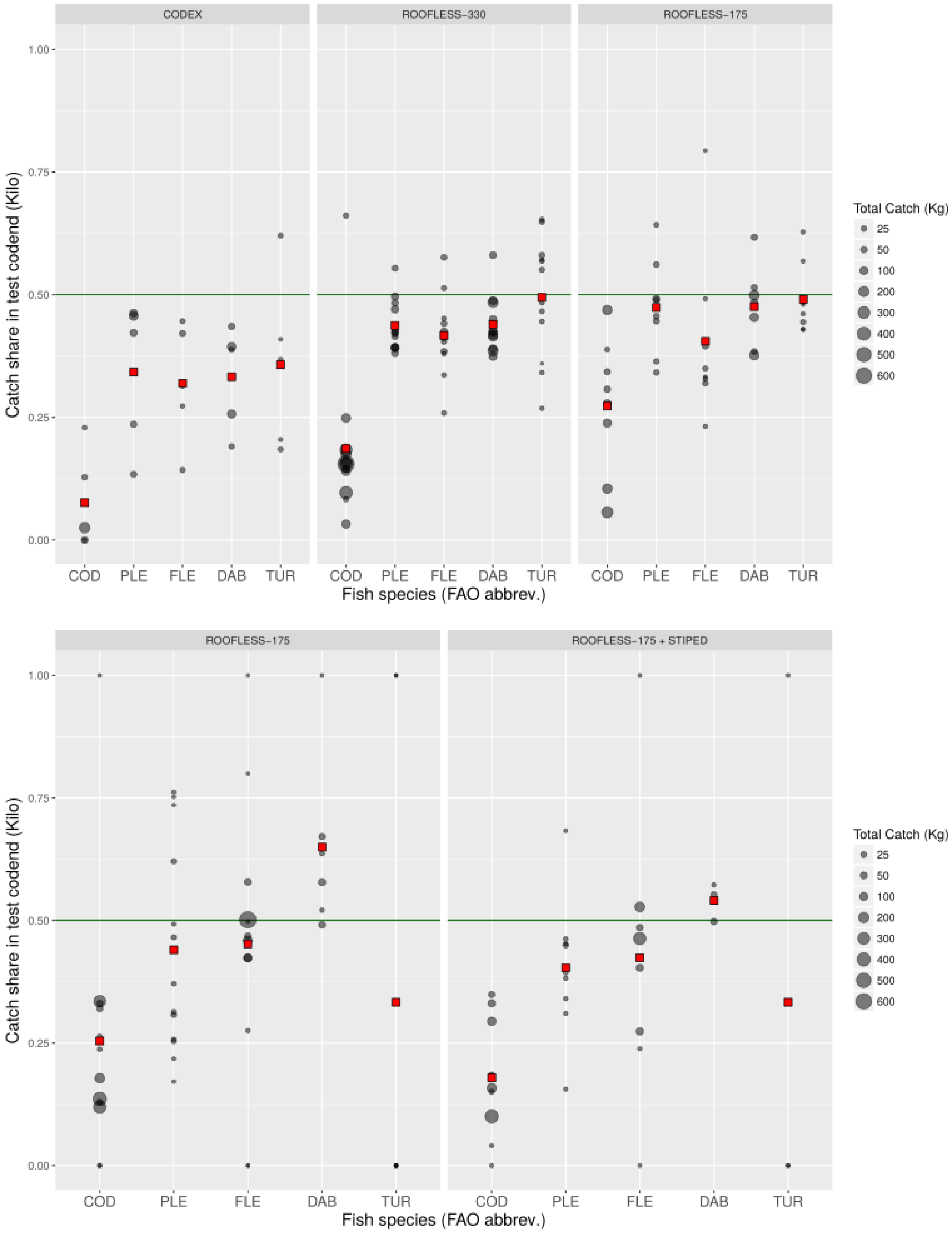

Figure 11: Catch weights per species shared in test trawls in relation to the combined catch of test trawl and control trawl (test + control = 100%). Top: cruise CLU340, Bottom: Cruise SO773. Round grey marks represent by-haul proportion of catches in the test gear relative to the total catch (size of the point directly related to the total catch obtained in the given haul), while red squares represent average catch share. Horizontal green line represent equal split (50%) of catches among trawls (same catch in both trawls). Values below the reference line indicate lower catches in the test trawl (trawl with selectivity device), while values above represent the opposite distribution of catches. Species: COD = cod; PLE = plaice; FLE = flounder; DAB = dab; TUR = turbot

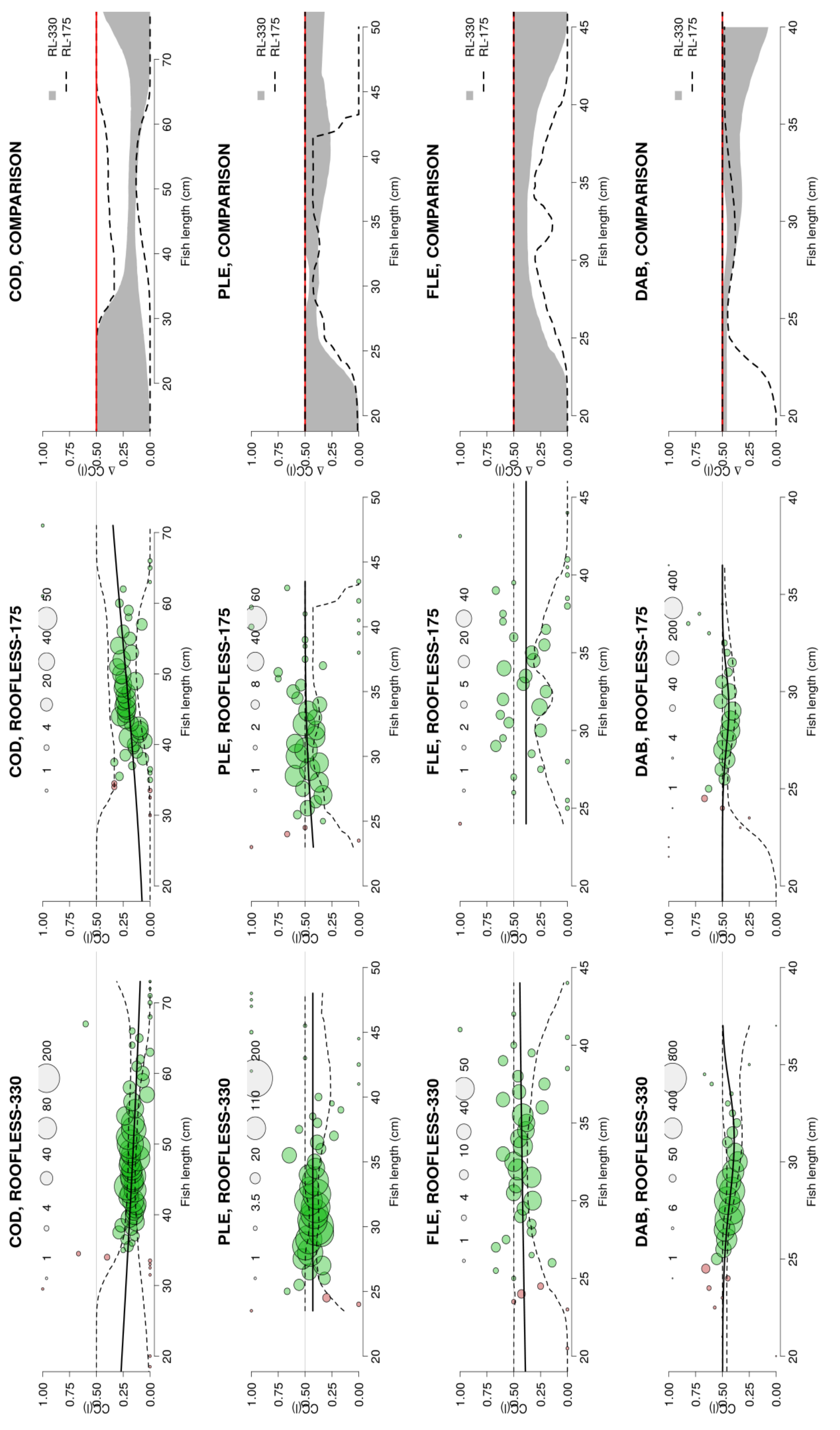

Figure 12: Models predictions for the catch comparisons ROOFLESS-330 vs. control (right column) and ROOFLESS-175 vs. control (middle column), on cod (COD), plaice (PLE), flounder (FLE), and dab (DAB). Green round marks represent experimental catch-comparison rates per length classes equal or above species MCRS, while red round marks represent catch comparison rates per length classes below MCRS. The size of the round marks is directly related to the total catch numbers per length in test and control gears. Dashed lines represent Efron 95% confident intervals around the average curve. Plots in the right column compare performance of both BRD by plotting together the confidence intervals from ROOFLESS-330 (grey shade) and ROOFLESS-175 (dashed lines) curves. Lines at CC=0.5 represent equal catches in both test and control gears, Values CC<0.5 indicate catch reduction in the test gear.

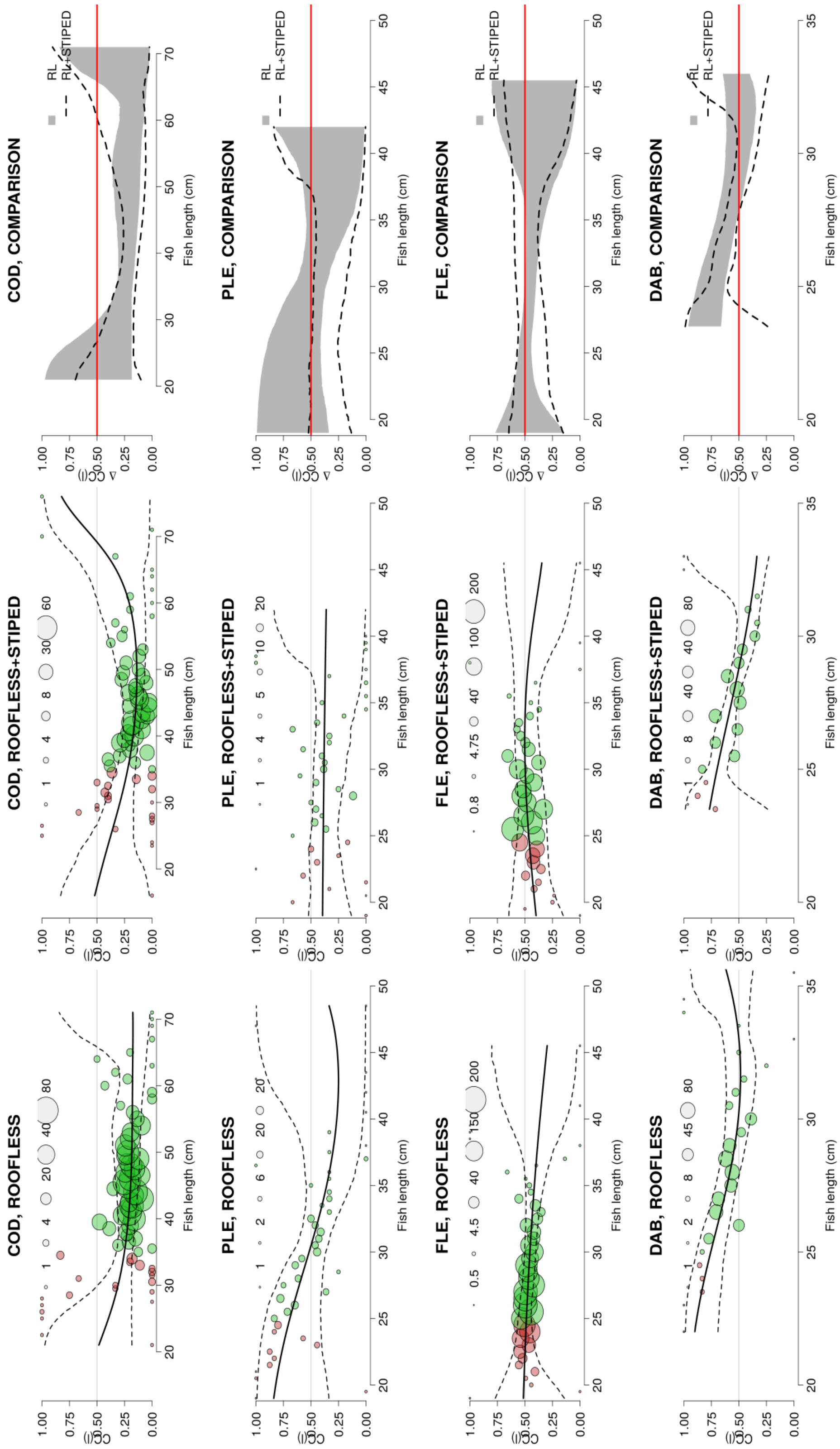

Figure 13: Models predictions for the catch comparisons ROOFLESS-175 vs. control (right column) and ROOFLESS-175 +STIPED vs. control (middle column), on cod (COD), plaice (PLE), flounder (FLE), and dab (DAB). Green round marks represent experimental catch-comparison rates per length classes equal or above species MCRS, while red round marks represent catch comparison rates per length classes below MCRS. The size of the round marks is directly related to the total catch numbers per length in test and control gears. Dashed lines represent Efron 95% confident intervals around the average curve. Plots in the left right column compare performance of both BRD by plotting together the confidence intervals from ROOFLESS-175 (grey shade) and ROOFLESS-175 +STIPED (dashed lines) curves. Lines at CC=0.5 represent equal catches in both test and control gears. Values CC<0.5 indicate catch reduction in the test gear.

Table 2: Catch numbers above and below MCRS from the most relevant species (cod, dab, flounder, plaice, turbot), caught by each of the four test gears and the paired control gear, and resulting release efficiency indicators obtained with Equation 2. 95% Efron percentile confidence intervals based on double bootstrap in brackets. nR-/nR+/nR-values coloured in grey indicate poor data basis due to low catches for this species in this category (n<50).

				catches in test gear (n)		catches in control gear (n)		catch reduction in test (%relative to control)		
Cruise	**BRD**	**Species**	**MCRS**	**below_MCRS**	**above_MCRS**	**below_MCRS**	**above_MCRS**	**nR- (below_MCRS)**	**nR+ (above_MCRS)**	**nR (total)**
CLU340	CODEX	cod (COD)	35	0	4	3	147	100.0 (100-100)	97.3 (86.7-99.6)	97.3 (86.7-99.6)
CLU340	ROOFLESS-330		35	6	390	14	2004	57.1 (22.2-88.9)	80.5 (76.4-84.4)	80.4 (76.2-84.2)
CLU340	ROOFLESS-175		35	2	186	9	728	77.8 (0-100)	74.5 (40.0-88.5)	74.5 (40.3-88.4)
SO773	ROOFLESS-175		35	22	265	49	1077	55.1 (22.7-78.3)	75.4 (56.3-84.3)	74.5 (55.8-83.2)
SO773	ROOFLESS-175+STIPED		35	23	139	57	720	59.6 (33.3-84.6)	80.7 (62.8-87.4)	79.2 (60.5-86.9)
CLU340	CODEX	dab (DAB)	25	15	420	18	807	16.7 (0-56.2)	48.0 (25.7-66.2)	47.3 (24.8-65.4)
CLU340	ROOFLESS-330		25	67	2135	46	2803	0 (0-16.4)	23.8 (13.3-32.3)	22.7 (12.4-30.8)
CLU340	ROOFLESS-175		25	33	1170	25	1360	0 (0-28.6)	14.0 (0-28.7)	13.1 (0-27.3)
SO773	ROOFLESS-175		25	18	322	3	225	0 (0-0)	0 (0-0)	0 (0-0)
SO773	ROOFLESS-175+STIPED		25	16	254	4	207	0 (0-45.5)	0 (0-0)	0 (0-0)
CLU340	CODEX	flounder (FLE)	25	7	83	12	167	41.7 (0-91.7)	50.3 (28.4-75.6)	49.7 (28.7-74.0)
CLU340	ROOFLESS-330		25	5	252	11	340	54.5 (0-88.9)	25.9 (10.0-39.1)	26.8 (11.3-39.9)
CLU340	ROOFLESS-175		25	1	111	0	179	0 (0-0)	38.0 (17.5-52.3)	37.4 (15.8-52.0)
SO773	ROOFLESS-175		25	270	917	275	1052	1.8 (0-31.3)	12.8 (0-26.3)	10.5 (0-22.5)
SO773	ROOFLESS-175+STIPED		25	153	701	195	738	21.1 (0-61.3)	5.0 (0-49.9)	8.3 (0-51.9)
CLU340	CODEX	plaice (PLE)	25	1	417	2	633	50.0 (0-100)	34.1 (14.8-65.3)	34.2 (14.7-65.3)
CLU340	ROOFLESS-330		25	4	842	10	1123	60.0 (0-93.3)	25.0 (14.4-34.0)	25.3 (14.7-34.4)
CLU340	ROOFLESS-175		25	4	341	3	375	0 (0-75.6)	9.1 (0-27.0)	8.7 (0-26.7)
SO773	ROOFLESS-175		25	48	139	17	129	0 (0-47.4)	0 (0-44.5)	0 (0-42.3)
SO773	ROOFLESS-175+STIPED		25	19	76	30	123	36.7 (0-75.0)	38.2 (15.7-68.1)	37.9 (19.1-64.4)
CLU340	CODEX	turbot (TUR)	30	25	14	62	21	59.7 (26.5-86.4)	33.3 (0-84.6)	53 (9.4-82.1)
CLU340	ROOFLESS-330		30	121	69	114	60	0 (0-28.2)	0 (0-18.6)	0 (0-21.1)
CLU340	ROOFLESS-175		30	61	36	74	35	17.6 (0-40.9)	0 (0-24.3)	11.0 (0-31.1)
SO773	ROOFLESS-175		30	2	0	3	3	33.3 (0-100)	100 (24.4-100)	66.7 (0-100)
SO773	ROOFLESS-175+STIPED		30	0	1	2	1	100 (100-100)	0 (0-100)	66.7 (0-100)

6 Approach 2: Codend selectivity

Historically, alterations in the selectivity aimed to reduce the catch of undersized Baltic cod while keeping as much as possible cod above landing size. These selectivity alterations of Baltic trawls were achieved by changes in codend mesh size of standard netting. A number of studies indicated that such a classical approach did not always deliver the desired selection patterns for Baltic cod. The reason is that the rounded cross section of cod does not fit well through the opening of diamond-mesh netting when stretched by the towing forces. Therefore, the classical modification of changing the mesh size was subsequently combined with other modifications (e.g. mesh configuration) that aimed to keep the meshes open during towing. Applying either square-mesh netting or diamond-mesh netting turned 90 degrees (T90) were found to be the most successful approaches to increase the escape probabilities of (undersized) cod.

Currently, two codend configuration are legal and routinely used in the Baltic demersal trawl fishery:

- Bacoma codend, mesh size ≥ 120 mm: T0 105 mm codend and square mesh window with minimum mesh size of 120 mm
- T90 codend, mesh size ≥ 120 mm: T90 netting with minimum mesh size of 120 mm (stretched mesh opening)

As described above, both codends were developed with the aim to optimize the catch efficiency for marketable cod. At the same time, the selective properties for flatfish species of these codends is rather poor and prevent even small flatfish from escaping the trawl. An additional complication is that flatfish can block meshes in the codend / exit window, thus potentially reducing the escapement probability of cod (Figure 14).

Figure 14: Underwater recording of Bacoma codend (seen from outside) with flatfish blocking meshes and therefore limiting escapement probabilities of cod.

Consequently, it does not appear to be an optimal cod avoidance strategy to fish with codends optimised for catching sized cod (Bacoma 120 mm and T90 120 mm).

Therefore, we have investigated whether the catch of cod could be also reduced by codend modifications, while keeping catch efficiency for flatfish species. The most important results are summarized below, additional information (incl. methodology) is given in ICES (2019c).

The selectivity parameters were calculated for three different codend types (Bacoma, Full-square-mesh, T90; Figure 15) and mesh sizes (Table 3).

Simulated catch comparison trials were conducted based on these selectivity parameters and a population structure derived from BITS-survey (ICES SD24, quarter 4). The legal codend Bacoma 132 mm was chosen as control codend and its simulated catches were compared against the catches from the other codend types/configurations (Figure 16).

Catch ratios from each of the different codends considered in the simulation and the control codend are used for comparison (Figure 16). A catch ratio of 100% would imply identical catches from the test and the control codends, while for example a 30% catch ratio would indicate 70% catch reduction in the test codend relative to the control.

The theoretical study presented here indicates that adapting the mechanical selection in Baltic codends could lead to a large reduction in cod catches (mostly on small and medium length classes). The latest experimental comparison between the two mandatory codends in the Baltic Sea published to date (Wienbeck et al., 2014) showed the T90 ≥ 120 mm codend (measured mesh size 127 mm) to be less efficient in catching medium-sized cod compared to the control BACOMA ≥ 120mm codend (measured mesh size 132 mm). Based on such differences, our simulation indicates that using T90 codends can lead to a catch reduction of around 50% (relative to expected catches when using the control BACOMA codend), at least when exploiting cod populations composed mainly by small and medium sizes, as is the case now in the eastern Baltic. Limited reduction in catches of sized plaice (MCRS = 25cm; around -15% relative catches) suggest that the trade-off between cod avoidance and losses of flatfish catches might be acceptable for the industry. Increasing the mesh size of T90 codends can contribute to mitigate cod bycatch further, at the prize of further reduction of flatfish catches. For example, T90 codends made of netting with 140 mm mesh size are expected to achieve approx. 80% and approx. 100% bycatch reduction of cod above and below MCRS, respectively. However, the catch reduction of marketable plaice is estimated to be around 68%. This catch loss is mainly due to reduced catchability for plaice between 25 and 30cm. If the commercially realised minimum size is larger than 25 cm, then it is also possible to use other codend options with higher reduction of cod catches (Figure 17 and Figure 18). If this is acceptable, T90 140mm is an option. Therefore, minimum mesh size for T90 codends to be applied in flatfish fisheries should be assessed experimentally, considering plaice MCRS, as well as the market value by size classes for plaice and other flatfish species.

Alternatively, another codend could be chosen with lower catch reduction of cod, but higher catchability for marketable flatfish.

The results of this simulation exercise needs to be taken with caution due to the following limitations:

- the theoretical study was based on a “static picture” of the exploited fish populations. The effect of codend size selectivity on catches would vary under variations in the population structure. For example, an increased abundance of large cod would lead to an increase in cod bycatch.
- The simulations only consider population-average selectivity patterns, therefore do not account for selectivity variations often occurring even between hauls on the same fishing trip. The selective properties of codends may depend on a variety of parameters, such as type of fishing vessel (side trawler vs. stern trawler), type of netting (yarn diameter, single/double), catch volume, catch composition, swell.
- The selectivity properties from four out of ten codend designs considered in the simulation were simultaneously and experimentally quantified (Wienbeck et al., 2014). However, the selectivity from the remaining six designs had to be determined theoretically, and may need to be confirmed experimentally.

It was planned to verify the results of this theoretical study on a research cruise in March 2020. This cruise had to be cancelled due to measures taken to address the Covid-19 pandemic. Nevertheless, initial tests could be conducted on short-term – given the relaxation of Covid-19 measures and the availability of commercial vessels.

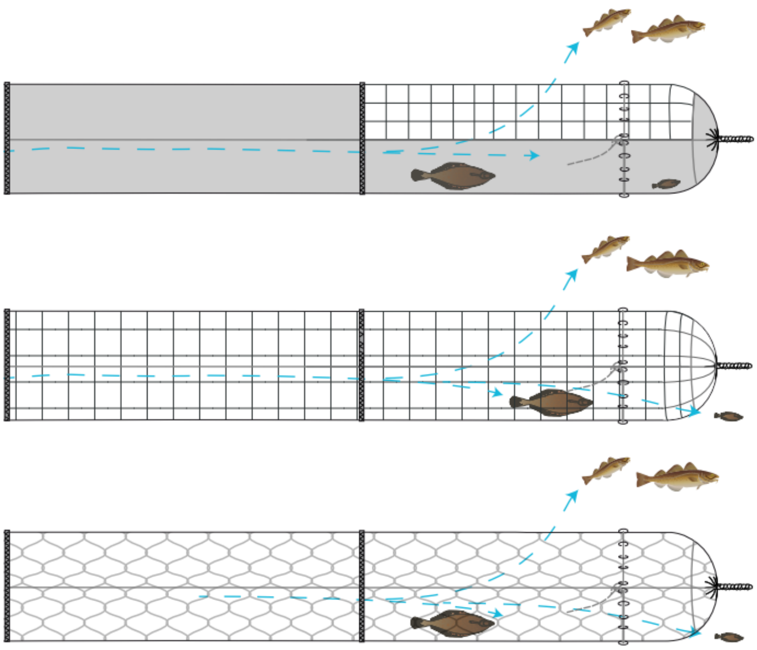

Figure 15: Codend-types (Schematical drawings) taken into account for investigation related to catch reduction of cod. Top: Bacoma-codend; Mid: Square mesh codend; Below: T90-codends.

Table 3: Estimated selectivity parameters for three codend types and different mesh size (stretched measured mesh opening): The length at 50% retention of a given species in the codend (L50) and selection range (SR). Some estimates are based on experimental fishing (Wienbeck et al., 2014) (Source 1), while others are based on theoretical modelling (Herrmann, 2008; Herrmann et al., 2009) (Source 2, 3). Grey values for SR are adapted from similar codends where data are available from experimental fishing.

		selection parameter [cm]					
		cod		plaice		basis for estimation	
codend-Type	mesh opening [mm]	L50	SR	L50	SR	experiment / modelling	Quelle
Bacoma-codend	132	38.7	8.0	21.4	2.0	experiment (reference)	1
	146	45.2	10.3	24.9	4.3	experiment	1
Full-square-mesh codend	120	42.4	7.2	20.8	3.0	modelling	1
	127	45.6	7.2	20.2	3.0	experiment	1
	130	46.1	7.2	22.3	3.0	modelling	2,3
	140	50.0	7.2	24.4	3.0	modelling	2,3
T90-codend	120	42.3	6.7	24.3	2.1	modelling	2,3
	127	43.4	6.7	24.7	2.1	experiment	1
	130	44.5	6.7	26.0	2.1	modelling	2,3
	140	48.0	6.7	29.0	2.1	modelling	2,3

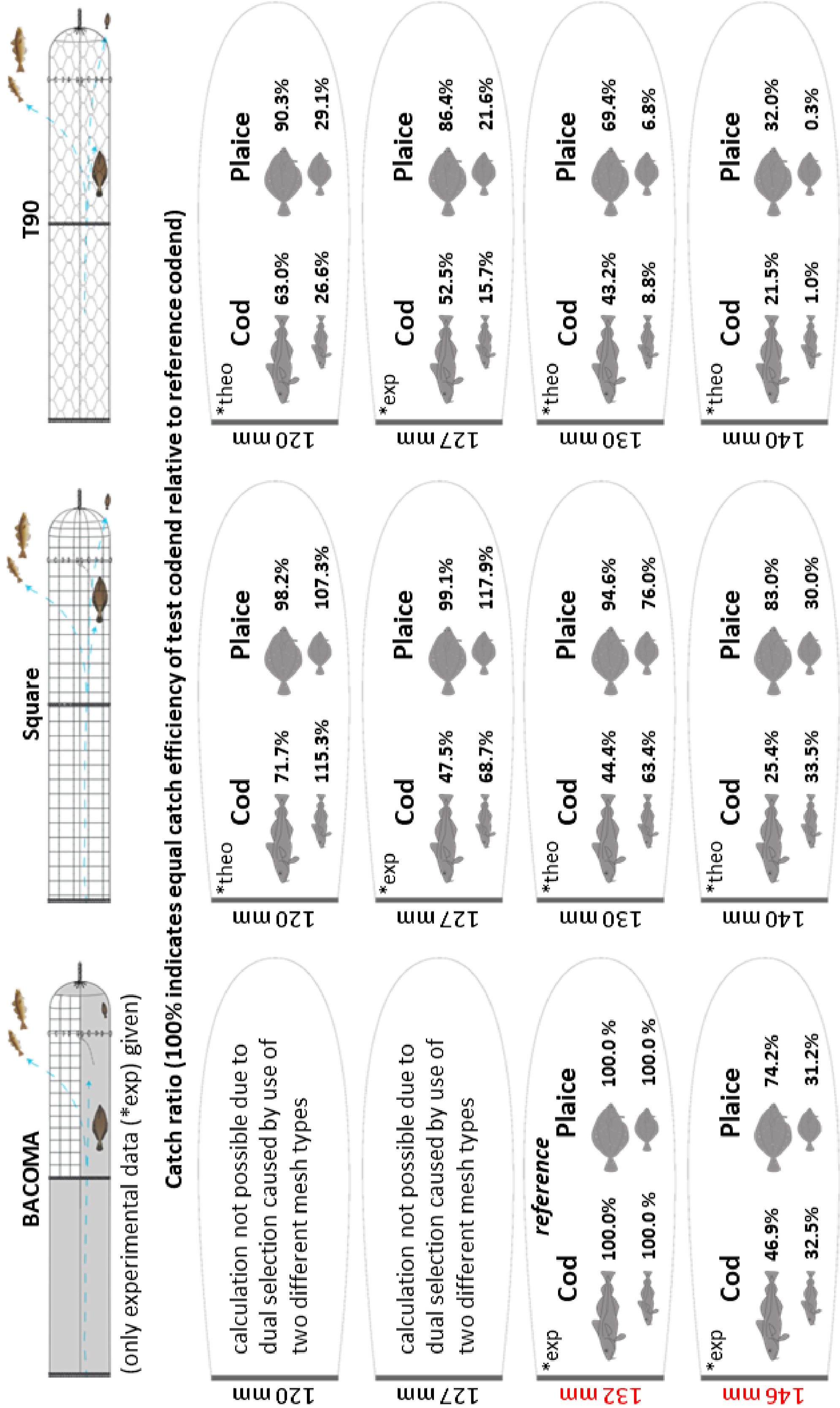

Figure 16: Simulated catch comparison experiments for different codends (codend type / mesh opening). See text for explanation or ICES (2019c).

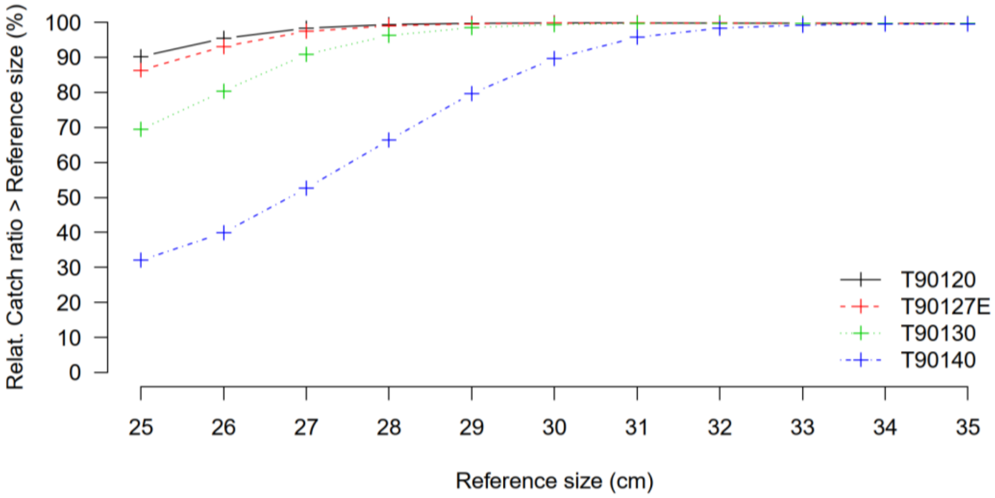

Figure 17: Simulated catch comparison experiments for T90-codends with different mesh sizes in relation to the reference codend (Bacoma ≥ 120 mm, measured mesh size 132 mm). Catch ratios given for flatfish above different references size. A catch ratio of 100% indicates an identical catch between the test and the control codend.

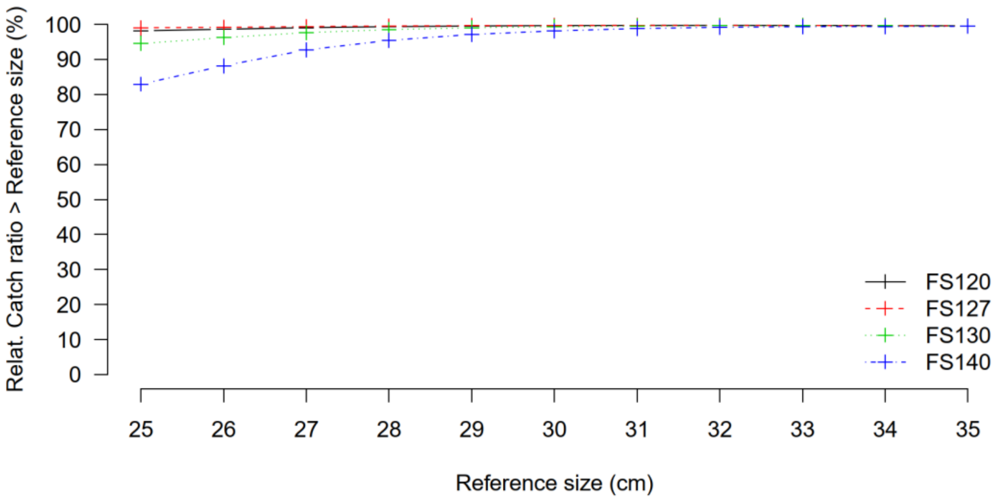

Figure 18: Simulated catch comparison experiments for Full-square-mesh-codends with different mesh sizes in relation to the reference codend (Bacoma ≥ 120 mm, measured mesh size 132mm). Catch ratios given for flatfish above different references size. A catch ratio of 100% indicates an identical catch between the test and the control codend.

7 Approach 3: Combination of codend selectivity and selection device

Cod-avoidance strategies from approaches 1 and 2 (described above) could be simultaneously applied in fishing operations to reduce cod catches further, at least considering selective technologies currently available.

The simulation study described in the previous section (approach 2: Codend selectivity) was updated to assess the combined effect of supplementing the selectivity provided by mandatory codends with the release efficiency of ROOFLESS-175. In particular, the updated simulation generates artificial catches after applying the selectivity properties from mandatory codends (based on experiments from Wienbeck (2014); see Table 3 for details), and the release efficiency of ROOFLESS-175 (based on experiments conducted during the CL340 cruise; further details in section 5).

In particular, the simulation considered four different fishing scenarios:

a. BACOMA ≥ 120 mm (132 mm stretched mesh size)

b. T90 ≥ 120 mm codend (127 mm stretched mesh size)

c. BACOMA ≥ 120 mm + ROOFLESS 175

d. T90 ≥ 120 mm codend + ROOFLESS 175

Fishing scenarios a, b, c, d were applied on the same fish population used in the previous section (ICES SD 24, 2018, Quarter 4). Resulting catches were used to estimate the catch ratio of (b, c, and d), relative to the baseline scenario (a).

Being the scenario (a) the baseline (100% catch rate), the simulation resulted in catch reduction of 51% when applying the selectivity properties of T90 ≥ 120 mm codend (Figure 19). Supplementing the selectivity of the BACOMA codend with ROOFLESS-175 would lead to an overall cod reduction of 80%, relative to scenario (a). Maximum reduction in cod catches is achieved in scenario (c), with 89% compared to the baseline scenario (a). Catch losses of sized plaice are less pronounced, with a maximum reduction of around 25% in scenario (d).

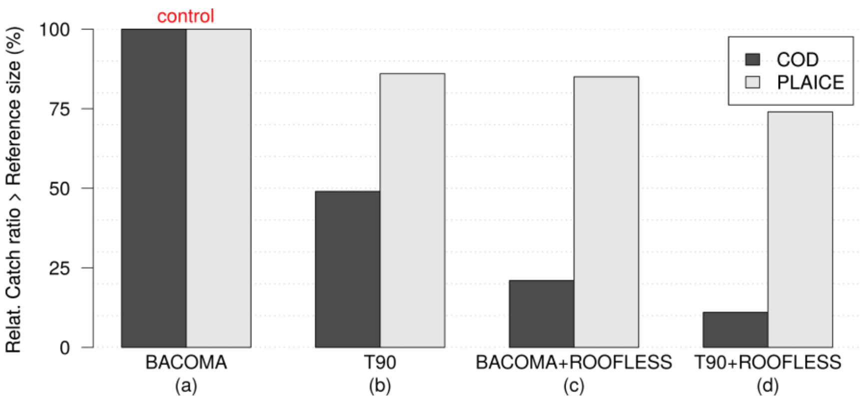

Figure 19: Simulated experiment comparing catches of cod (full range of lengths available) and sized plaice (length classes ≥ 25 cm) in fishing scenarios applying the mandatory codends (BACOMA ≥ 120 mm codend, measured mesh size 132 mm, and T90 ≥ 120 mm codend, measured mesh size 127 mm), and fishing scenarios resulting from adding the release efficiency of ROOFLESS to the selectivity properties of the codends. Values calculated as the ratio of catches obtained from each scenario to the baseline (a).

As the uncertainty of the presented estimates of the combined effect is relatively high, it is advisable to confirm the calculation in experimental tests. This is not possible until the measures to combat the Covid-19 pandemic are lifted.

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Intensive work was carried out with the netmakers of ROFIA-Kloska on the further development of the NEMOS, CODEX and ROOFLESS concepts. Special thanks go to the production manager Stefan Lehmann.

A big thank you also goes to the staff of the Thuenen Institute, as well as to the crew of the ships, who made the experiments possible with great commitment

We would especially like to thank Annemarie Schütz, who tirelessly provides us with illustrations and videos.

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10 Annex I: Technical drawings

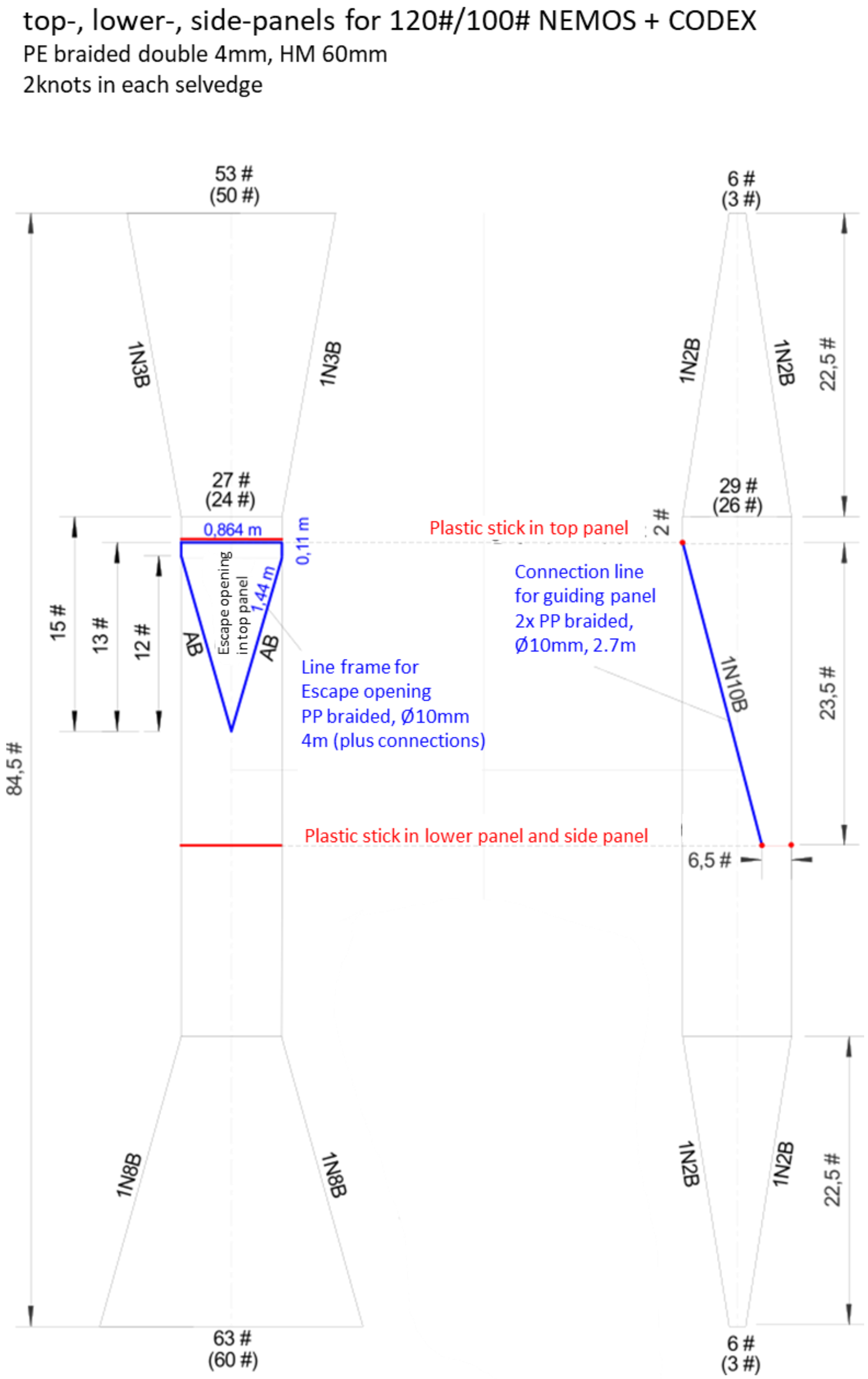

Figure 20: Technical drawing (Top and side view) of NEMOS (NEt Enabling MOdular Selectivity) gear in CODEX configuration (NEMOS+CODEX).

top-, lower-, side-panels for 120#/100# extension
PE braided double 4mm, HM 60mm
2knots in each selvedge

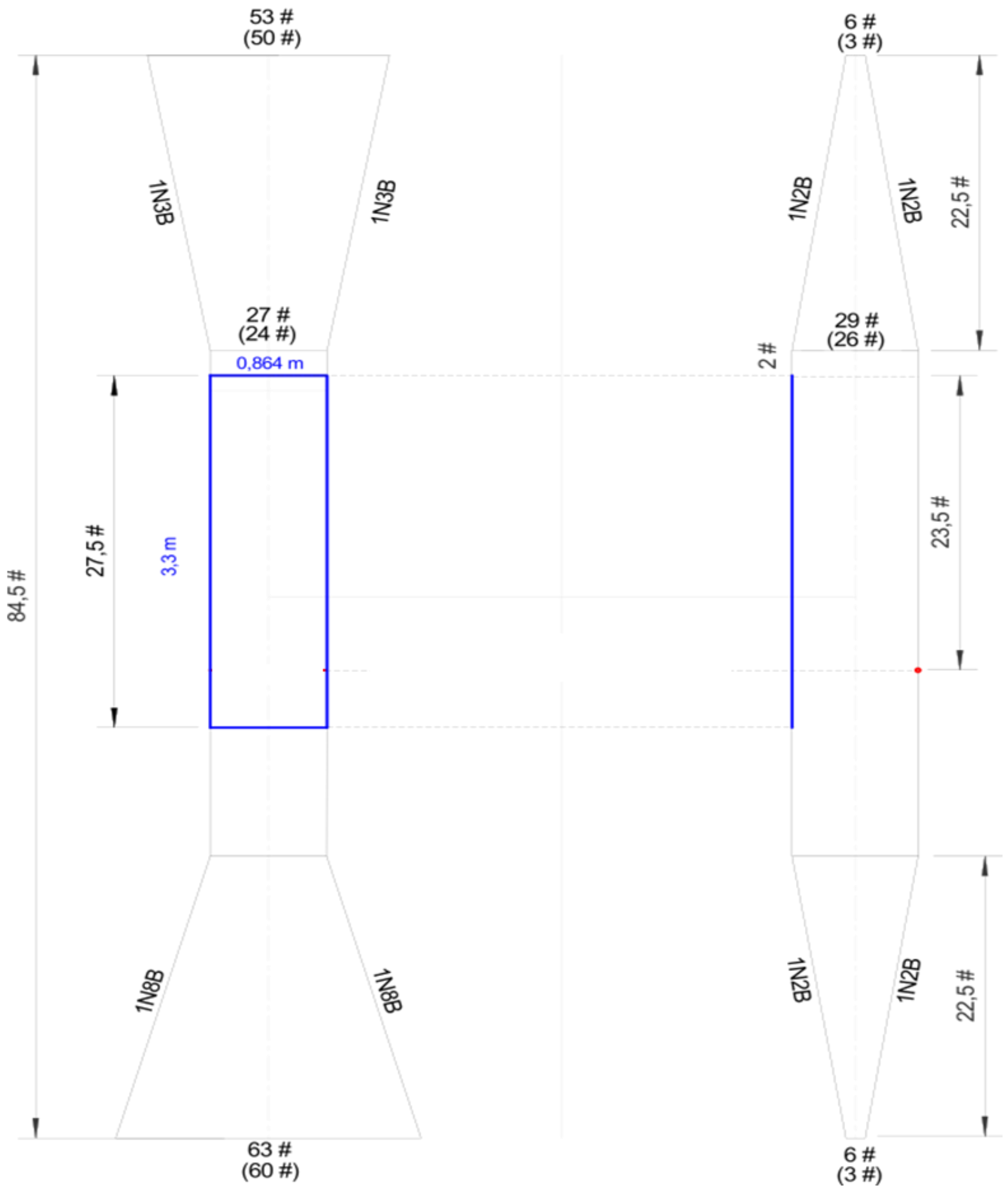

Figure 21: Technical drawing (Top and side view) of NEMOS (NEt Enabling MOdular Selectivity) gear in ROOFLESS configuration (NEMOS+ROOFLESS, here ROOFLESS-330).

11 Annex II: Models for catch comparison

This Annex describes the model and length-dependent catch comparison method applied on fish counts caught in the test and control gears, at haul level. Simple derivations enables quantifying the length-dependent release efficiency of the BRD being tested. In more detail, the method compares the catches obtained with the two gears (test and control) and relates the observed proportions of the catches to the release efficiency of the tested BRD. Because both gears fished simultaneously, the collected catch data were treated as paired catch comparison data (Krag et al., 2015).

Based on Herrmann et al. (2018), the size selection processes in the two compared gears can be considered as sequential processes, first with a size selection $r_{front}(l)$ in the part of the trawl ahead of the extension, followed by the size selection provided by NEMOS netting $r_{nemos}(l)$, and finally the selection process in the codend $r_{codend}(l)$. The only difference between the two gears is that one has the BRD tested installed in the NEMOS section of the test gear. This leads to an additional selection process, which can be expressed as $r_{brd}(l)$ = 1.0-$e_{brd}(l)$, where $e_{brd}(l)$ is the length-dependent escape probability (release efficiency) through the BRD being tested for a fish entering the extension. Based on these sequential selectivity processes, the total selectivity for the test gear with the BRD installed $r_t(l)$ and the control gear $r_c(l)$ can be modelled as:

$$
\begin{aligned}
r_t(l) &= r_{front}(l) \times r_{nemos}(l) \times \left(1.0 - e_{brd}(l)\right) \times r_{codend}(l) \\
r_c(l) &= r_{front}(l) \times r_{nemos}(l) \times r_{codend}(l)
\end{aligned}
\qquad (1)
$$

Based on the group of valid hauls h, we can quantify the experimental average catch comparison rate CC_l (Herrmann et al., 2017) as follows:

$$
CC_l = \frac{\sum nT_{il}}{\sum (nC_{il} + nT_{il})} \qquad (2)
$$

where nT_{il} and nC_{il} are the numbers of fish in length class *l* caught in haul *i* in the codend of the test gear and the codend of the control gear, respectively. The next step is to express the relationship between the catch comparison rate CC_l and the size selection processes (retention probability) for the test gear with any of the BRD installed $r_t(l)$, and the control gear $r_c(l)$. First, the total number of fish n_l in length class *l* being caught by the paired gear is separated into the test or the control. The split parameter (*SP*) accounts for this initial catch share process by quantifying the proportion of fish entering the test gear compared with the total entering both gears. *SP* is assumed to be length independent; therefore, the expected values for $\sum_{i=1}^{h} nT_{il}$ and $\sum_{i=1}^{h} nC_{il}$ are:

$$
\begin{aligned}
\sum_{i=1}^{h} nT_{il} &= n_l \times SP \times r_t(l) \\
\sum_{i=1}^{h} nC_{il} &= n_l \times (1 - SP) \times r_c(l)
\end{aligned}
\qquad (3)
$$

The expected equal catch efficiency of both sides of the paired gear setup and a balanced distribution of hauls during the experiment led to the assumption that fish have an average equal probability of entering either the test or the control gear. Therefore, the parameter *SP* in Equation 3 was initially fixed to a value of 0.5. Based on Equations 1–3, the theoretical catch comparison rate *CC(l)* becomes:

$$
CC(l) = \frac{SP \times \left(1.0 - e_{brd}(l)\right)}{1.0 - SP \times e_{brd}(l)} \qquad (4)
$$

Equation 4 establishes a direct relationship between the escape probability through the BRD being tested $e_{brd}(l)$ and the catch comparison rate *CC(l)*. Therefore, the length-dependent release efficiency can be assessed by estimating the catch comparison rate as formulated in Equation 4.

The release efficiency of the tested BRD depends on species-specific behaviour and length-dependent swimming ability. Therefore, to be able to model $e_{brd}(l)$ for the different species investigated, we used a highly flexible function often used in catch comparison studies (Herrmann et al., 2018; Krag et al., 2015, 2014):

$$e_{brd}(l,v) = \frac{exp(f(l,v))}{1.0+exp(f(l,v))} \qquad (5)$$

where $f(l,\boldsymbol{v})$ is a polynomial of order 4 with parameters $\boldsymbol{v} = (v_0, v_1, v_2, v_3, v_4)$ (Krag et al., 2015).Therefore, the estimation of the catch comparison rate in Equation 4 is conducted by minimising the following maximum likelihood equation with respect to the parameters $\boldsymbol{v}$ describing $CC(l,\boldsymbol{v})$:

$$-\sum_i \sum_l \{nT_{il} \times ln(CC(l,v)) + nC_{il} \times ln(1.0 - CC(l,v))\} \qquad (6)$$

Leaving out one or more of the parameters v_0–v_4 in Equation 5 led to 31 additional simpler models, which were also considered potential candidates for modelling release efficiency, and therefore, also estimated by Equation 6. The 32 competing models were ranked by decreasing AIC value (Akaike, 1974). The model with the lowest AIC was finally selected from among the candidates. Following the guidelines in Wileman et al. (1996), the ability of the selected model for $CC(l,\boldsymbol{v})$ to describe the data sufficiently well was based on the calculation of the *P*-value associated with the Pearson statistic, together with the visual inspection of residual length-dependent patterns.

Efron confidence intervals (95% CI) of the curves predicted by Equations 4 and 5 were obtained using the same double bootstrap procedure (1000 replications) as in Santos et al. (2016).This includes accounting for between-haul variation in the release efficiency, and the uncertainty in individual hauls resulting from the capture of a finite number of fish. In addition, the bootstrap method accounts for uncertainty resulting from uncertainty in model selection to describe $e_{brd}(l,\boldsymbol{v})$ by incorporating in each of the bootstrap iterations an automatic model selection based on which of the 32 models produced the lowest AIC. The analysis of release efficiency described above was carried out using software tools SELNET (Santos et al., 2016) and R (R Development Core Team, 2018).