THÜNEN Institute of Baltic Sea Fisheries (TI-OF)

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Cruise Reports
FRV „Clupea" Cruise 340
28.11.2019 – 19.12.2019

Gear technology investigations in German waters

Scientists in charge: Bernd Mieske and Juan Santos (Thünen-OF)

FRV „Solea" Cruise 773
02.02.2020 – 14.02.2020

MuPEdS; Gear technology investigations

Scientists in charge: Dr. Daniel Oesterwind; Dr. Uwe Krumme (Thünen-OF)

1. In a nutshell

- Selectivity trials were conducted during cruises FRV "Clupea" No 340 (28.11.-19.12.2019) and FRV "Solea" No 773. (02.02.-14.02.2020) to assess the performance of three different cod-bycatch reduction devices for Baltic flatfish fisheries. The devices were developed by Thünen Institute of Baltic Sea Fisheries in collaboration with Baltic fishers and netmakers. Sea trials were conducted using the paired-gear method. The release efficiency provided by each device was assessed for the most frequent demersal Baltic species.
- First trials with the ROOFLESS-175 device onboard "Clupea" led to a large (75%) and stable catch reduction of cod. Catches from the most abundant flatfish species were also reduced, but to a lesser extent (~10% reduction). However, this difference was not statistically different from 0% catch reduction in flatfish, at least considering the fishing conditions and techniques applied during the cruise.
- Results obtained with the ROOFLESS-175 device were replicated during the FRV "Solea" trial, conducted under different fishing conditions (vessel, trawl design, fishing grounds and fishing depths), therefore demonstrating the robustness of the device's selection principle.

The cruises were conducted within the framework of the CODEX-project, funded as EMFF-project by the EU and the 'Ministerium für Landwirtschaft und Umwelt Mecklenburg-Vorpommern'.

Distribution list:

BLE, Hamburg
Schiffsführung FFS „Clupea"
BMEL, Ref. 614
Thünen-Institut - Pressestelle (M. Welling)
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Landesverband der Kutter- und Küstenfischer
Sassnitzer Seefischer
Thünen-Seeeinsatzplanung, Herr Dr. Rohlf
Euro-Baltic Mukran

2. Introduction

In 2019, the European Commission requested advice from ICES on how to avoid limited cod quotas from choking demersal fisheries targeting other species. Among other solutions, fishing technologists from Denmark (DTU-Aqua), Sweden (SLU) and Germany (Thünen Institute) jointly presented a set of Bycatch Reduction Devices (BRDs) to avoid cod catches in flatfish fisheries. The devices proposed were classified based on their basic functioning principle: (1) mechanical selectivity devices that take advantage of differences in morphology between cod and flatfish, (2) selectivity devices that make use of differences in behaviour between species to sort and exclude cod, and (3) selectivity devices which combine strategies 1) and 2). In the final advice, ICES noted the need for further investigations on the performance and effectiveness of the solutions proposed, since most of them were in early stages of development at the time of reporting, or new developments.

To address the research needs reported by ICES, the Thünen Institute of Baltic Sea Fisheries scheduled three research cruises in 2019-20 to conduct selectivity sea trials with the proposed BRDs using two German research vessels, FRV "Clupea" and FRV "Solea". The field experiences obtained during the trials should provide information regarding the functioning of the proposed BRDs and quantification of their efficiency, as well as opportunities for further development of the initial designs.

This document reports on the results obtained by the two initial sea-cruises, used to test behavioural selection devices related to functioning principle (2). The first cruise took place during November-December 2019 onboard "Clupea" (cruise No 340, hereafter referred as CLU340). The second cruise was conducted in February 2020 onboard "Solea" (cruise No 773, hereafter referred as SOL773).

A third cruise scheduled for March-April 2020, onboard FRV "Solea" was cancelled due to measures taken to address the Covid-19 pandemic.

The two cruises were conducted within the framework of the CODEX-project, funded as EMFF-project by the EU and the 'Ministerium für Landwirtschaft und Umwelt Mecklenburg-Vorpommern'.

3. Experimental gears

Three different BRD concepts, CODEX, ROOFLESS and ROOFLESS+STIPED (Figure 2 - Figure 4) were tested in experimental fishing during CLU340 and SO773. The devices were developed by the Thünen Institute of Baltic Sea Fisheries in collaboration with Baltic fishers and netmakers from Rofia-Kloska. The three devices were mounted (one at a time) in the so-called NEMOS-device (Net Enabling MOdular Selectivity, Figure 1), a multi-purpose 2-4-2-panel net section located between the codend and the trawl body. The special design of NEMOS enables easy installation and removal of the selection devices described above. Such modularity provided a large degree of flexibility to switch among BRDs during the experiments. Such flexibility might be also attractive for fishers interested in adapting the selectivity of their trawls without major changes of the trawl body. Basic selective concepts and functioning principles from each BRD are described below. Further construction details can be found in the annex.

CODEX (COD EXcluder) device consisting of three elements; i) codend inlet, ii) inclined (guiding) panel and iii) outlet, (Figure 2). The device aims to sort cod and flatfish to be able to exclude cod without significant loss of targeted flatfishes. The selection concept relies on observed behavioural differences between species in the aft of the trawl. Underwater video recordings from previous trials illustrates that flatfishes prefer to swim close to the bottom panel of the trawl. Such swimming behaviour is held even when the fish enters the narrow codend inlet from the current device (Figure 2-i). In contrast, cod observations indicate a preference to keep distance to the bottom and avoiding contact with the trawl net even when it enters narrow spaces. In conclusion, the functioning principle of CODEX is to establish a rather flexible inlet in the lower part of the device to keep flatfish swimming close the bottom and entering the codend, while cod should be guided by the inclined panel (Figure 2-ii) upwards to the escape window (Figure 2-iii).

ROOFLESS is a simple adaptation which involves removing a section of the top panel of NEMOS (Figure 3). The device provides a wide, net-free open window that could be used to escape by cod in its way to the codend. Previous experiments have shown that it is insufficient to use very large meshes in the top panel (e.g. 400mm mesh opening), as cod still shows avoidance reaction. Establishing ROOFLESS might induce a deep visual contrast between the open zone and the net panels around. It is also expected to produce a drastic perturbation of the water flow in the net tunnel. The species selection concept relies on the assumption that such visual and/or hydrodynamic perturbations will activate e.g. optomotor responses from cod towards the escape window. In contrast, the concept assumes that flatfish will not react to the established perturbations, due to their preference to stay near the bottom panel of the trawl. Two different ROOFLESS designs were considered for testing, the initial ROOFLESS design involves a 330 cm-long open window, while the second design has a reduced window length of 175 cm.

ROOFLESS + STIPED: The idea of STIPED is to use ropes with floats (Figure 4) to stimulate cod to perform upwards escape reactions towards ROOFLESS. The STIPED should therefore increase the escapement rate of cod relative to the simple ROOFLESS device. In addition, stimulating ropes may help to reduce potentially high between-haul variability, which might be caused by the influence of varying physical conditions (light, water turbidity, currents) on the behavior of cod in the presence of ROOFLESS. It is expected that mounting STIPED will not influence flatfish behaviour significantly.
The concept of stimulating ropes (STIPED) was introduced and tested by Herrmann et al. (2015). The study demonstrated that using STIPED could significantly enhance release efficiency of selection devices such as square mesh windows.

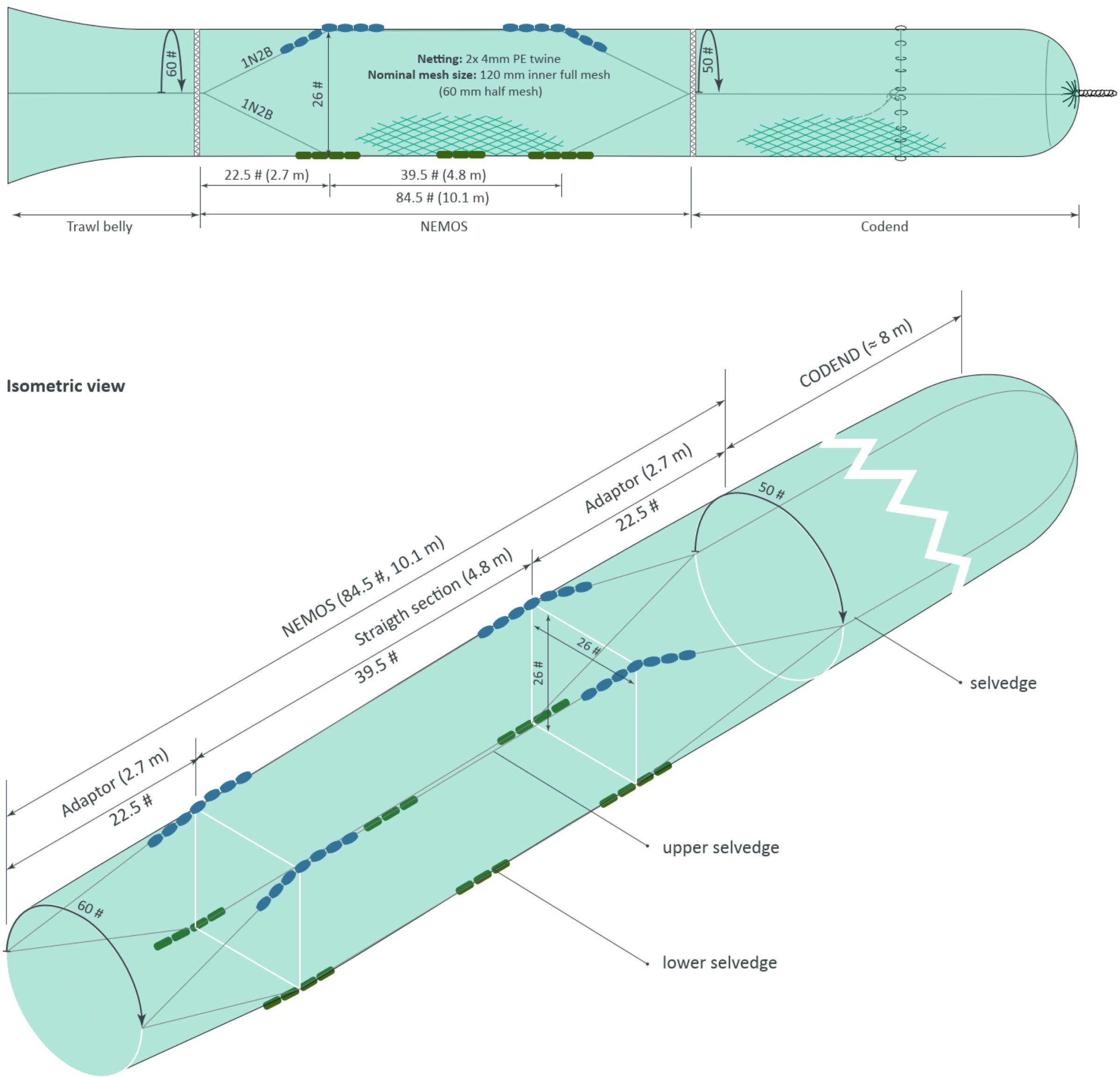

Figure 1: NEMOS (NEt Enabling MOdular Selectivity) device: A multi-purpose 2-4-2-panel net section located between the codend and the trawl body. NEMOS can be used for easy installation and removal of the selection devices in the trawl

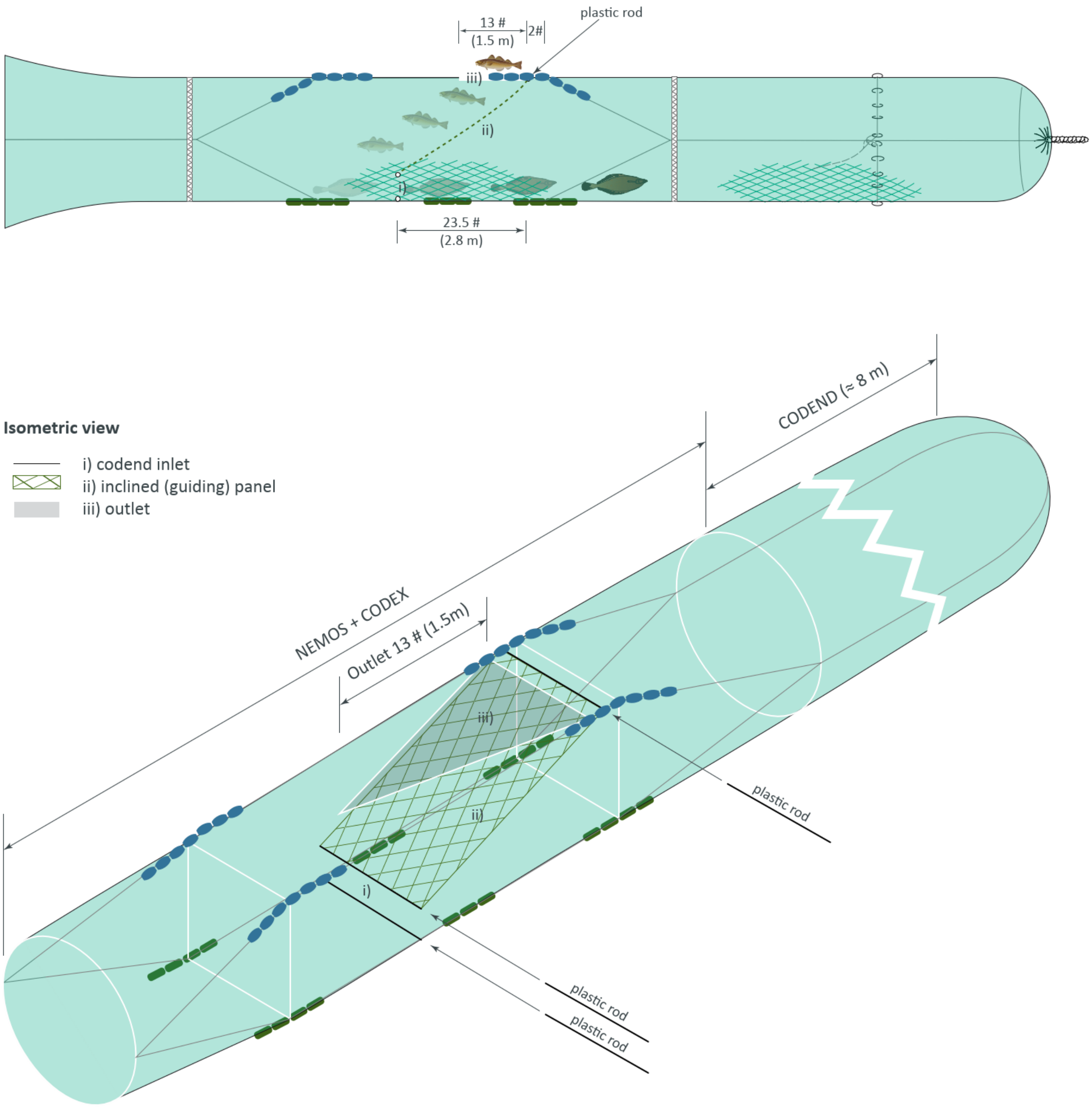

Figure 2: CODEX (COD EXcluder) device consisting of three elements: i) codend inlet, ii) inclined (guiding) panel and iii) outlet. Top: side view of the device showing the intended species selective principle. Bottom: Isometric view showing montage details of the device.

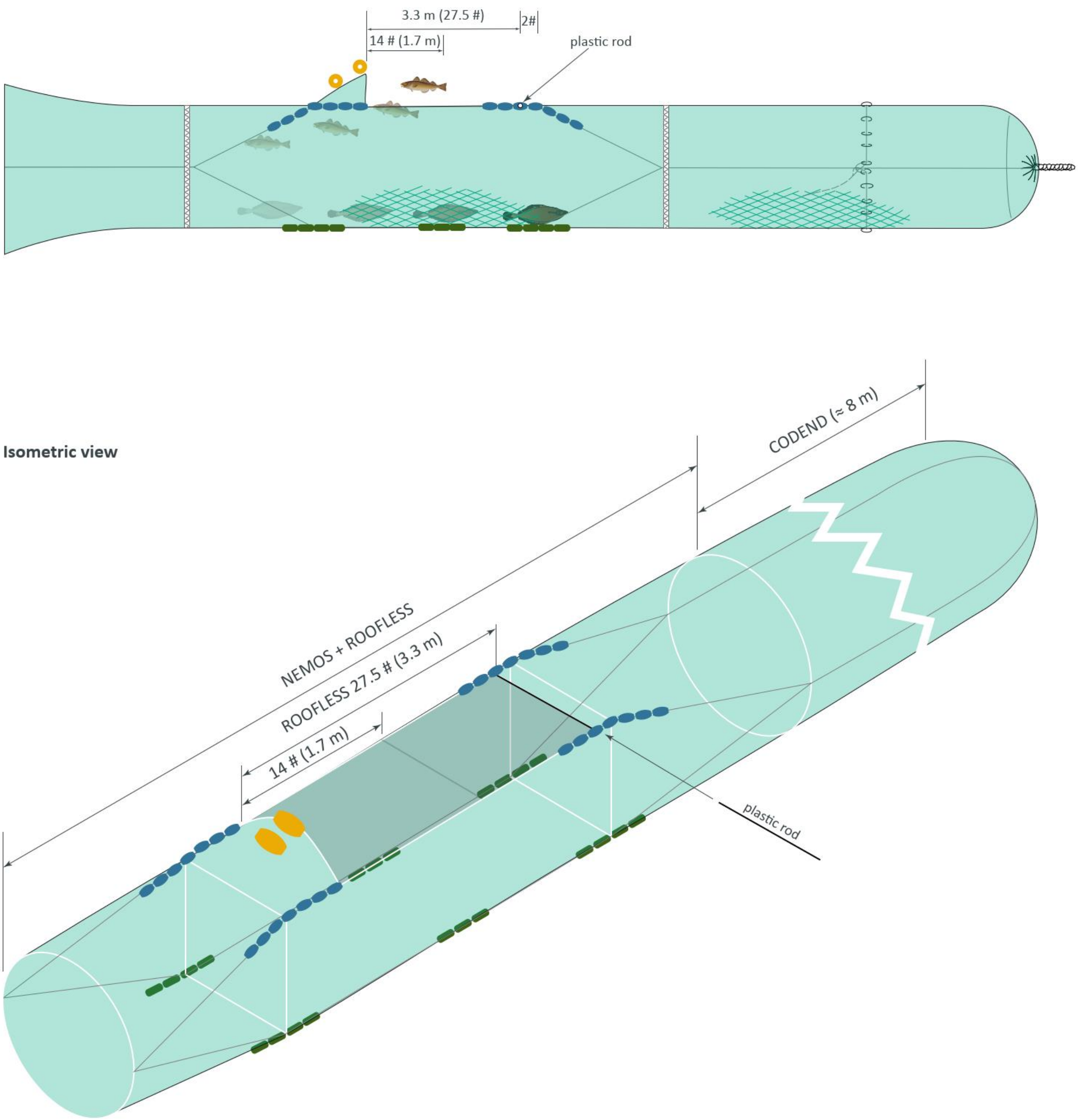

Figure 3: ROOFLESS Bycatch reduction device mounted in NEMOS device to reduce the catch of cod in flatfish fisheries. This adaption of the NEMOS (Figure 1) device includes a removed section of the top panel of NEMOS (tested in two configurations with window length of 330cm and 175cm), as well as a lifted 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. Top: side view of the device showing the intended species selective principle. Bottom: Isometric view showing montage details of the device.

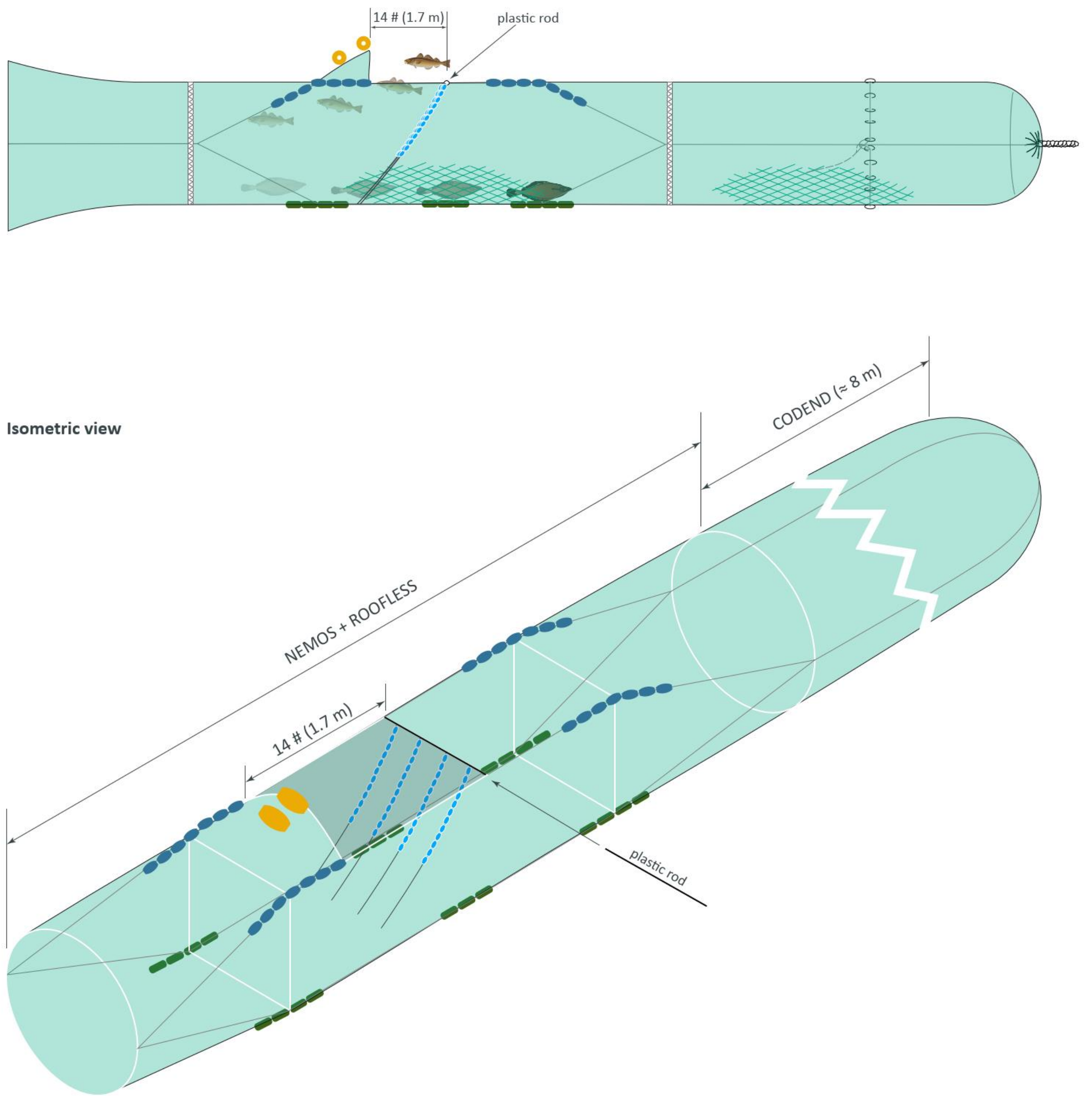

Figure 4: ROOFLESS+STIPED device: Bycatch reduction device mounted in NEMOS device to reduce the catch of cod in flatfish fisheries. This adaption of the NEMOS (Figure 1) device includes i) a removed section of the top panel of NEMOS (tested in configuration with window length of 175cm), ii) a lifted 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 montage details of the device.

4. Experimental design and catch-data analysis

During cruises CLU340 and SO773 the performances of the different BRDs were assessed using the paired gear method (Wileman et al., 1996), whereby 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 ~125 mm measured inner mesh size (Fonteyne et al., 2007), 50 meshes in circumference and ~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.

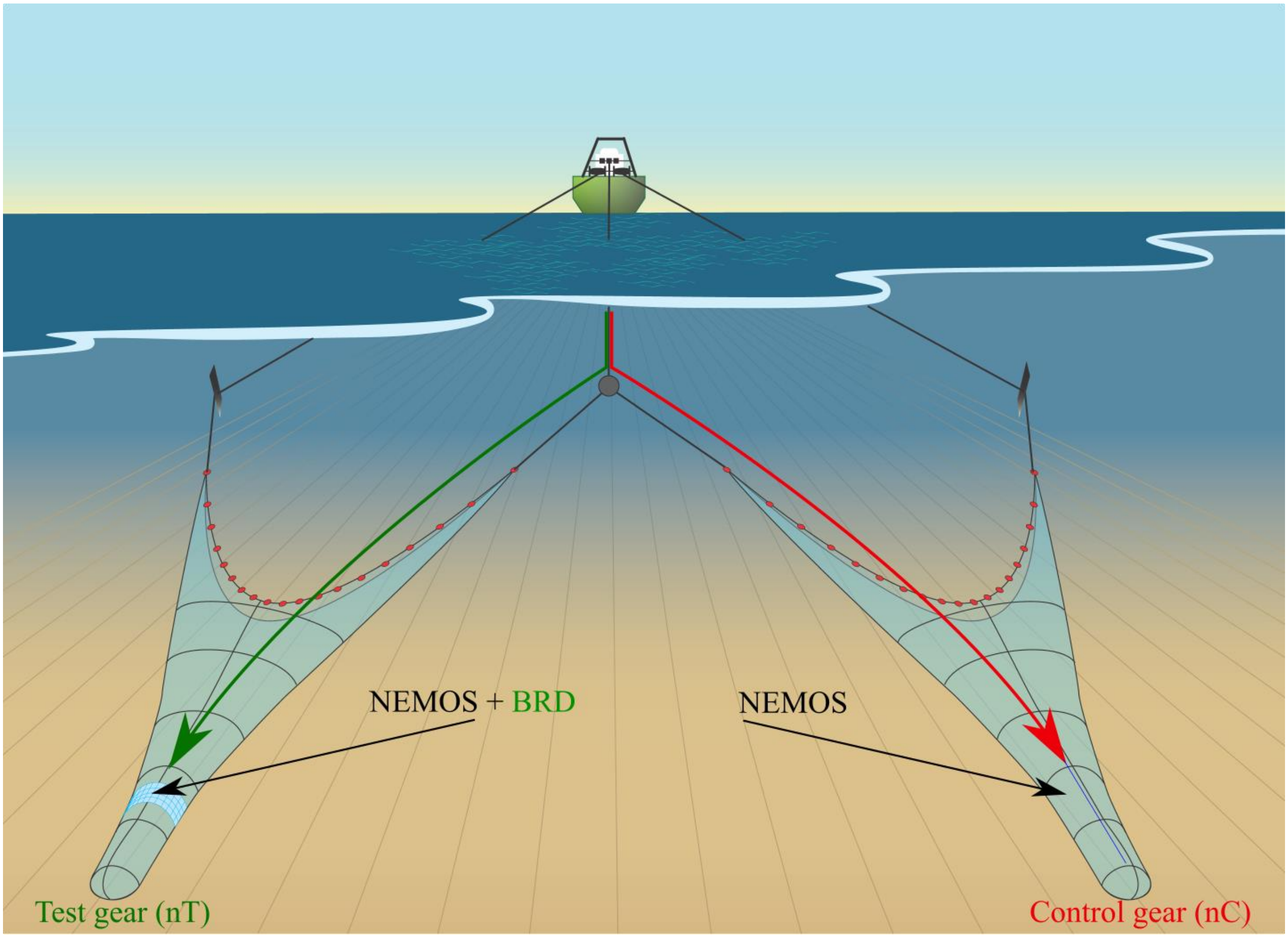

Figure 5: Schematical illustration of the paired gear method (Wileman et al., 1996), where a test gear (mounting NEMOS with one of the BRDs installed) fished in parallel with a control gear (mounting NEMOS with no BRD installed). Although this illustration shows a test-set up for a twin trawler (CLU340), the general concepts also applies for studies using double-belly trawls/trouser trawls studies (SO773).

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*):

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

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 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 (plaice MCRS 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:

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

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. 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. 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 were 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/de/of/arbeitsbereiche/forschung/fischerei-und-surveytechnik/

6. Cruise CLU340

Cruise CLU340 was entirely used to address the research topics related to the CODEX project.

6.1. Aims

- Conduct the first systematic assessment on the selectivity properties of CODEX, ROOFLES-330 and ROOFLESS-175.
- Quantify trade-offs between cod-bycatch reduction and flatfish losses during the use of the tested BRDs.
- Identify behavioural traits of fish interacting with the BRDs that could help to understand the species selection being tested, and to guide in the search for further development opportunities of the devices.
- Develop the fourth BRD combining ROOFLESS-175 + STIPED, to be tested during the next cruise SO773.

6.2. Experimental setup, operations and catch information

The sea trials were conducted between November 28 and December 19, 2019, over daily trips from the port of call (Rostock-Marienehe, Germany) to nearby fishing grounds off the coast of Warnemünde and Kühlungsborn (Mecklenburg Bay, ICES Subdivision 24, see Figure 6). Catch-comparison experiments were conducted by fishing simultaneously with two identical demersal trawls model TV 300/60 using the twin-trawl facilities onboard FRV ”Clupea” (See Annex for further details of the trawl design used). The BRD devices were mounted, one at a time, in the starboard trawl (test gear), while the portside trawl was used with no BRD installed ahead of the codend (control gear). Previous experiments indicated equal fishing efficiency from both TV 300/60 trawls independently to the side they were mounted. Therefore, it was considered not needed to switch the BRDs among sides during the experiment.

Altogether, 26 valid hauls with the paired gear were conducted during ten fishing days. CODEX (Figure 2) was tested during the first two days of trials (November 28, December 3), during which five valid hauls were made. Most species caught during the CODEX test were plaice (PLE) with an average catch of ~71 kg haul-1 (s.d. ~36), followed by cod (COD, ~61 kg haul-1; s.d. ~85) and dab (DAB,~61 kg haul-1 ; s.d. ~45). Catches of flounder (FLE, ~19 kg haul-1; s.d. ~9) and turbot (TUR, ~11.45 kg haul-1; s.d. ~5) were much lower than those from the three previous species. Other species catches are not reported here due to very low volumes (< 1 kg haul-1). Even though the device avoided (almost) totally cod catches (97% catch reduction), researchers onboard decided to finalize this experiment due to large reduction in flatfish catches (50-40% depending on the species). CODEX was replaced by the device ROOFLESS-330 (Figure 3), tested during five consecutive fishing days (December 10-13, 16), during which 12 valid hauls were conducted. In terms of catch weight, cod was the most relevant species during ROOFLESS-330 trials (~212 kg haul-1; s.d. ~194) , followed by dab (~106 kg haul-1; s.d. ~53), flounder (~60 kg haul-1; s.d. ~19), plaice (~22 kg haul-1; s.d. ~10) and turbot (~15 kg haul-1; s.d. ~7). The remaining three fishing days of the cruise (December 17-19, 2019; 8 hauls) were used to test ROOFLESS-175 (Figure 3). The catch profile was very similar to the previous experiment, but in general lower volume per haul. Cod was the most important species in terms of weight (~111 kg haul-1; s.d. ~79), followed by dab (~81 kg haul-1; s.d. ~58) and plaice (~31 kg haul-1; s.d. ~17) . Catches of flounder dropped remarkably compared to the three most caught species (~15 kg haul-1; s.d. ~12), while turbot catches were similar to those obtained during the previous experiments (~12 kg haul-1; s.d. ~5). Catch weights per species shared in test and control trawls were used to in situ (onboard) assessment of release efficiency of the different devices tested (Figure 7). Cod catches in test trawl were clearly below 50% relative to the total catch (catches from both test and control trawls combined), indicating that all three devices released significant amounts of cod. The share of flatfish catches in test trawl using CODEX was clearly below 50%, however the devices ROOFLESS-330, and ROOFLESS-175 led to a progressive increment of flatfish catches in the test trawl, reaching nearly equal catch split of these species among trawls (values around 50% catch share of the total catch). This was specially the case for plaice and dab, the most caught species.

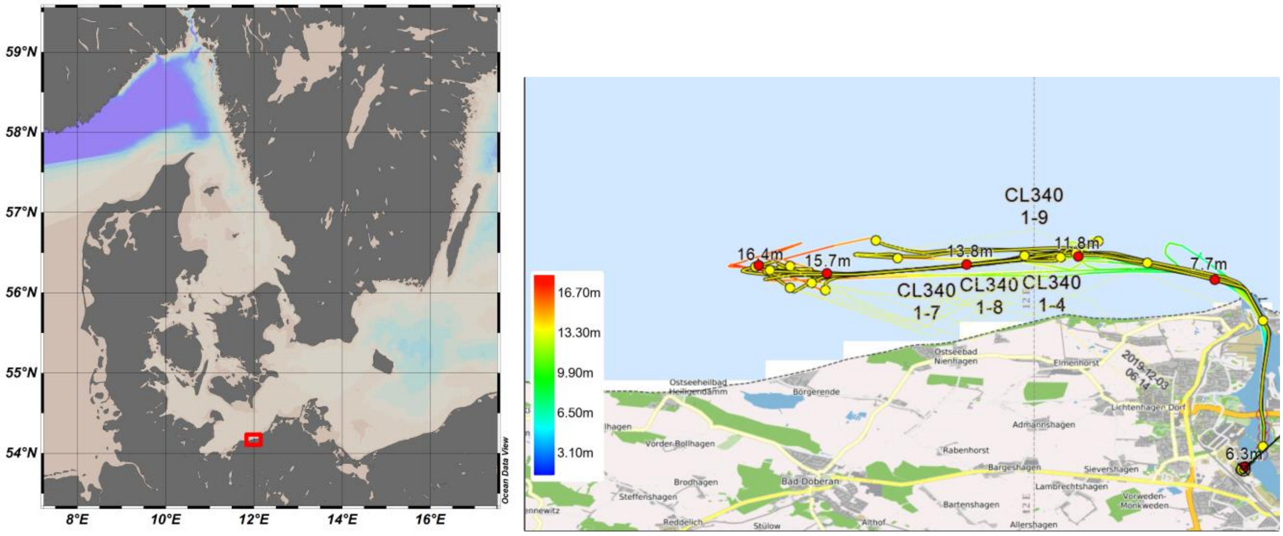

Figure 6: Cruise track of FRV "Clupea" cruise No. 340 (CLU340).

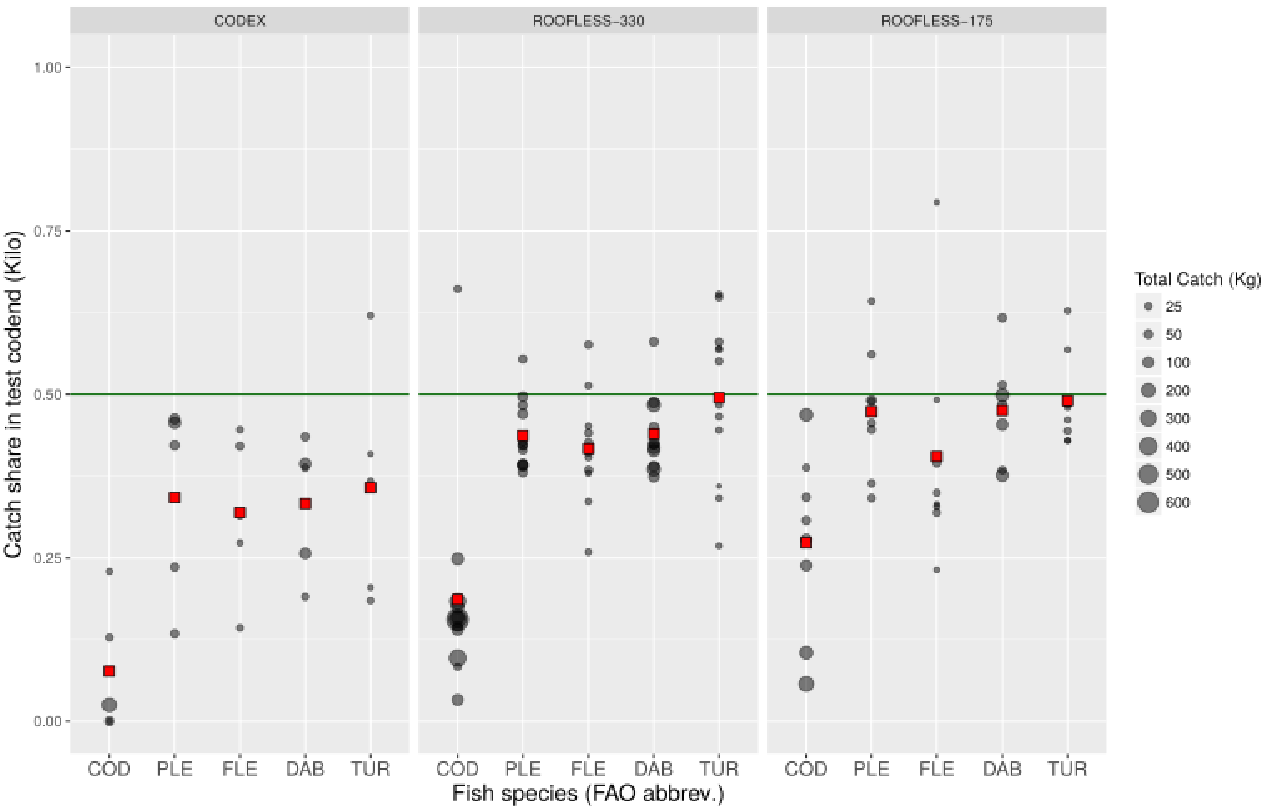

Figure 7: Catch weights per species shared in test trawls in relation to the combined catch of test trawl and control trawl (= 100%). Round grey marks represent by-haul proportion of catches in the test gear relative to the total catch (size of the point directly related to the total catch obtained in 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, while values above represent the opposite distribution of catches. Species: COD = cod; PLE = plaice; FLE = flounder; DAB = dab; TUR = turbot

6.3. Release efficiency indicators

The catch numbers for each species and the resulting release efficiency indicators based on the experiments conducted during CLU340 are given – together with the values from SO773 in Table 1 at page 21).
The most abundant species in the catches was dab (DAB=8899), followed by plaice (PLE=3755) and cod (COD=3493), while catch numbers of flounder and turbot were the lowest (FLE=1168; TUR=692) (Table 1). Except for turbot, catches below species reference size / MCRS (COD = 35 cm; PLE=25 cm; TUR taken as 30 cm; Plaice MCRS taken as reference length also for FLE and DAB) were negligible. The low catch numbers of undersized fish explains the high similarity between the indicators *nR* and *nR+* (Equation 2), and the very large confidence intervals associated to *nR-*.

CODEX delivered the highest release efficiency for cod; *nR*=97.3% (86.7-99.6). However, the release of flatfish was also high, with a value for plaice of *nR*=34.1% (14.8-65.3), and average nR~50% for flounder and dab. Cod release efficiency for ROOFLESS-330-device was significantly lower than the efficiency obtained with CODEX, dropping to *nR*=80.4% (76.2-84.2). Nevertheless, the average release efficiency for flatfishes was also reduced , yielding a value of *nR*=25.3% (14.7-34.4) for plaice, and *nR* values 50% lower relative to CODEX *nR* values obtained for flounder and dab. Consequently, the catch loss of flatfish species was reduced in comparison to the CODEX-device. The cod release efficiency by ROOFLESS-175 was comparable to the efficiency by the ROOFLESS-330 design, however the release efficiency for plaice and dab dropped dramatically to values of *nR*=8.7 and *nR*=13.1, respectively. Note that the lower limit of the confidence intervals estimated for plaice and dab for *nR* indicators equals to zero, indicating not significant evidences that the reduced catch losses of plaice and dab were caused by the BRD. Inconsistently, the *nR* indicator for flounder was higher compared to the value obtained with the ROOFLESS-330 design, however this results needs to be taken with caution due to the limited number individuals caught for this species.

6.4. Catch-comparison analysis

The assessment of length-dependencies (see Annex II for further details) in the release efficiencies from ROOFLESS-330 and ROOFLESS-175 was successfully done for cod, plaice, flounder and dab. CODEX catch-comparison data was not analysed due to the reduced number of hauls conducted with this device. The catch comparisons in Figure 8 show no clear length-dependency for any of the species assessed, as most of the curves describe flat trends over lengths. Cod curves are significantly below the reference line at CC=0.5 (corresponding to equal catch between test and control gear), expressing significant catch reduction in the test gears from lengths above 30 cm for the ROOFLESS-330 design, and between 30 and 60 cm for the ROOFLESS-175 design. Potential differences among ROOFLESS designs relative to cod release efficiency were not statistically detected in the current trials. This lack of significance is expressed by the total overlap of the confidence intervals all over the length classes available (Figure 8, top-left plot). Catch comparison for flatfish species detected significant reduction in plaice and dab catches at lengths around 30 cm, only when using ROOFLESS-330. Such significant reduction was neutralized by the ROOFLESS-175 design. Results from the catch comparison on flounder has to be taken with caution due to the limited number of catches obtained for this species, which could be behind the large dispersion of the catch comparison data from the ROOFLESS-175 analysis.

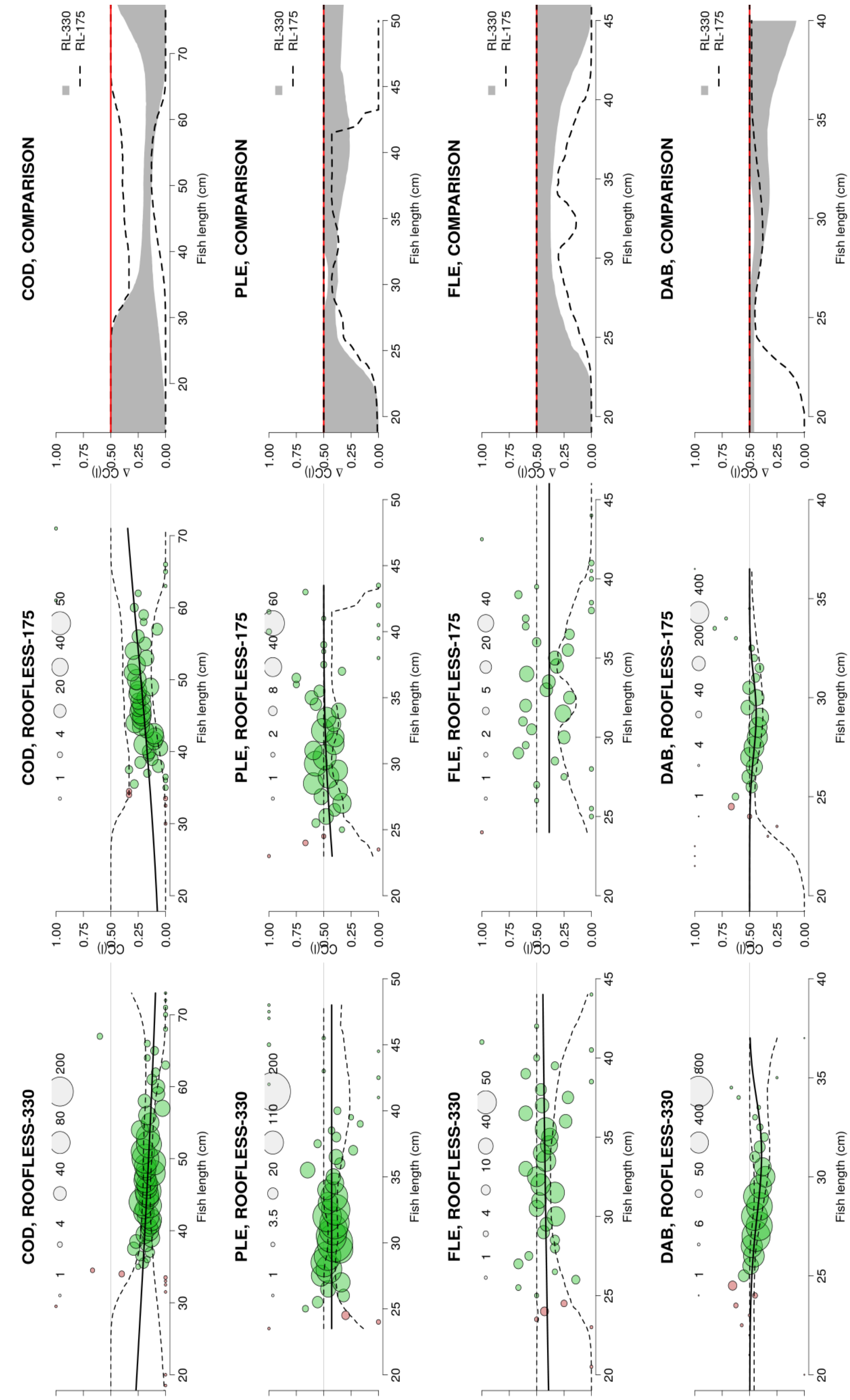

Figure 8: Models predictions for the catch comparisons ROOFLESS-330 vs. control (right column) and ROOFLESS-175 vs. control (middle column), on cod (COD), plaice (PLE), flounder (FLE), and dab (DAB). Green round marks represent experimental catch-comparison rates per length classes equal or above species 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.

6.4. Cruise participants

Name	Position	Affiliation	Dates on board
Bernd Mieske	Cruise leader	TI-OF	27.11. – 13.12.2019
Peter Schael	Technician	TI-OF	27.11. – 16.12.2019
Juan Santos	Cruise leader	TI-OF	16.12. – 20.12.2019
Kerstin Schöps	Technician	TI-OF	03.12-13.12, 16.12– 20.12.2019
Dr. Kristina Barz	Scientist	TI-OF	28.11., 11.12.
Dr. Daniel Stepputtis	Researcher	TI-OF	17.12.2019
Marco Jacobi	Electronic engineer	ThyssenKrupp	17.12.2019
Marc Schiemann	Electronic engineer	ThyssenKrupp	17.12.2019
Jesper Haahr Christensen	Electronic engineer	ThyssenKrupp	17.12.2019
Annemarie Schütz	Technician	TI-OF	18.12.2019

6.4. Acknowledgments

Thanks to the crew of FRV "Clupea" for the help given to conduct the experiments, hospitality onboard, and specially to the flexibility showed to adapt their work to sudden alterations of the experimental plan. Their active involvement in the research contributed significantly to a successful cruise. We also thank those colleagues at the Thünen Institute who showed their availability to get onboard and help in the sampling of catches.

Finally, we would also like to make special mention that this was the last research trip for Bernd Mieske (cruise leader) before retirement. The staff of the Thuenen Institute of Baltic Sea Fisheries will miss him as friendly colleague and his special character.

The cruise was partly funded by by the EU and the 'Ministerium für Landwirtschaft und Umwelt Mecklenburg-Vorpommern' within the framework of the EMFF.

7. Cruise SO773

The 'MUltiPurpose EDucation Survey' (MuPedS) survey was used to continue and support the investigations initiated during CLU340 (11-12/20219) on fishing technologies to avoid cod catches in flatfish fisheries. This activity was closely related to the CODEX-project.

7.1. Aims

Aims related to Student education were:

- Student training and data collection for the subsequent preparation of "papers" by the students for educational purposes
- Standardized 30 – 60 -minute hauls at fixed stations along the depth gradient from the Adlergrund / Rönnebank area to the Bornholm Basin
- Fisheries biological analysis of catches
- Acquisition of oceanography data

Aims related to CODEX project were:

- Assess for the first time the selectivity performance of ROOFLESS-175 + STIPED (Figure 4).
- Compare the performance of ROOFLESS-175 + STIPED with the simpler ROOFLESS-175.
- Assess the performance robustness of ROOFLESS-175 by comparing results from the current experiment with those obtained with the same device during CLU340.
- Assess the selectivity performance from the tested devices under different fishing conditions, including different trawl, fishing locations, fishing grounds and towing depths.
- Quantify trade-offs between cod-bycatch reduction and flatfish losses by the use of the tested BRDs.
- Identify behavioural traits of fish interacting with the BRDs that could help to understand the effect of STIPED to the baseline ROOFLESS-175 performance.

7.2. Experimental setup, operations and catch information

The applied experimental design was the paired gear method. However, due to the lack of twin-trawl facilities onboard FRV "Solea", NEMOS gears (Figure 1) were mounted to each side of a Double-Belly Trawl (DBT, see Figure 15 in Annex I). As in the previous trials, the NEMOS+BRDs were mounted, one at a time, in one side of the DBT (test gear), while the NEMOS gear without BRD (control gear) was mounted in the other side. To ensure a balanced distribution of hauls from the baseline ROOFLESS-175 (0), and ROOFLESS-175 + STIPED (1), among the different fishing conditions during the cruise, both BRDs were used simultaneously in clusters of two-days opposite sequence, comprising four hauls per day (1001, 0110,….).
FRV "Solea" left the port (Rostock-Marienehe, Germany) on the 4th of February and performed four hauls westerly of Warnemünde in depths between 11 and 22m. Due to the bad weather forecast, FRV "Solea" came back to Rostock-Warnemünde to stay in harbour overnight. On the next day, the vessel shipped to the same fishing area and 5 hauls were performed in a depth range of 12 to 18m. During night FRV "Solea" steamed to the area east of Rügen and continued fishing on the next morning. A total of 4 fishing hauls and two CTD casts were conducted between 21 and 54 m depth. During night the vessels shipped further North East to the deeper basin south-east of Bornholm and performed 5 fishing hauls and two CTD casts in a depth range of 61 and 76 m. The vessel was able to stay in the area for the next day and four additional fishing hauls and two additional CTD casts were conducted in depths between 44 and 62 m. Due to the very bad weather forecasts, FRV "Solea" steamed back to Rostock-Marienehe and rested safely in the harbour during the heavy storm between the 9th and 12th of February. FRV "Solea" left port for one more fishing day on the 13th of February. The last fishing day was used exclusively for students' education and fishing was performed close to Rostock-Warnemünde using the survey trawl TV-520.
In total, 22 fishing hauls were performed to test both ROOFLESS-175 and ROOFLESS-175+STIPED. Further, 8 CTD casts were conducted to document oceanographic conditions and one TV-520 haul was performed for students' education.

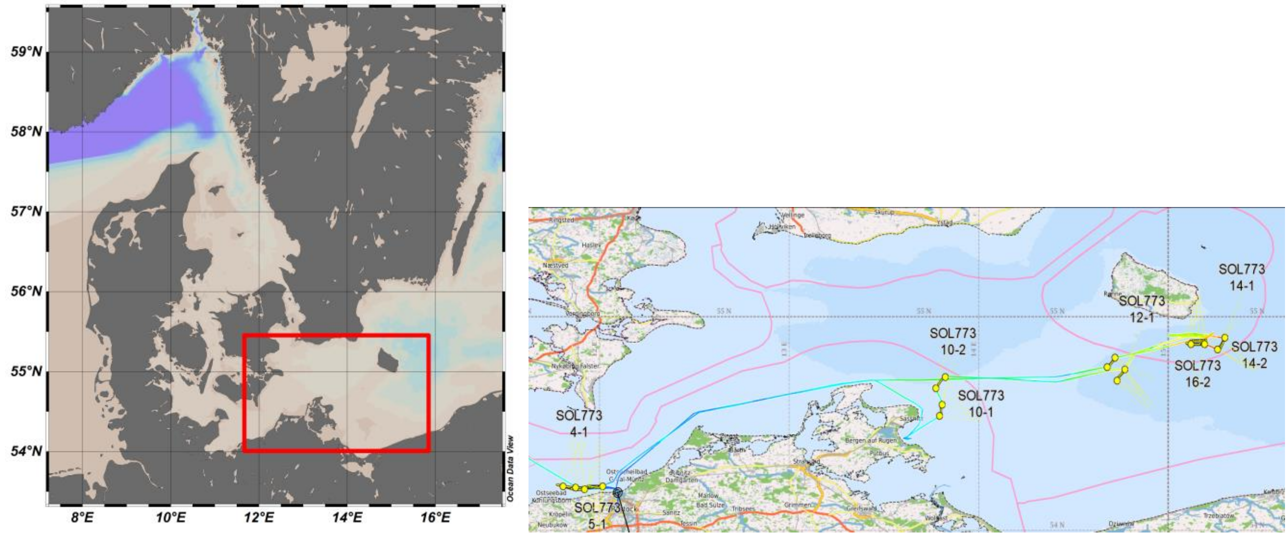

Figure 9: Cruise track of FRV "Solea" cruise No. 773 (SO773).

Altogether, 22 valid hauls with the paired gear were conducted during ten fishing days. The main caught species in hauls using ROOFLESS-175 was cod (~92 kg haul-1; s.d. ~142) and flounder (~80 kg haul-1; s.d. ~180). Catches of dab (~11 kg haul-1; s.d. ~20),and plaice (~6 kg haul-1; s.d. ~6) were much lower. Only four kilo of turbot catches were reported across hauls using ROOFLESS. As expected, hauls with ROOFLESS-175 + STIPED had the same order of species by fished biomass. Adding STIPED did not significantly influenced the mean catches per haul of cod (~84 kg haul-1; s.d. ~120), flounder (~72 kg haul-1; s.d. ~107), dab (~14 kg haul-1; s.d. ~20), or plaice (~7 kg haul-1; s.d. ~7). Only two kilo of turbot catches were reported across 'ROOFLESS-175 + STIPED' hauls. In terms of weight, the reduction in cod catches by ROOFLESS-175 was similar to the reduction obtained with the same device in the previous trials (CLU340), while ROOFLESS-175 + STIPED reduced the catches of the species further (Figure 10). The catch share of flounder - the second most important species in terms of weight - was about 50% among test and control gears – indicating similar catches in both gears. However, the average catch proportion in the test gear was slightly lower when using ROOFLESS-175 + STIPED. Catches of the three remaining species were small and therefore catch share of these species among test and control gears results in large uncertainty derived from the low number of fish caught (see Table 1 at page 21).

7.3. Release efficiency indicators

The catch numbers for each species and the resulting release efficiency indicators based on the performed experiments during SO773 are illustrated together with the values from CLU340 in Table 1. In contrast to CLU340, the most abundant species in the catches was flounder (FLE, n=4301) followed by cod (COD, n=2352). Catch numbers of dab and plaice were low (PLE, n=581; DAB, n=1049), and catches of turbot were negligible (Table 1). Except for flounder, catches below species MCRS were very low. For cod, the release efficiency of ROOFLESS-175 during SO773 (*nR*=74.5 (55.8-83.2)) is the same as during CLU340 (*nR*=74.5 (40.3-88.4)). The release efficiency (catch loss) of ROOFLESS-175 for flatfish species was in general lower during SO773 cruise compared to the former CLU340 cruise, with null release efficiency for dab and plaice, and a drastic reduction of release efficiency for flounder compared to CLU340 (*nR*=10.5 (0-22.5) versus *nR*=37.4 (15.8-52)). It is worth noting that flounder was the most abundant flatfish species in the current trial, while it was less abundant in CLU340. Therefore, it can be assumed that the current estimated indicators for flounder are more robust than the indicators from the CLU340 cruise. Adding STIPED to the baseline ROOFLESS-175 did not result in a remarkable improvement on the release efficiency of cod. Furthermore, ROOFLESS-175+STIPED raised significantly the release efficiency of plaice to similar values obtained with CODEX during CLU340 trials (*nR*=37.9 (19.1-64.4) vs *nR*=34.2 (14.7-65.3)). However, the later result needs to be considered with caution due to the limited number of catches obtained for this species.

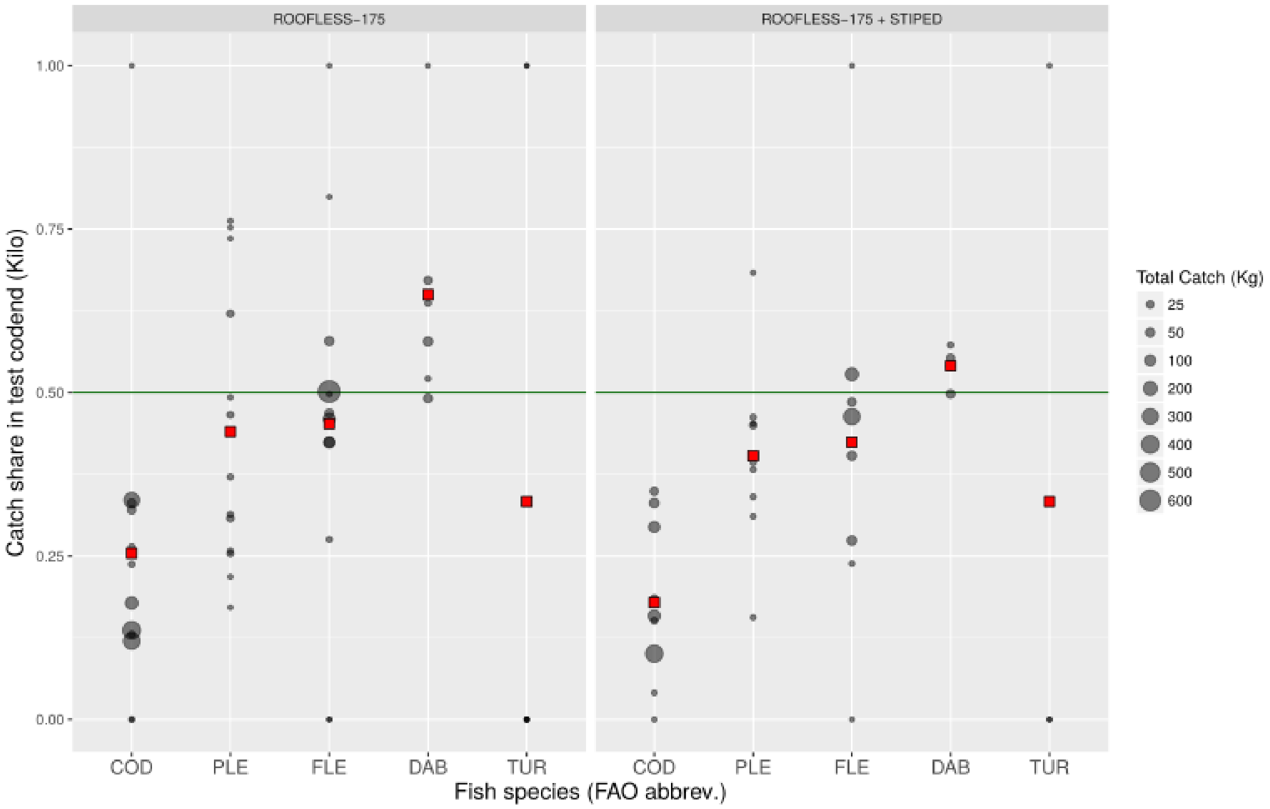

Figure 10: Catch weights per species shared in test trawls in relation to the combined catch of test trawl and control trawl (= 100%). Round grey marks represent by-haul proportion of catches in the test gear relative to the total catch (size of the point directly related to the total catch obtained 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, while values above represent the opposite distribution of catches. Species: COD = cod; PLE = plaice; FLE = flounder; DAB = dab; TUR = turbot

7.4. Catch-comparison analysis

The assessment of length-dependencies (see Annex II for further details) in the release efficiency from ROOFLESS-175 and ROOFLESS-175+STIPED was successfully done for cod, plaice, flounder and dab (Figure 11). Using ROOFLESS-175, the catch proportion of cod in the test gear was significantly below 50% (CC<0.5, corresponding to equal catches between test and control gear) at cod total lengths between ~30 and ~65 cm. The additional installation of STIPED has not significantly improved the cod release efficiency compared to the baseline-design (ROOFLESS-175). Surprisingly, more catches of plaice below 30 cm occurred in the test gear (ROOFLESS-175) in comparison to the paired control gear. This unexpected result was not shown in the ROOFLESS-175+STIPED experiment, which yielded in a flat line significantly below CC=0.5 in the range of lengths between ~27 cm and 37 cm (Figure 11). In contrast to CLU340 trials, large catches of flounder enabled arobust catch comparison analysis. Neither ROOFLESS-175 nor ROOFLESS-175+STIPED reduced significantly thecatches of flounder.

Again, higher catches of dab were obtained in the test gear at lengths below ~27 cm. This result was not expected because it violates the model assumptions on equal catch efficiency among both sides of the trawl or equal codend selectivity. Further examination of the raw data are required to clarify the reason of this unexpected result.

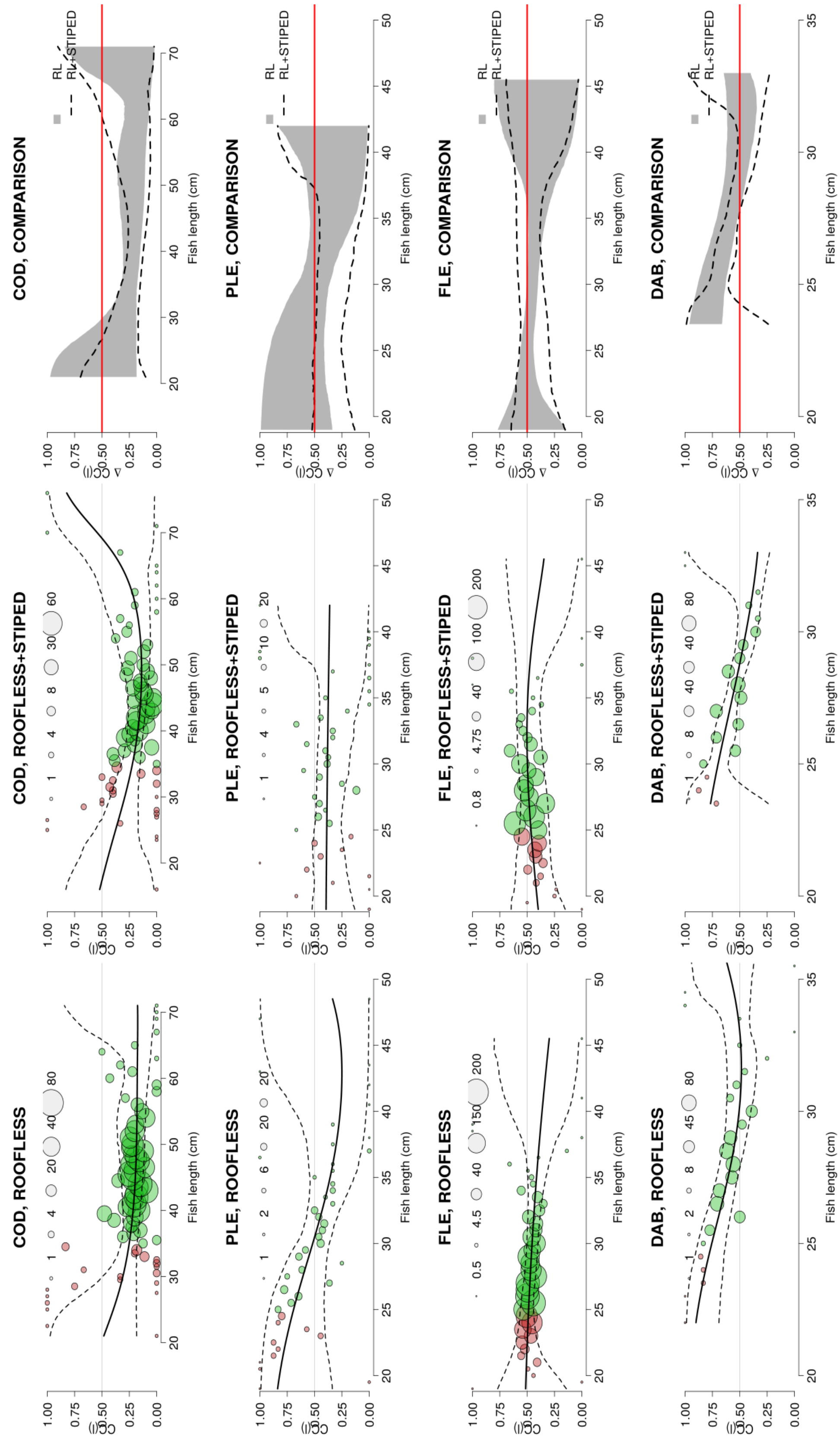

Figure 11: Models predictions for the catch comparisons ROOFLESS-175 vs. control (right column) and ROOFLESS-175 +STIPED vs. control (middle column), on cod (COD), plaice (PLE), flounder (FLE), and dab (DAB). Green round marks represent experimental catch-comparison rates per length classes equal or 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.

7.5. Cruise participants

Name	Position	Affiliation	Dates on board
Dr. Daniel Oesterwind	Cruise leader	TI-OF	04.02. – 13.02.20
Cornelia Albrecht	Technician	TI-OF	04.02. – 09.02.20
Juan Santos	Scientist	TI-OF	04.02.2020
Alexander Knorrn	Student	Uni-Rostock	04.02. – 08.02.20
Cosima Josephine Behrends	Student	Uni-Rostock	04.02. – 08.02.20
Katja Mehrwald	Student	Uni-Rostock	04.02. – 08.02.20
Ada Braun	Student	Uni-Rostock	04.02.2020
Jonathan Tschirsch	Student	Uni-Rostock	04.02. – 08.02.20
Kerstin Schöps	Technician	TI-OF	13.02.2020
Thies Rinner	Student	Uni-Rostock	13.02.2020
Franziska Kühnel	Student	Uni-Rostock	13.02.2020
Katharina Taube	Student	Uni-Rostock	13.02.2020
Lisa Falkenberg	Student	Uni-Rostock	13.02.2020
Marius Hoppe	Student	Uni-Rostock	13.02.2020

7.6. Acknowledgments

We thank the crew and captainof FRV “Solea” for the flexibility and their support.
The cruise was partly funded by by the EU and the ‘Ministerium für Landwirtschaft und Umwelt Mecklenburg-Vorpommern’ within the framework of the EMFF.

8. Results overview (CLU340 and SO773)

The catch numbers for each species and the resulting release efficiency indicators based on the experiments conducted during CLU340 and SO773 are given in Table 1.
For the description of results, refer to cruise-specific chapters.

9. Concluding remarks

This document reports on the development to reduce the bycatch of cod in Baltic flatfish fisheries. The used devices have been developed by the Thünen Institute of Baltic Sea Fisheries in collaboration with Baltic fishers and netmakers. Priorities of the further development were conceptual and constructive simplicity, economical feasibility, the reduction of constructive costs and the avoidance of rigid elements. Our results demonstrate that it is possible to reduce the cod bycatch in flatfish fisheries without significant losses of flatfish by applying a simple and adaptive technical modification in front of the codend. Among the four tested devices, ROOFLESS-175 show the best tradeoff between cod reduction and catchability of flatfish, while being the simplest BRD tested.

First trials with ROOFLESS-175 during CLU340 led to a significant reduction in cod catches (75%) and relative low (~10%) but not significant catch reduction of plaice and dab. On the other hand, a higher catch reduction (~37%) was observed for the less abundant flounder. Such concerns were clarified with SO773 trials on fishing grounds with high abundance of flounder. In these trials, relative catch losses of flounder were largely reduced to 10%, same value obtained for plaice and dab during CLU340. On the other hand, the relative reduction of cod catches were in both cruises equal, even if the trails were performed with different vessel, trawls, on different fishing grounds and depths. These results represent an empirical proof on the robustness of the selective properties of the ROOFLESS-175 device.

The basic functional principle to reduce cod catch in the tested devices is based on species-specific behaviour. Such selective strategy tends to be subjected to larger between-haul variation than classic mechanical size selection. Therefore, some uncertainties about the performance under different fishing conditions are still present. Further investigations under a wider range of fishing conditions (e.g. spatial, seasonal, day-night cycle, etc.) could support the better understanding of the properties and limitations of these devices. Nevertheless, the results for the ROOFLESS-175-device are very robust and could significantly contribute to the reduction of bycatch mortality of cod in the Baltic.
All devices were installed in NEMOS-device (NEt Enabling MOdular Selectivity; Figure 1), which allows a modular and flexible adaptation of the selectivity of the trawl. Making selection devices easy to mount and dismount provided us with dynamic control of trawl-species selectivity, even between hauls. This feature could also help fishers to a better adaptation of their fishing strategies under the current scenario, where the limited quota of cod limits the access to healthier and more abundant flatfish stocks.

Table 1: 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. Indicators 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	cod (COD)	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	cod (COD)	35	2	186	9	728	77.8 (0-100)	74.5 (40.0-88.5)	74.5 (40.3-88.4)
SO773	ROOFLESS-175	cod (COD)	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	cod (COD)	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	dab (DAB)	25	67	2135	46	2803	0 (0-16.4)	23.8 (13.3-32.3)	22.7 (12.4-30.8)
CLU340	ROOFLESS-175	dab (DAB)	25	33	1170	25	1360	0 (0-28.6)	14.0 (0-28.7)	13.1 (0-27.3)
SO773	ROOFLESS-175	dab (DAB)	25	18	322	3	225	0 (0-0)	0 (0-0)	0 (0-0)
SO773	ROOFLESS-175+STIPED	dab (DAB)	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	flounder (FLE)	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	flounder (FLE)	25	1	111	0	179	0 (0-0)	38.0 (17.5-52.3)	37.4 (15.8-52.0)
SO773	ROOFLESS-175	flounder (FLE)	25	270	917	275	1052	1.8 (0-31.3)	12.8 (0-26.3)	10.5 (0-22.5)
SO773	ROOFLESS-175+STIPED	flounder (FLE)	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	plaice (PLE)	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	plaice (PLE)	25	4	341	3	375	0 (0-75.6)	9.1 (0-27.0)	8.7 (0-26.7)
SO773	ROOFLESS-175	plaice (PLE)	25	48	139	17	129	0 (0-47.4)	0 (0-44.5)	0 (0-42.3)
SO773	ROOFLESS-175+STIPED	plaice (PLE)	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	turbot (TUR)	30	121	69	114	60	0 (0-28.2)	0 (0-18.6)	0 (0-21.1)
CLU340	ROOFLESS-175	turbot (TUR)	30	61	36	74	35	17.6 (0-40.9)	0 (0-24.3)	11.0 (0-31.1)
SO773	ROOFLESS-175	turbot (TUR)	30	2	0	3	3	33.3 (0-100)	100 (24.4-100)	66.7 (0-100)
SO773	ROOFLESS-175+STIPED	turbot (TUR)	30	0	1	2	1	100 (100-100)	0 (0-100)	66.7 (0-100)

10. Annex I: Technical drawings

Ober-Unter-Seitenblatt für 120#/100# Topless-Tunnel (Unterblatt ohne Fluchtöffnung)

PE geflochten doppelt 4 mm, Maschenweite (HM) 60 mm

je 2 Knoten in die Laschen

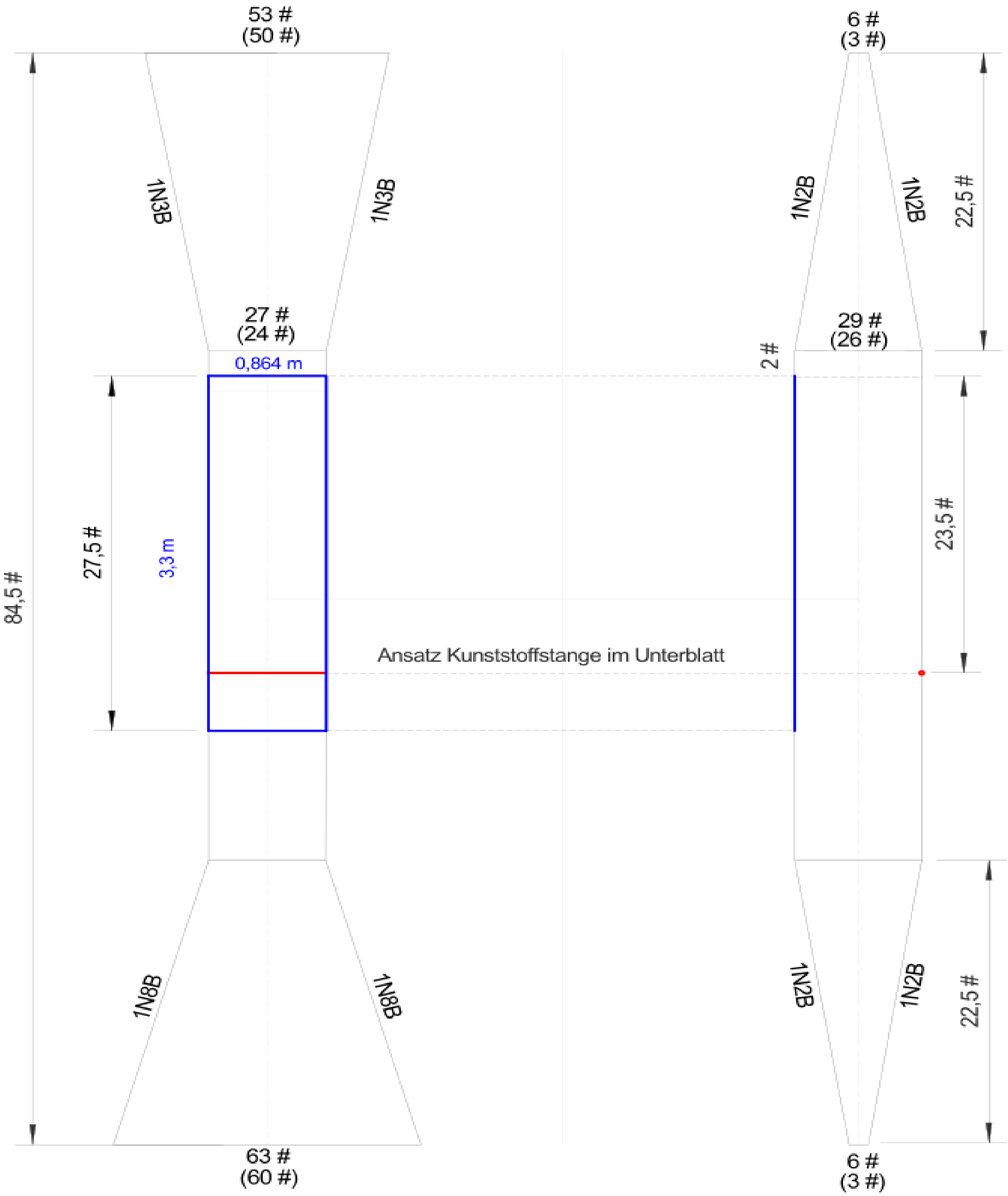

Figure 12: Technical drawing (Top and side view) of NEMOS (NEt Enabling MOdular Selectivity) gear in ROOFLESS configuration (NEMOS+ROOFLESS, here ROOFLESS-330).

Ober-Unter-Seitenblatt für 120#/100# CODEX (Unterblatt ohne Fluchtöffnung)

PE geflochten doppelt 4 mm, Maschenweite (HM) 60 mm

je 2 Knoten in die Laschen

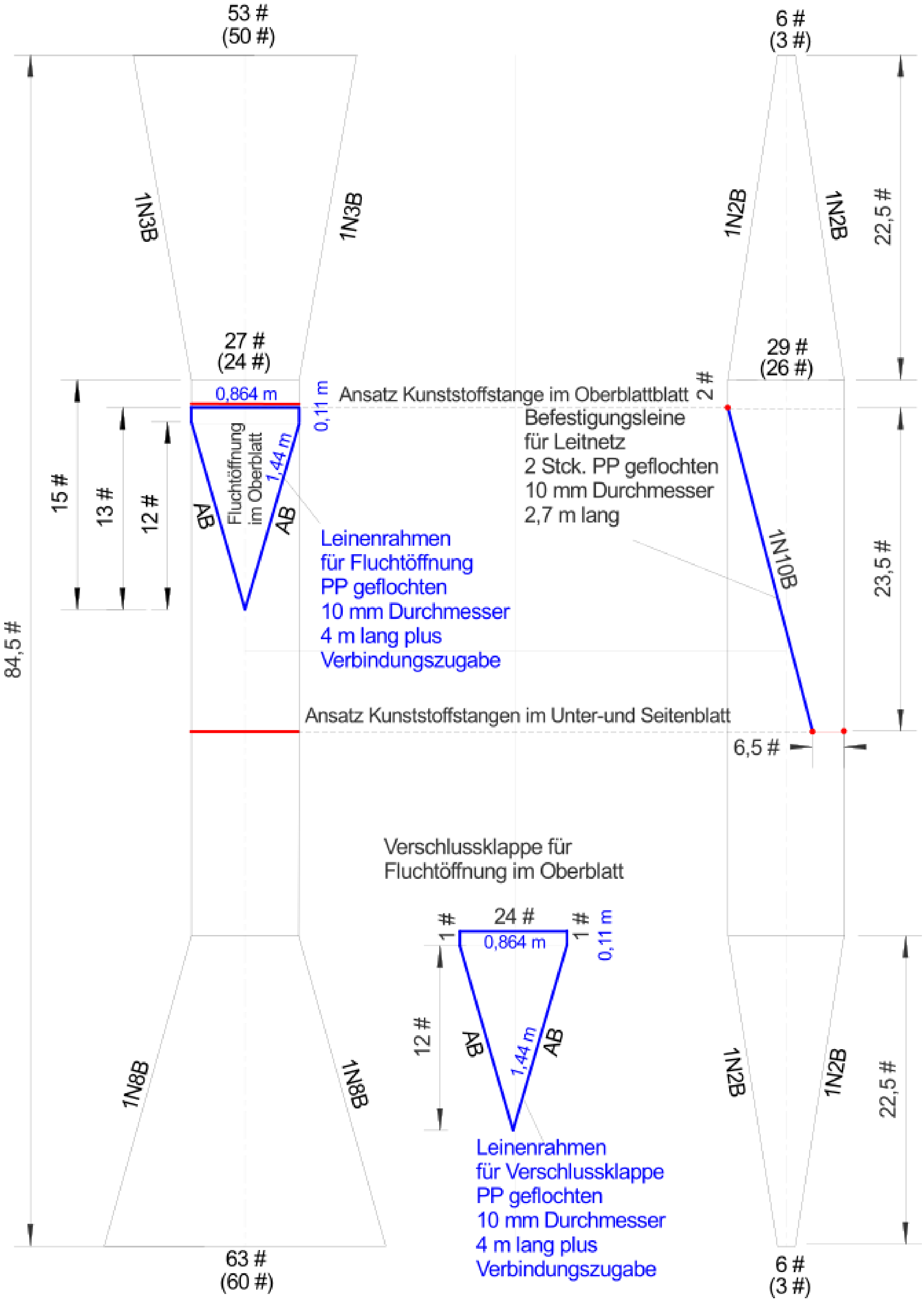

Figure 13: Technical drawing (Top and side view) of NEMOS (NEt Enabling MOdular Selectivity) gear in CODEX configuration (NEMOS+CODEX).

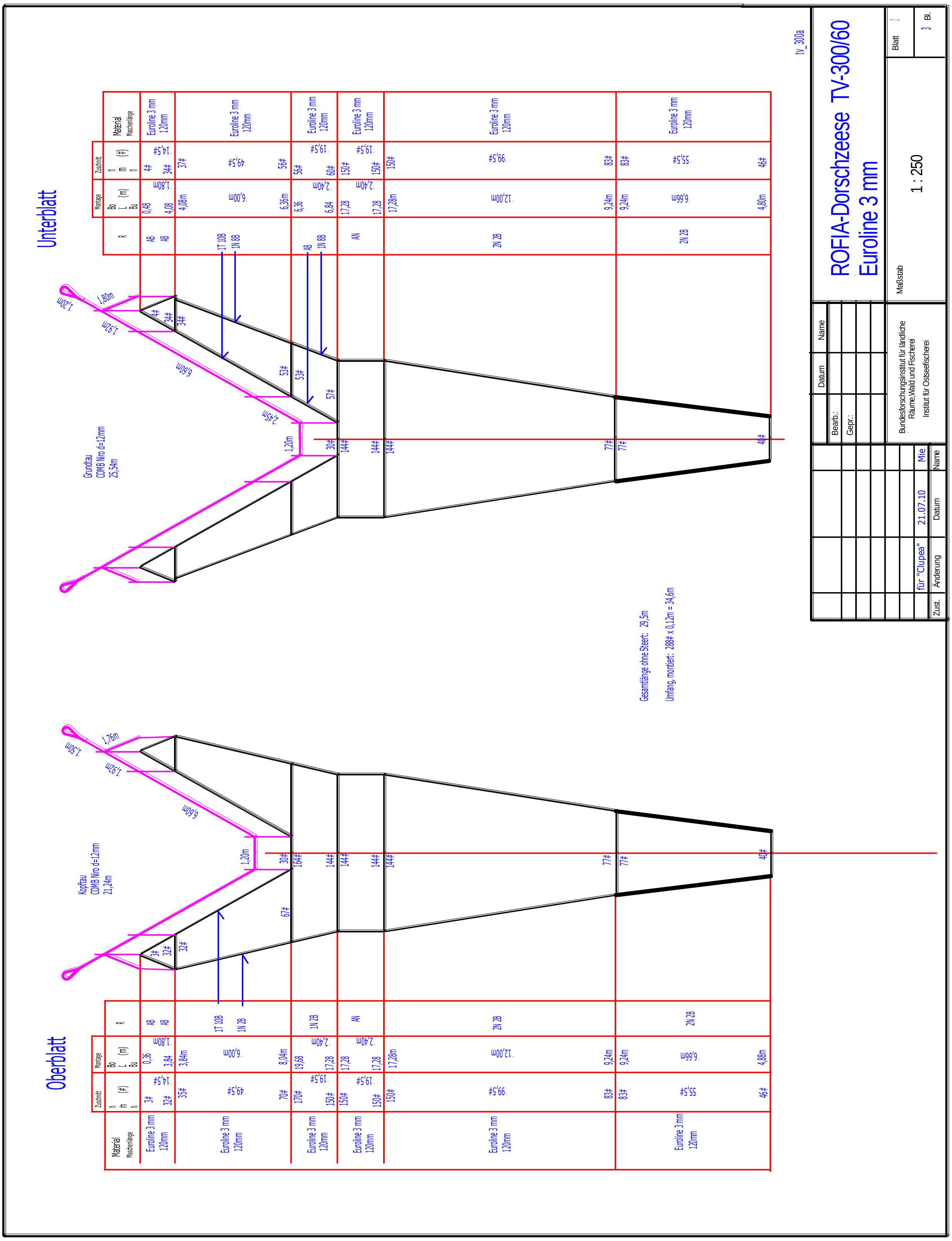

Figure 14: Technical drawing of the TV300/60 trawl used during CLU340 cruise (2x units in twin trawl).

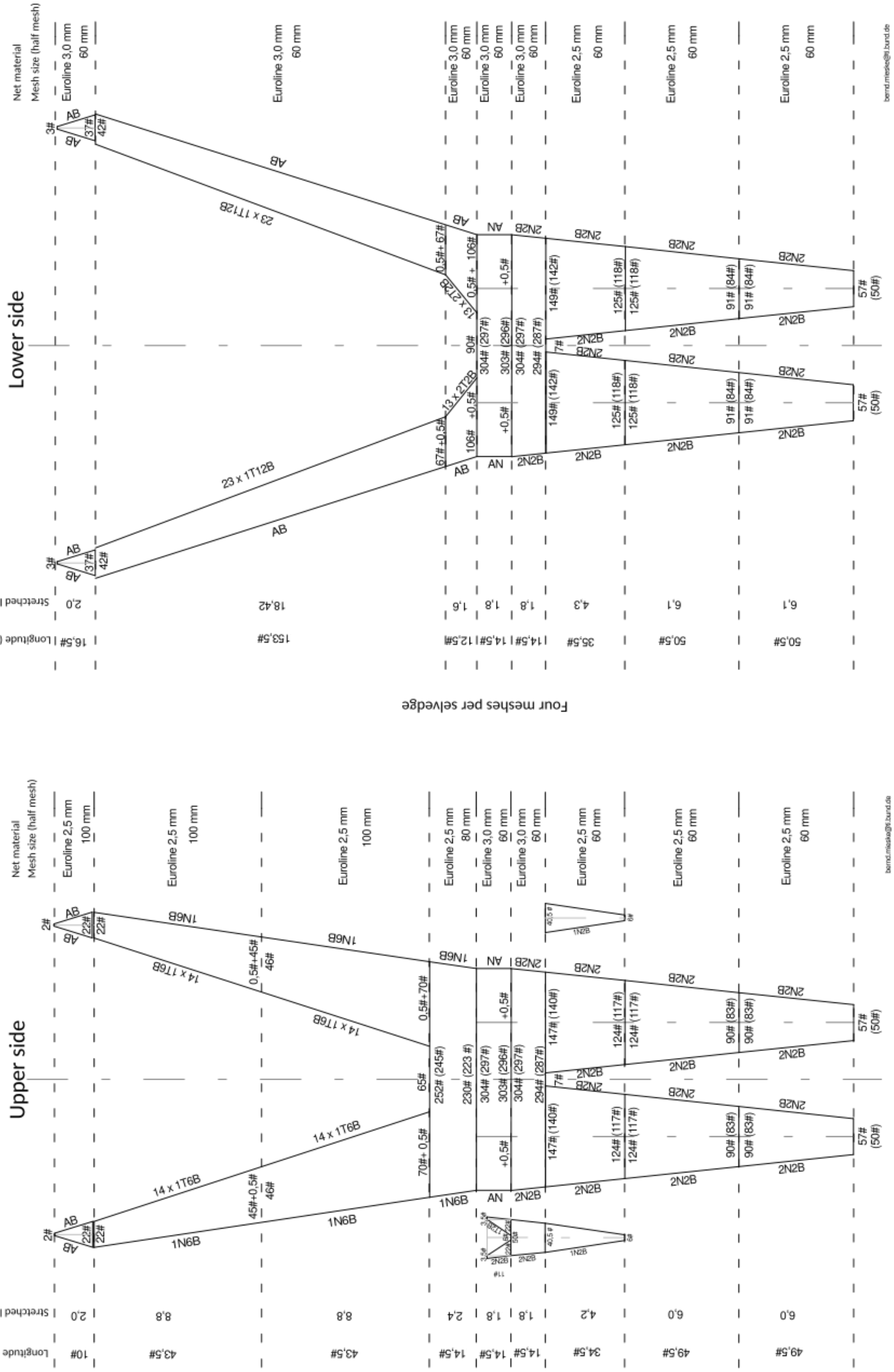

Figure 15: Technical drawing of the Double Belly Trawl (DBT) used during SO773 sea trials

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:

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

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:

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

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. 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:

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

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:

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

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):

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

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 $CC(l,\boldsymbol{v})$:

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

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).

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