DTU Library

Development of selective gears and technologies for commercial fisheries (SELEKT)

Feekings, Jordan P.; Avsar, Ercan; Bak-Jensen, Zita; Bertelsen, Sissel Kolls; Diernæs, Laura; Frandsen, Rikke P.; Herrmann, Bent; Karlsen, Junita D.; Krag, Ludvig A.; Svantemann, Mette M.

Total number of authors:
16

Publication date:
2023

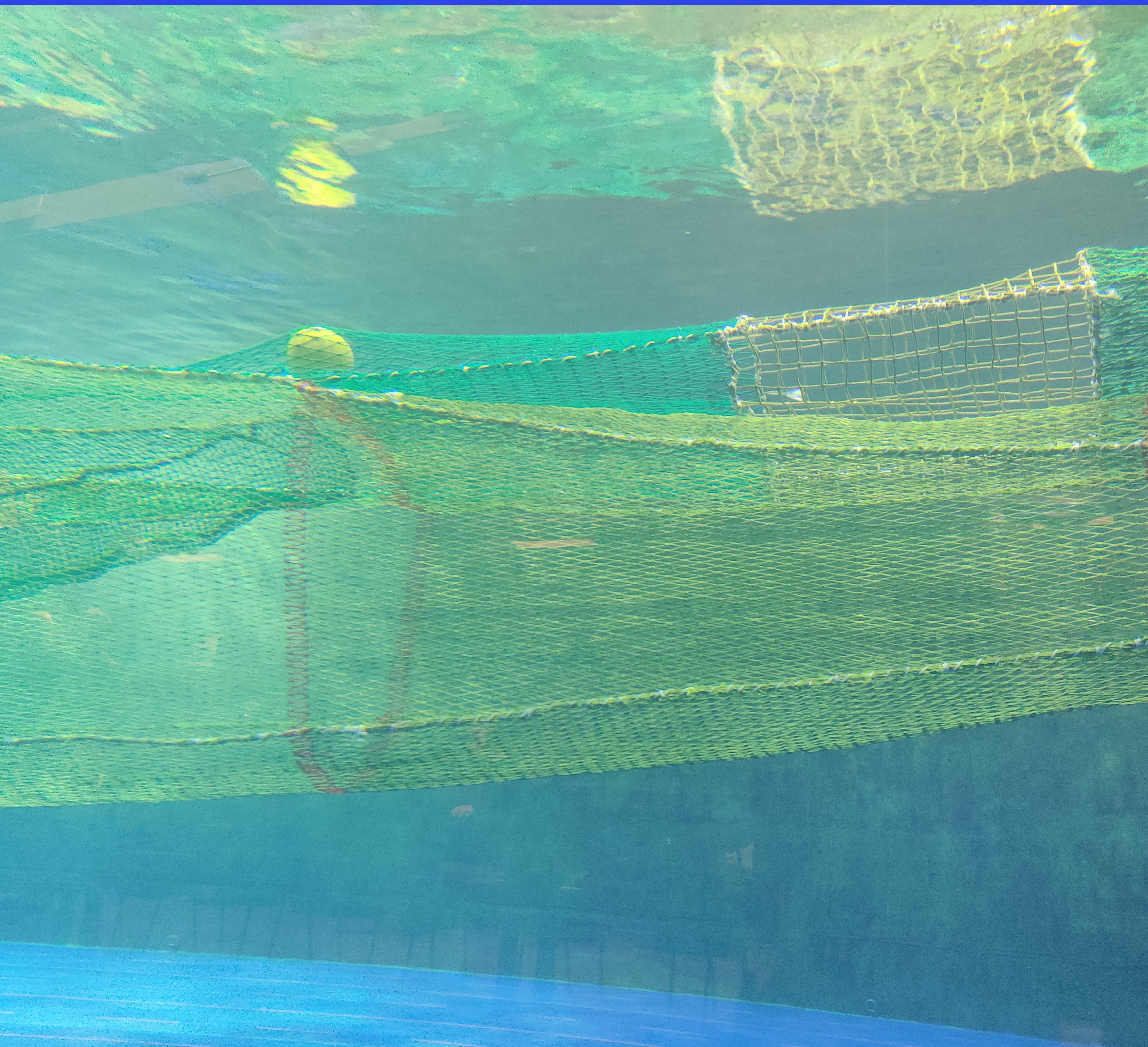
Document Version
Publisher's PDF, also known as Version of record

DTU Aqua
National Institute of Aquatic Resources

Development of selective gears and technologies for commercial fisheries (SELEKT)

Jordan P. Feekings et al.

DTU Aqua Report no. 441-2023



DTU Aqua
National Institute of Aquatic Resources

Development of selective gears and technologies for commercial fisheries (SELEKT)

Jordan P. Feekings, Ercan Avşar, Zita Bak-Jensen, Sissel Kols Bertelsen, Laura Diernæs, Rikke P. Frandsen, Bent Herrmann, Junita D. Karlsen, Ludvig A. Krag, Mette M. Svantemann, Luísa Machado, Tiago Veiga Malta, Valentina Melli, Martin M. Nielsen, Barry O'Neill, and Esther Savina

DTU Aqua Report no. 441-2023

Colophon

Title:	Development of selective gears and technologies for commercial fisheries (SELEKT)
Authors:	Jordan P. Feekings, Ercan Avşar, Zita Bak-Jensen, Sissel Kols Bertelsen, Laura Diernæs, Rikke P. Frandsen, Bent Herrmann, Junita D. Karlsen, Ludvig A. Krag, Mette M. Svantemann, Luísa Machado, Tiago Veiga Malta, Valentina Melli, Martin M. Nielsen, Barry O'Neill, and Esther Savina
DTU Aqua Report no.:	441-2023
Year:	Scientific work finalised December 2023. Report published January 2024
Reference:	Feekings, J.P., Avşar, E., Bak-Jensen, Z., Bertelsen, S.K., Diernæs, L., Frandsen, R.P., Herrmann, B., Karlsen, J.D., Krag, L.A., Svantemann, M.M., Machado, L., Malta, T.V., Melli, V., Nielsen, M.M., O'Neill, B. & Savina, E. (2023). Development of selective gears and technologies for commercial fisheries (SELEKT). DTU Aqua Report no. 441-2023. National Institute of Aquatic Resources, Technical University of Denmark, 38 pp. + app.
Cover photo:	An excluder in the flume tank in Hirtshals. Photo: Jordan Feekings
Published by:	Technical University of Denmark, National Institute of Aquatic Resources, Willemoesvej 2, 9850 Hirtshals, Denmark
Download:	www.aqua.dtu.dk/publikationer
ISSN:	1395-8216
ISBN:	978-87-7481-375-0

DTU Aqua Reports contain results from research projects, reviews of specific topics, expositions for authorities etc. Unless stated in the colophon, the reports are not peer reviewed, which means that the content has not been reviewed by researchers outside the project group.

Preface

This is the final report for the project “SELEKT - Development of selective gears and technologies for commercial fisheries” under the scheme ”Fiskeri, Natur og Miljø 2022”(Journal number: 33113-I-22-187). The project ran from 30th of May 2022 t31st of December 2023, and was led by senior scientist Jordan P. Feekings from the Section of Fisheries Technology at DTU Aqua.

The object of the project has been to develop and test new selective fishing gears and -technologies. Selective properties of new gears with potential to solve challenges in catch composition in the North Sea, Skagerrak, Kattegat, and the Baltic have been documented at a scientific level that serve as input into the legislative process. Furthermore, new technologies have been developed for better observation and documentation of catches, the use of technologies to reduce the impact trawling has on the seabed, and modelling tools for fast and precise multi-species selectivity. The project’s primary focus was on the reduction of unwanted bycatch of cod (*Gadus morhua*), however, other bycatch issue in Danish fisheries were also addressed, for example bycatches of haddock.

A steering committee with participation from management (Fiskeristyrelsen, FVM) and the Danish fisheries organizations (DFPO, DPPO, FSKPO) was established in the beginning of the project. Their participation aimed to assist in the prioritization of gears to be tested. The steering committee did not influence the obtained results and the reporting.

The project was carried out with financial support from the EU, the European Maritime and Fisheries Fund, and the Ministry of Foreign Affairs' fisheries development program.

Inquiries regarding this report can be made to:

DTU Aqua
Willemoesvej 2
DK-9850 Hirtshals
Tel: + 45 35 88 32 00
Fax: + 45 35 88 32 60

The project is funded by:

European Union
European Maritime and Fisheries Fund

HAV & FISK

Content

Summary

The SELEKT project set out to develop and test new selective fishing gears and technologies, as well as document their selective effect with a view to these being implemented in commercial fishing in the North Sea, Skagerrak, Kattegat and the Baltic Sea. The project was divided into two main pillars, the first being the adaptive development of selective fishing gears in direct co-operation with the industry (section 2 - 4) and the second focusing on building up knowledge on novel methodologies and preparing their application in fisheries (section 5). The gears developed under the 1st pillar were done so following the cooperative model between industry (fishers and net makers) and researchers, which was developed and tested in the Fast-Track projects. The technologies developed in pillar 2 focused on the collection of data, in real time, while fishing, the collection of data onboard fishing vessels, the use of new technologies to observe fish behavior inside the trawl, and the use of technologies to reduce the impact trawling has on the seabed.

During the project, issues in a number of different fisheries throughout Danish waters were highlighted. All gears developed pertained to the demersal trawl fisheries, namely the Baltic Sea trawl fishery targeting flatfish, the Pandalus trawl fishery, the mixed demersal trawl fishery, the Norway lobster trawl fishery, and the Brown shrimp beam trawl fishery. The gears tested either aimed at reducing catches of unwanted species and/or sizes. In total, 20 gears were developed during the life of the project, 12 of which have been tested onboard commercial (10) and research vessels (2), and 8 of which were developed and tested in the flume tank towards the end of the project and are still to be tested.

This report provides and overview of the work undertaken during the project and presents the results from the individual trials in the form of fact sheets (Appendix 1). Furthermore, the report highlights some of the challenges which arose during the project and how these can be addressed in the future.

Resumé

SELEKT projektet havde til formål at udvikle og teste nye selektive fiskeredskaber og teknologier og dokumentere deres selektive effekt og med henblik på at de potentielt kunne implementeres i erhvervsfiskeriet i Nordsøen, Skagerrak, Kattegat og Østersøen. Projektet var delt op i to søjler; én indeholdt en adaptiv udvikling af fiskeredskaber i direkte samarbejde med industrien (sektion 2-4), mens en anden fokuserede på at opbygge og udvikle kendskabet til nye teknologier og forberede disse til optagelse i fiskeriet (sektion 5). Udviklingen af fiskeredskaberne i den første søjle fulgte den samarbejdsmodel mellem industri (fiskere og vodbindere) og forskere, der blev udviklet i FastTrack-projekterne. Udviklingen af teknologier i søjle to fokuserede på indsamling af data i real-tid og under fiskeri, automatiseret indsamling af fangstdata ombord på fartøjer, anvendelse af nye teknologier til at observere fiskeadfærd inde i trawlen samt teknologier der kan reducere trawlens bundpåvirkning.

I løbet af projektet blev flere udfordringer i fangstsammensætningen i forskellige fiskerier i dansk farvand fremhævet. Alle redskaber, der blev udviklet i projektet, omhandlede fiskeri med bundslæbende redskaber mere specifikt trawlfiskeri i Østersøen efter fladfisk, trawlfiskeri efter dybvandsrejer, blandet-arts-fiskerier med bundtrawl, jomfruhummerfiskeri med trawl og bomtrawlsfiskeriet efter hesterejer. Redskaberne havde til formål at reducere fangsten af uønskede arter og / eller størrelser. I alt blev 20 forskellige redskabsdesigns udviklet i løbet af projektet. Af disse blev 10 testet ombord på kommercielle fartøjer, 2 blev testet om bord på et forskningsfartøj og 8 blev testet i prøvetanken i Hirtshals hen imod slutningen af projektet og er endnu ikke testet til søs.

Denne rapport giver et overblik over det udførte arbejde og præsenterer resultater fra de enkelte forsøg i form af faktaark (appendix). Derudover fremhæver rapporten nogle af de udfordringer der blev afdækket i løbet af projektet og hvordan disse bedst imødekommes fremover.

1. Introduction

Danish fisheries involve the use of a variety of different fishing gears, and their use is determined, among other things, by target species, quotas, fishing grounds, as well as vessel type and capacity. Trawling constitutes approximately 90% of the value of landings, with about half of that originating from bottom trawling (Gislason, 2021). Bottom trawls are dragged along the seabed and excel in efficiently capturing bottom-dwelling fish species such as Norway lobster, plaice, sole, and cod. However, they simultaneously pose a risk of unintended bycatch and seabed impact. Additionally, bottom trawling is associated with relatively high fuel consumption. For these reasons, a significant portion of fisheries technology research in Denmark is focused on bottom trawling.

The management of Danish fisheries is governed by the European Union Common Fisheries Policy (CFP), under which the Landing Obligation belongs. With the revision of the CFP and the introduction of the Landing Obligation in 2015, it was anticipated that fishers would more actively adjust the selectivity of their gears to ensure unwanted catches were kept to a minimum since the unwanted component now had an economic negative value as it would be counted against their quotas. On top of these regulations, the design of the codend – the rearmost part of the trawl – is legislated in detail. However, as the combination of gear, fishing practice and quota shares differ between vessels, catch composition needs are unique from vessel to vessel and based on the quotas which are available to the vessels at a given time. Therefore, the limited selection of legal codends available, is unfit for this purpose.

To address this diversity of catch goals and issues throughout Danish fisheries, the SELEKT project was divided into two main pillars, one being the adaptive development of selective fishing gears in direct cooperation with the industry (section 2 - 4) and the second being building up knowledge on novel methodologies and preparing their application in fisheries (section 5). To ensure involvement from the industry, and to identify and address the main issues in Danish fisheries, the three producer's organizations (POs), DFPO, DPPO, and FSKPO were invited to a stakeholder meeting with scientists and managers. Since the main issues in Danish fisheries occur in the demersal trawl fisheries, the main involvement in the project came from DFPO.

2. Stakeholder Engagement

The engagement of stakeholders throughout the project was recognized as a central and important aspect in the project. Therefore, stakeholder engagement and how it should take place in the project was a key discussion point during the project's kick-off meeting. The objective of the projects kick-off meeting was threefold, firstly to present the activities in the project, secondly to discuss how to involve industry in the project, and finally to have participants map the gear development and fisheries management approval pipeline.

To ensure stakeholder engagement from fishers, DTU Aqua proposed a series of harbor meetings in the main fishing harbors throughout Denmark. This was met with hesitation from the POs as they felt there would be limited participation from their members. Consequently, it was agreed during the meeting to drop the harbor visits and replace this with an article in Fiskeritidende (22nd September 2022) inviting fishers to come with ideas to improve the selectivity of their gears. This led to several trials being initiated (two in the Baltic Sea (Annex 1 and 1D), one in the Skagerrak (Annex 1I) and two in the North Sea (Annex 1J).

During the kick-off meeting, participants were divided into three groups with the objective of mapping the gear development and approval timeline. The different steps in the process and the approximate duration were mapped (Figure 2.1). Results from the three groups were very similar, identifying a timeline of approximately 2 years from idea to approval. It should be noted that this is a best-case scenario where all steps in the process follow on from one another without any delays, which is highly likely not the case as certain steps in the process are held periodically. Therefore, it is likely that the timeline identified during the meeting will be longer. Such a long development and approval timeline is problematic considering how quickly stocks dynamics can change, and consequently issues can arise.

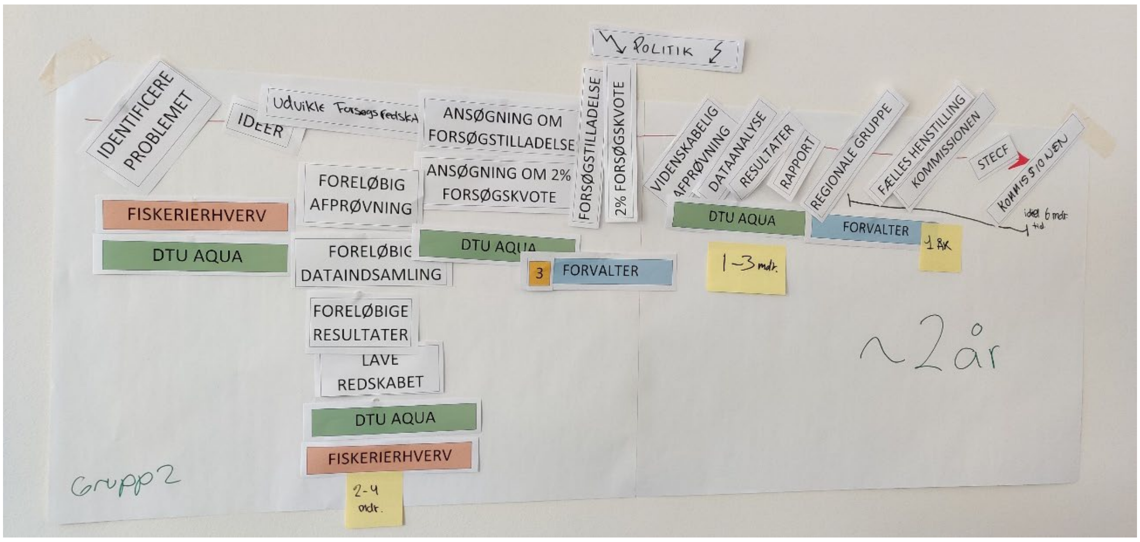


Figure 2.1. Gear development and approval timeline.

A number of follow-up meetings were held online, however, further ideas coming forward from the industry were lacking. The lack of input from industry was discussed together with DFPO at a meeting in Taulov. It was decided at the meeting that if ideas were to come forward the trials would need to be undertaken in a different format, where participating fishers would need to be responsible for the collection of data following a self-sampling protocol. This led to a number of ideas coming forward towards the end of the project (Annex 1A, 1C, 1D, 1F, 1H, 1L).

To accommodate further concerns from the fishing industry, it was decided to organize a demonstration day in the flume tank in Hirtshals. 8 different gears were developed following a dialog with fishers, POs, and net makers and were presented to more than 50 participants. Fishers in attendance were provided the opportunity to register their interest in testing the gears presented on the day. These trials will occur after the life of this project and are therefore not presented herein.

The project also aimed to strengthen collaboration with neighboring scientific institutes. Here, fishing gear trials were carried out in collaboration with Thünen Institute, Germany and the University of Tromsø, Norway. These collaborations aimed to ensure that the work carried out in the project had applicability in neighboring regions and fisheries.

Finally, the engagement of stakeholders in the project was through diverse media, including the publication of scientific articles and presentations held at international meetings (e.g. DanFish, ICES working group on Fisheries Technology and Fish Behaviour), a list of which can be found in Table 2.1.

Table 2.1. Methods used to engage different stakeholder groups.

News articles	Formal Meetings	Harbour Visits	Electronic	Scientific publications
8 x Fiskeri-tidende (22/9/2022, 5/4/2023, 1/6/2023, 19/10/2023, 19/10/2023, 19/10/2023, 2/12/2023, 16/12/2023) 1 x News on TV2 Østjylland (12/10/2023)	Kickoff meeting (Hirtshals) Steering group meeting (online) Demonstration day in the flume tank (Hirtshals) Fiskeristyrelsens tilskudskontor (Online) DANFISH (Aalborg)	4 x Strandby 1 x Bønnerup 2 x Hirtshals 2 x Thyborøn 2 x Hanstholm	Social media (www.facebook.com/ fiskeriteknologidtuaqua/)	Bak-Jensen et.al. 2022. Fixed mesh shape reduces variability in codend size selection Avsar et.al. 2023. Estimating catch rates in real time Development of a deep learning based *Nephrops* counter for demersal trawl fisheries Palder et.al. 2023. Approaching single-species exclusion in mixed demersal trawl fisheries Bak-Jensen et.al. 2023. The capability of square-meshes and fixed-shape meshes to control codend size selection Svantemann et.al. 2024. Improving escape efficiency in selective devices with the use of a dark tunnel

3. Description of the fisheries and problems raised

Danish waters range from low to high saline, resulting in area specific differences in species composition. Fisheries in different areas will thus meet different challenges with regards to by-catch and the risk of losing valuable target species. In order to cover the entire Danish fishery when addressing the selective challenges, the tasks on gear development and testing have been allocated into three work packages based on area.

3.1. Kattegat and the Baltic

The cod stocks in the Baltic Sea and Kattegat are currently in a critical state (ICES, 2023). Consequently, cod can only be landed as by-catch in the flatfish or Norway lobster fisheries. In addition to the struggling cod stocks, several stocks in the region have seen good recruitment in recent years, resulting in unwanted bycatch issues. This includes haddock in the Kattegat and plaice in the Baltic. The extraordinarily large year classes of plaice in recent years in the Baltic, coupled with the loss of fishing opportunities for cod, means that demersal fisheries in the Baltic have changed from mixed fisheries targeting primarily cod to directed flatfish fisheries targeting primarily plaice (ICES, 2023). These recent changes in stock dynamics mean that fishers' quota compositions have also changed, and the legislated gears are not sufficient to address the current situation. Therefore, there is an urgent need for technical solutions that can minimize the catch of cod and haddock while allowing viable flatfish and Norway lobster fisheries to continue.

According to these challenges, the following issues were identified during the stakeholder dialogue that require further gear development in the Kattegat and Baltic Sea fisheries:

1) Minimize cod catches while maintaining marketable catches of flatfish
2) Minimize catches of cod while maintaining marketable catches of Norway lobster
3) Reduce the catch of juvenile haddock in Norway lobster-directed fisheries.

To address these issues, the following ideas were co-designed through collaboration between fishers, scientists and net-makers, and tested during the project:

Fishery	Problem	Proposed solution	Type of trial	Annex
Flatfish trawl fishery	Lack of cod quota	Large mesh (800 mm) in the upper panel of the trawl	Commercial trial, fishers self-sampling	1A
Flatfish trawl fishery	Loss of marketable sizes plaice	Document loss of marketable sized plaice	Scientific trial onboard commercial vessel	1B
Norway lobster-directed fishery	Bycatch of juvenile roundfish	Diamond opening	Commercial trial, fishers self-sampling	1C
Norway lobster-directed fishery	Bycatch of juvenile roundfish	Roofless	Commercial trial, fishers self-sampling	1D

3.2. Skagerrak

Several commercial species are targeted and caught in the Skagerrak, including multiple pelagic, demersal and benthic fish, as well as valuable crustacean species, such as Norway lobster (*Nephrops norvegicus*) and northern shrimp (*Pandalus borealis;* (Figure 3.2.1). While the fisheries targeting pelagic fish and northern shrimp are mostly single-species, Norway lobster and demersal fish are typically caught together with multi-species bottom trawls. As such, these fisheries are exposed to choke risks if the quota for one of the species caught becomes unavailable. The highest risk is typically posed by cod, whose quota in the Skagerrak is at historically low levels. This has led to the introduction in legislation of multiple technical gear specifications aimed at minimizing catches of cod, including both undersized and marketable sizes. Among the legal options, skippers choice of gear design, varies within a fishery depending on the vessel's individual catch goals and quota availability, as well as multiple economic, sociological, and legislative factors. Nonetheless, each of the legal option's available leads to undesired losses of marketable catches of target species, and the current toolbox of gear options cannot sustain complex and dynamic multispecies catch goals while preventing unwanted bycatch. Moreover, periodically high densities of juvenile fish like cod and haddock (*Melanogrammus aeglefinus*) can often trigger real-time area closures (RTC), interfering with the fishing operations of several fisheries. These bycatch hotspots can particularly affect crustacean-directed fisheries, where a small mesh size in the codend is required to effectively target these species.

According to these challenges, the following issues were identified during the stakeholder dialogue that require further gear development in the Skagerrak fisheries:

1) Minimize cod catches while maintaining marketable catches of all other species of interest, including Norway lobster, flatfish and roundfish;
2) Separate catches of Norway lobster from those of mixed demersal fish in two-codend gears with the possibility of using a more appropriate mesh size for each group;
3) Reduce the catch of juvenile roundfish in flatfish-directed fisheries;
4) Facilitate the adoption of real-time observation technologies which can aid the avoidance of bycatch hotspots.

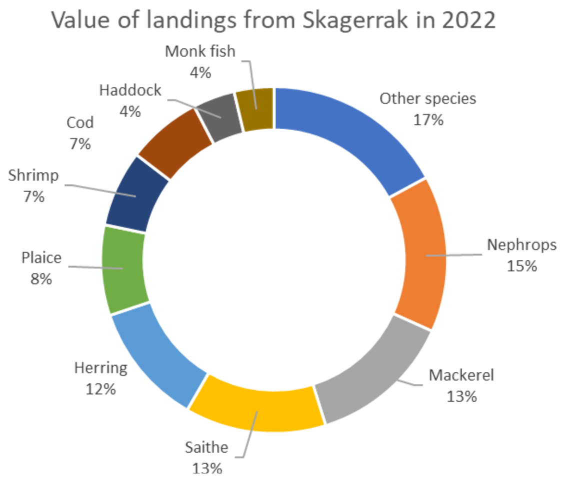


Figure 3.2.1. Landings (in value) of the main species caught by Danish vessels in the Skagerrak in 2022 (source: https://fiskeristyrelsen.dk/fiskeristatistik/dynamiske-tabeller, 2023).

To address these issues, the following ideas were co-designed through collaboration between fishers, scientists, and net-makers, and tested during the project:

Fishery	Problem	Proposed solution	Type of trial	Annex
Mixed demersal trawl fishery	Lack of cod quota	Bottom escape window	Scientific trial onboard R/V Havfisken	1E
Mixed demersal trawl fishery	Size-selection of fish in the Norway lobster directed fisheries	Excluder leading to separate codends with different mesh sizes	Commercial trial, fishers self-sampling	1F
Mixed demersal trawl fishery	Bycatch of fish	Large opening followed by a dark tunnel	Scientific trial onboard R/V Havfisken	1G
Seine fishery targeting flatfish	Bycatch of juvenile roundfish	Change in mesh orientation (from T0 to T90) in the codend	Commercial trial, fishers self-sampling	1H
Mixed demersal trawl fishery	Bycatch of juvenile roundfish	Real-time observation technologies	Scientific trial onboard commercial vessel	1I

Additionally, two ideas were proposed but could not be tested due to technical challenges and the short timeline of the project:

- Scaling down of the trawl in the northern shrimp fishery to save fuel while maintaining catch efficiency;
- A new trawl concept to target exclusively Norway lobster.

These two ideas will be further explored in future projects.

3.3. North Sea

The Danish fisheries occurring in the North Sea are primarily industrial fisheries, being responsible for over 80% of the landings (in weight). The pelagic and demersal trawl fisheries make up for the majority of the remaining landings.

Even though beam trawls targeting brown shrimp account for only 3% of total landings in value (Figure 3.3.1), they operate within the North Sea using a fleet of 25 vessels, constituting approximately 10% of the Danish fleet of trawlers larger than 15 m. The fishing grounds of this fishery can overlap with nursery areas of commercially important species such as plaice, cod, and whiting as well small pelagic species, thus catches can have large by-catches of juvenile fish in specific seasons of the year. Fishing gear improvements that reduce the by-catch of juvenile fish in these fisheries are therefore highly relevant to maintain and improve the health of important fish stocks in the North Sea.

The stock of cod in the North Sea has been reduced to a critically low level in recent decades. Therefore, a new national cod plan was prepared in 2020. Under the national cod plan, there are several very selective gears for cod that are specified. In addition to these gears, the cod plan allows further development and testing of new highly selective cod gears. Additionally, in more recent years, a new issue has emerged for demersal trawl fishers in the North Sea. The strong year-classes of haddock in 2019 and 2020 has led to an increase in catch rates of juvenile haddock in 2021 and 2022 and has been reported by fishers to be equally as high in 2023. These high catch rates of juvenile haddock highlights the inability of the currently legal gears to adequately allow for the escape of undersized roundfish species.

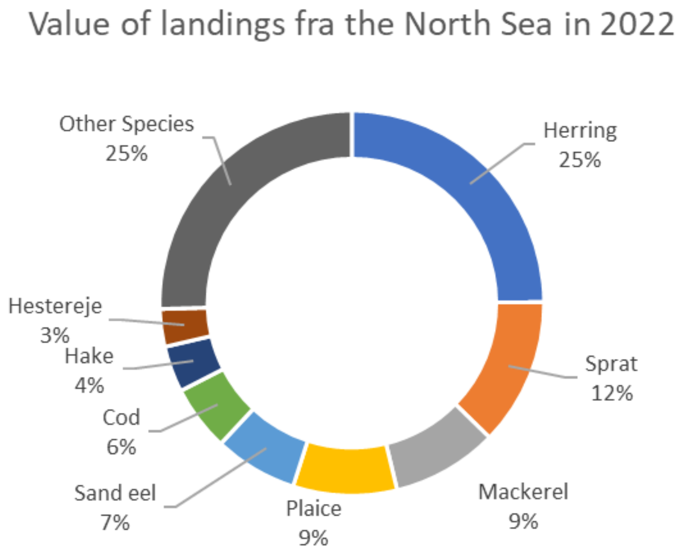


Figure 3.3.1. Landings composition (in value) of the main species caught by Danish vessels in the North Sea in 2022 (source: https://fiskeristyrelsen.dk/fiskeristatistik/dynamiske-tabeller, 2023).

To address these issues, the following ideas were proposed through collaboration between fishers, scientists, and net-makers, and tested during the project for North Sea's fisheries:

Fishery	Problem	Proposed solution	Type of trial	Annex
Demersal fish trawl fishery	Bycatch of undersized roundfish, especially haddock	T90 120 mm codend	Scientific trial onboard commercial vessel	1J + 1K
Brown shrimp beam trawl fishery	Bycatch of small pelagic species and undersized whiting	Use of large mesh panel on the upper panel of the trawl's mouth	Commercial trial, fishers self-sampling	1L

4. Results on selective fishing gears

Below we present the results of the different trials undertaken in the project. These have been grouped according to the type of fishery; trawling and seining for flatfish, mixed demersal trawl targeting Norway lobster, and beam trawling for brown shrimp. A more detailed description of the trials and the specific gears tested can be found in the factsheets in Annex 1A - 1L.

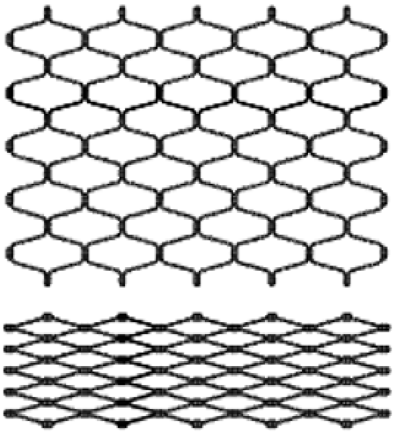
4.1. Trawling and seining for flatfish

In all areas, issues regarding bycatch of juvenile roundfish when targeting flatfish were raised. In some cases, all sizes of cod were unwanted due to lack of quota, in other cases only juvenile cod were unwanted. Finally, the smallest vessels in the fleet (<10 m) highlighted that they experience a loss of their main target species, plaice, when using the mandatory SELTRA300.

4.1.1. T90

AIM: Reduce bycatch of juvenile roundfish while maintaining marketable flatfish.

Turning the sheet of netting 90° (Fig. 4.1.1) results in a mesh with different selective properties than the traditional diamond meshes. Due to the orientation of the knot, the T90 meshes are more open and for the same mesh size, this will allow more round fish and flatfish below MCRS to escape while retention of marketable flatfish remains largely unchanged (or can potentially increase). T90 is used in the Baltic and during this project, the effect of turning 120 mm meshes 90 degrees was tested in commercial trials by a Danish Anchor Seiner (**Annex 1H**) fishing in the Skagerrak and a demersal twin trawler (**Annex 1J**) fishing in the North Sea and Skagerrak. As found for similar codends in the Baltic, both trials demonstrated that the T90 codend reduced the retention of juvenile roundfish and improved the retention of smaller sized marketable flatfish. The scientific trial (Annex 1J) further documented a significant reduction of cod and haddock up to a size of 43 cm and 40 cm, respectively. On the demersal twin trawler, the 120 mm T90 codend was also tested against the 105 mm codend with a 140 mm square mesh panel which is standard in this fishery (**Annex 1K**), Again, the T90 caught significantly less small round fish. However, the increase in mesh size compared to the standard codend (105 mm vs. 120 mm), also resulted in a significant loss of small marketable plaice (27-28 cm) and lemon sole (26-28 cm). No difference in catch efficiency was found for the larger commercial-sized individuals.



T90 meshes

Diamond meshes

Figure 4.1.1. Turning a sheet of diamond meshes 90° to obtain T90 meshes.

4.1.2. Large mesh panel in the roof of trawl

<u>AIM</u>: Reduce catches of roundfish while maintaining marketable flatfish.

Introducing a panel of large meshes in the roof of the trawl (Fig. 4.1.2.) has the dual purpose of a possible reduction in fuel consumption while it may serve as an escape route out of the trawl for the catch that has just entered. A version of the gear was tested on a twin trawler fishing in the Baltic (**Annex 1A**) and the aim was to minimize cod catches. Results indicate that the large meshes in the upper panel reduce catches of cod with a minor loss of marketable flatfish.

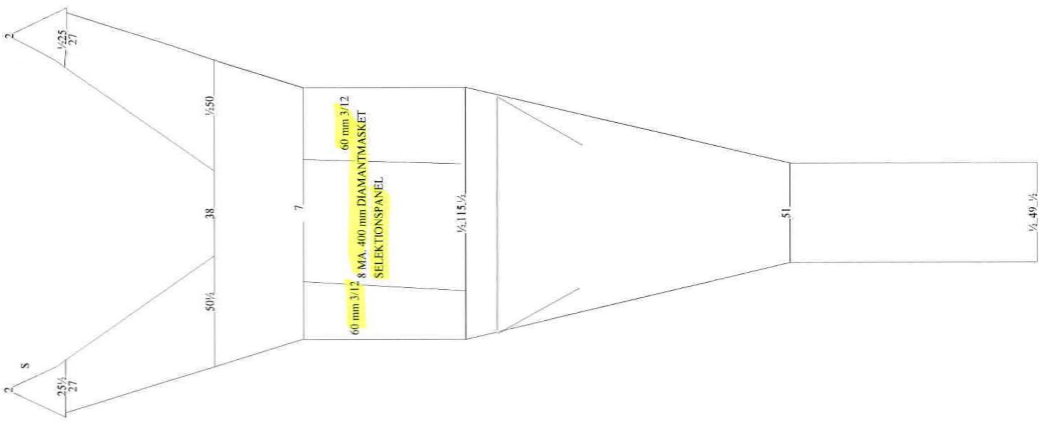


Figure 4.1.2.: Schematic drawing of the upper panel of a trawl. A panel with 800 mm meshes (mesh size on the drawing is half mesh) is inserted into the roof section of the trawl.

4.1.3. Roofless extension piece

<u>AIM</u>: Eliminate catches of cod and other roundfish while retaining commercially important flatfish species.

The Roofless extension piece is developed by the Thünen Institute in Germany and could serve as a solution in flatfish fisheries with no cod quota (Fig. 4.1.3). The opening creates a zone of visual and hydrodynamic change to trigger upwards escape reactions of fish. It was tested on a commercial vessel in the Baltic where it was fished in a twin trawl setup and directly compared with the 800 mm panel mentioned in section 4.1.2. (**Annex 1D**) Results indicate that the roof-less design is extremely efficient in reducing cod catches and catches of juvenile flatfish. The loss of marketable flatfish ranged from 11 – 35% (more for dab and less for flounder).

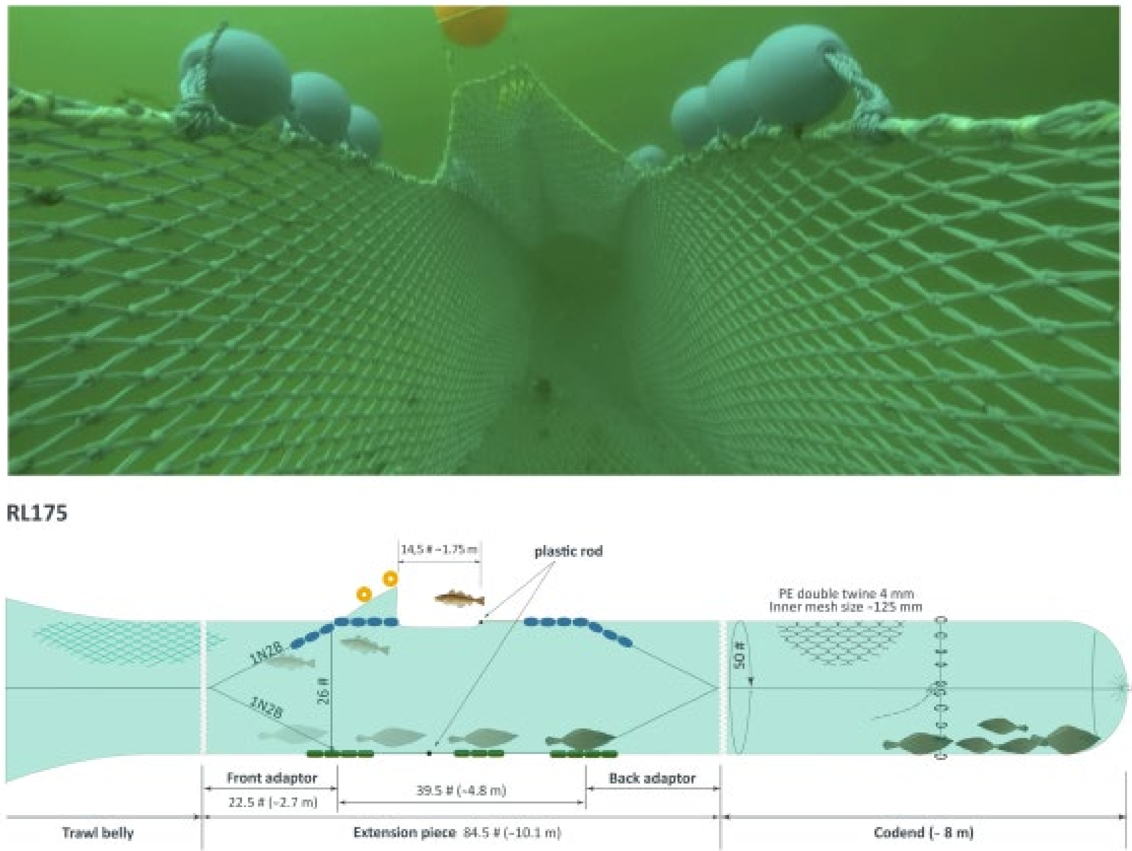


Figure 4.1.3. Schematic drawing of general characteristics of the roofless design and UW footage pointing forwards. The figure is reproduced with the permission from Thünen institute (Stepputtis et al 2020).

4.1.4. SELTRA300 on small vessels (< 10 m)

<u>AIM</u>: Investigate size selectivity of plaice in a SELTRA300 when fished from a small vessel.

SELTRA300 is a large mesh panel which is placed 4-7 meters from the codline. Only few individuals in the catch will be too big to escape through these meshes and once the catch has passed the panel and entered the codend, it is therefore important that they don't move forward. This can happen if speed is reduced e.g. when hauling back. Small vessels with limited engine power report that they lose part of their catch through the panel. This was confirmed in a scientific trial which documented a significant loss of plaice above 30 cm that can be attributed to the SELTRA 300 panel (**Annex 1B**)

4.2. Mixed demersal trawl fisheries targeting Norway lobster

Norway lobsters are relatively small and therefore need small meshes to be retained. Using small meshes increases the risk of unwanted bycatches, and a series of highly selective gears with additional escape routes have therefore been introduced in legislation. On some vessels, and in some areas, the quota composition or the availability of species does not match the selectivity of these gears and a series of alternatives were tested in the project.

4.2.1. Bottom escape window

AIM: Reduce catches of cod while maintaining other marketable fish and Norway lobster.
Cod behaves different from most other fish species targeted in Danish fisheries and this is exploited in this gear which is designed to retain Norway lobster and all marketable fish species except from cod. Cod will in general stay low in the gear and they are relatively strong swimmers. A combination of these traits is exploited by dividing the codend horizontally and creating an escape route for fish that stay low and are strong enough to swim forward at this point (**Annex 1E**). Footage from the trial shows the vertical separation of haddock and cod in the codend, which favours the escapement of cod through the bottom escape window and the retention of haddock (Figure 4.2.1). The design was successful in reducing catches of cod without losses of Norway lobster, flatfish (plaice and witch flounder) and with minimal losses of marketable haddock. Aside from cod, only saithe seemed to make use of the bottom escape window. This is a unique catch composition that none of the other legal gears is currently able to achieve. Now that its relevance to Danish fisheries has been confirmed, the prototype tested needs to undertake further development steps to simplify the design and facilitate its commercial implementation.

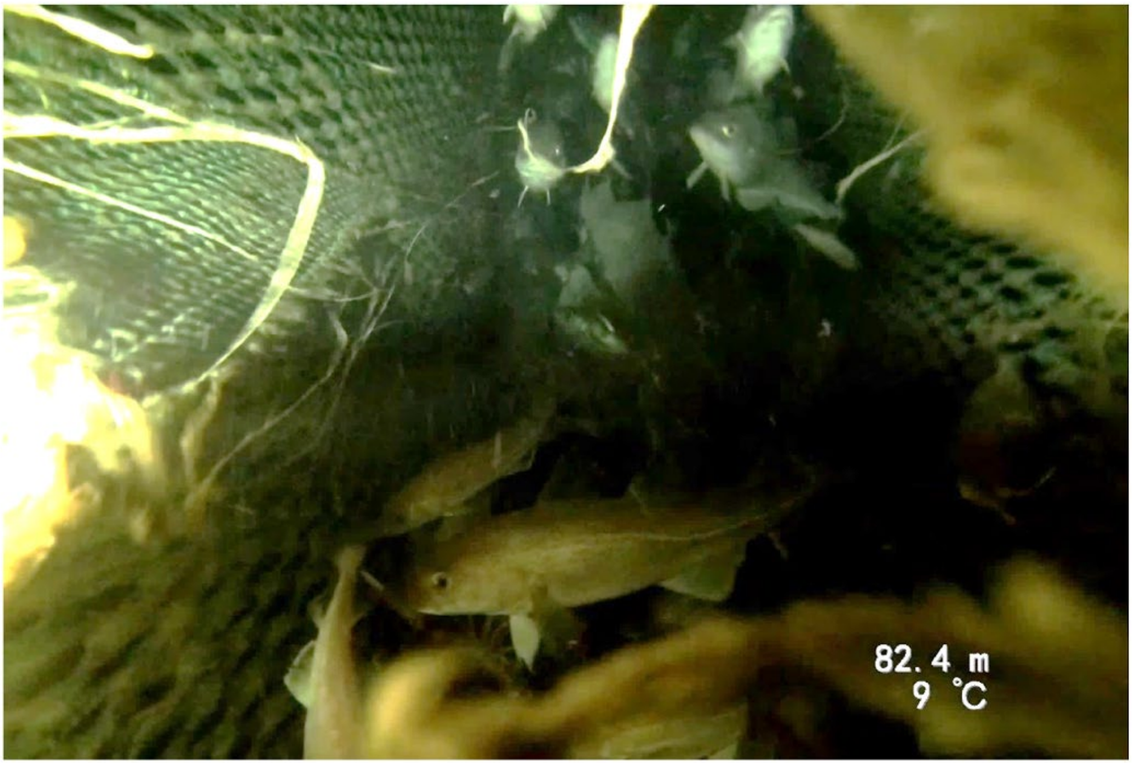


Figure 4.2.1. Footage from the aft end of the codend illustrating the preferred position of haddock (high) and cod (low) (Palder et al. 2023).

4.2.2. Excluder separating Norway lobster and fish into different codends

AIM: Reduce bycatch of juvenile fish with no loss of Norway lobster.

Previous studies have shown improved selective performance for several species as well as improved catch quality when the fish catch in a mixed species fishery is separated from the Norway lobster (Karlsen et al. 2024). In this project, an inclined netting panel guided fish upwards in a large mesh (120 mm) codend while Norway lobster could pass underneath the netting panel and end up in a codend with smaller meshes (90 mm) ((Fig, 4.2.2 and **Annex 1F**). The codend was developed by Tormo Trawl (Egersund Hirtshals). At the end of the project the trials on board a demersal twin trawler were still on-going. The preliminary results indicate that the gear has no loss of Norway lobster, and when using the tested mesh sizes, it reduces the catch of round-fish with 30-60%. These results, in combination with a reduction in sorting time and an increase in catch quality, have gained interest from other vessel operating in the Norway lobster directed mixed fisheries in Skagerrak.

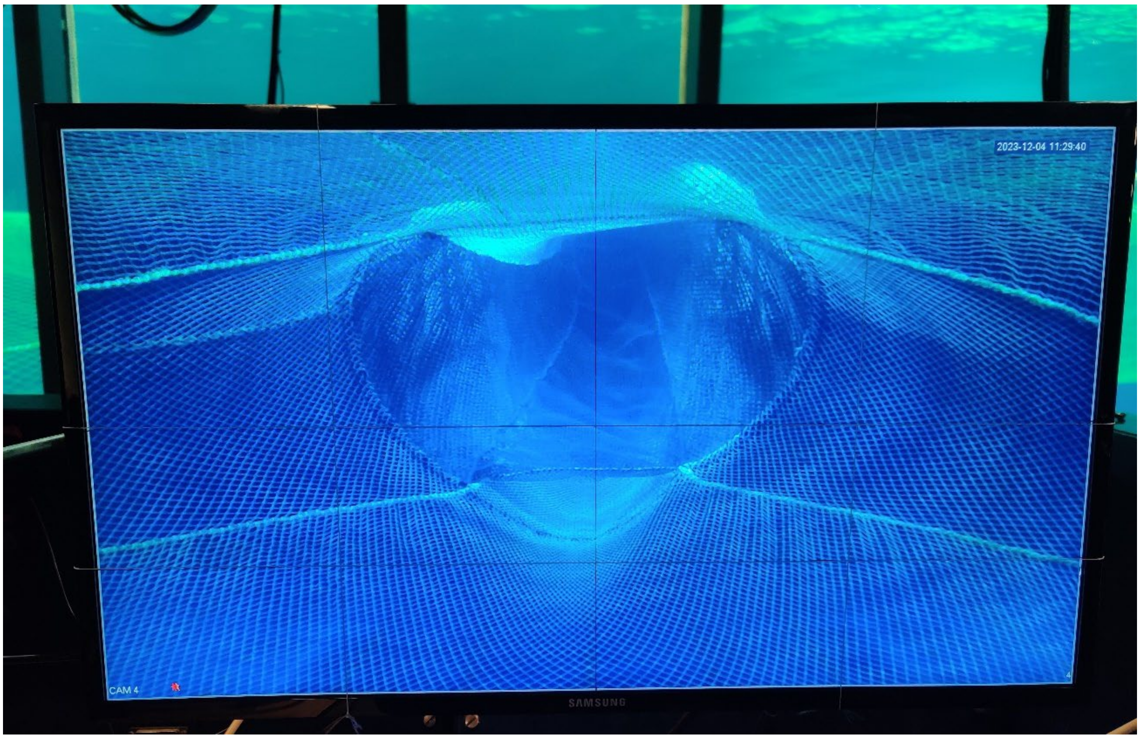


Figure 4.2.2. View into the excluder section showing the inclined panel and the small opening in the bottom which allow access to the small mesh Norway lobster codend.

4.2.3. Large escape opening followed by a dark tunnel

AIM: Investigate the effect of a dark tunnel on the escapement through large mesh panels.

Escapement of fish through panels in the codend is dependent on the fish shifting from a behavoural state where they avoid the netting to a state where they approach and pass the netting. This shift is initiated when catch builds up in the codend. If the panels are moved further away from the codline, additional devices are needed to initiate the escape. In Skagerrak, a large escape opening was followed by a dark tunnel with the aim of minimizing all catches of roundfish while maintaining catches of Norway lobster (**Annex 1G**). The trial showed that adding the dark tunnel to the setup significantly enhanced the selective performance of the large escape opening for all investigated species. As target species, a loss of Norway lobster, highlighted the importance of optimising the integration of the dark tunnel in demersal trawls. Providing the dark tunnel is integrated correctly, our results suggest that currently implemented escape panels and openings with low selective efficiency could be substantially improved by simple means like a dark tunnel.

4.2.4. Large window as an alternative to SELTRA300

AIM: Reduce catches of all sizes of cod and haddock while retaining commercially important flatfish species and Norway lobster.

Cutting out a large diamond shaped window in the upper panel of the extension piece is the concept in this design (**Annex 1C**). It was tested on board a twin trawler targeting Norway lobster in the Kattegat. Catches of cod were low and results on this species are therefore uncertain but indicate a reduction compared to the SELTRA300. Results further indicated higher catches of haddock in the diamond opening codend whereas catches of plaice and Norway lobster were similar in both codends.

4.2.5. Selective effect of the set-up for real-time observation in trawls

AIM: To facilitate the adoption of real-time observation technologies which can aid the avoidance of bycatch hotspots; this requires the documentation of any change in selectivity caused by the the real-time observation setup (**Annex 1I**).

Though the design of this gear is not in itself aiming at improving the catch composition in mixed fisheries, it is crucial for obtaining readable real-time footage. The system includes: i) a tarpaulin sheet (Panama-green PVC coated tarpaulin sheet, type B71311 12×12) (5m L and 3m W) centered in the bottom panel behind the ground gear to suppress and limit the sediment entering the trawl; ii) a 2-m long, tapered (70 cm diameter at the entrance and 50 cm at the end) observation section, of the same material to secure stable and consistent video quality; and iii) an underwater camera placed in the observation section, aiming downwards, cable-connected to the vessel (Figure 4.2.3). The camera cable is secured to the top panel of the trawl using shackles and connects to the vessel from the center of the trawl headline.

Changes in selectivity were identified for most species and attributed to different components of the experimental set-up. For example, catches of cod and haddock increased due to a higher headline height caused by the pull of the camera cable. This issue could be resolved by altering the rigging of the cable to the vessel. Moreover, catch accumulation ahead of the tapered observation section was observed in most hauls. This led to substantial losses of Norway lobster below 40 mm Carapace Length (CL) and minimal losses of witch flounder (*Glyptocephalus cynoglossus*) across length sizes. We attributed this effect to the pressure build up ahead of the observation section, which increased mesh openness and, thus, affected the selection of Norway lobster and increased the likelihood of narrow-bodied fish such as witch flounder getting stuck in the meshes. No loss of plaice was observed, possibly due to the species' morphology or swimming behaviour. Design changes will be required to prevent this hydrodynamic effect, for example by reducing the tapering of the tarpaulin observation section and increasing the overall size to secure a fit between the mesh circumference and the observation section. Additionally, the mesh size ahead of the section could be reduced to prevent any selection from occurring in that area.

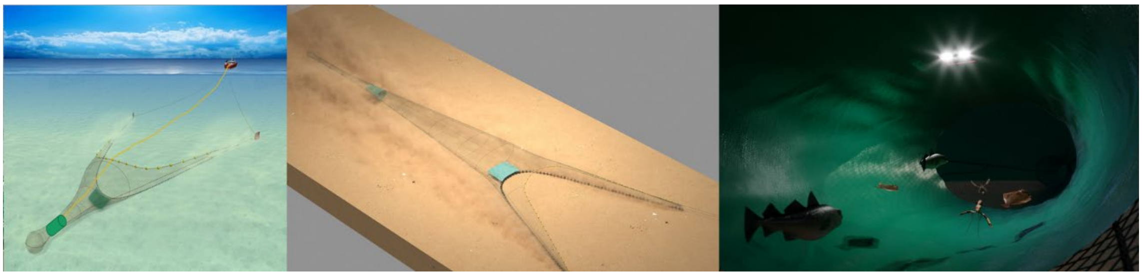


Figure 4.2.3. Left: schematic illustration of the real-time observation set-up developed by the EU H2020 SMARTFISH project. Center: detail of the two tarpaulin sections inserted in the trawl (the sediment suppressor sheet in the front and the tapered observation section). Right: illustration of the camera placement and view of the species in the observation sections. All illustrations were reproduced with permission from the EU H2020 SMARTFISH project.

4.3. Brown shrimp beam trawl fishery

The fishing grounds of this fishery can overlap with nursery areas of commercially important species such as plaice, cod, whiting and small pelagic species, and the small mesh size increases the risk of bycatches of large quantities of these recruits.

4.3.1. Large mesh panel in the roof of a beam trawl

<u>AIM</u>: Reduce the bycatch of small individuals of cod, haddock and whiting and pelagic species such as herring and sprat in a brown shrimp beam trawl fishery while maintaining catches of brown shrimp.

In this project, a large mesh (200 mm) panel ranging from the beam to the beginning of the sieve net was tested (Fig. 4.3.1) (**Annex 1L**).

Preliminary results show no significant effect of the panel on amount of bycatch or catches of shrimp. However, simple and preliminary visual inspection of images of the pounders (Fig. 4.3.2) seem to support the impression of reduced bycatches when larger proportions of herring, sprat or whiting was encountered. Despite the lack of significant effects in the data recorded, the fisher reports that he is happy with the panel's performance and believes its use reduces the overall fuel consumption of the vessel. The fisher formed his opinion by observing a decrease in drag on the side with the panel.

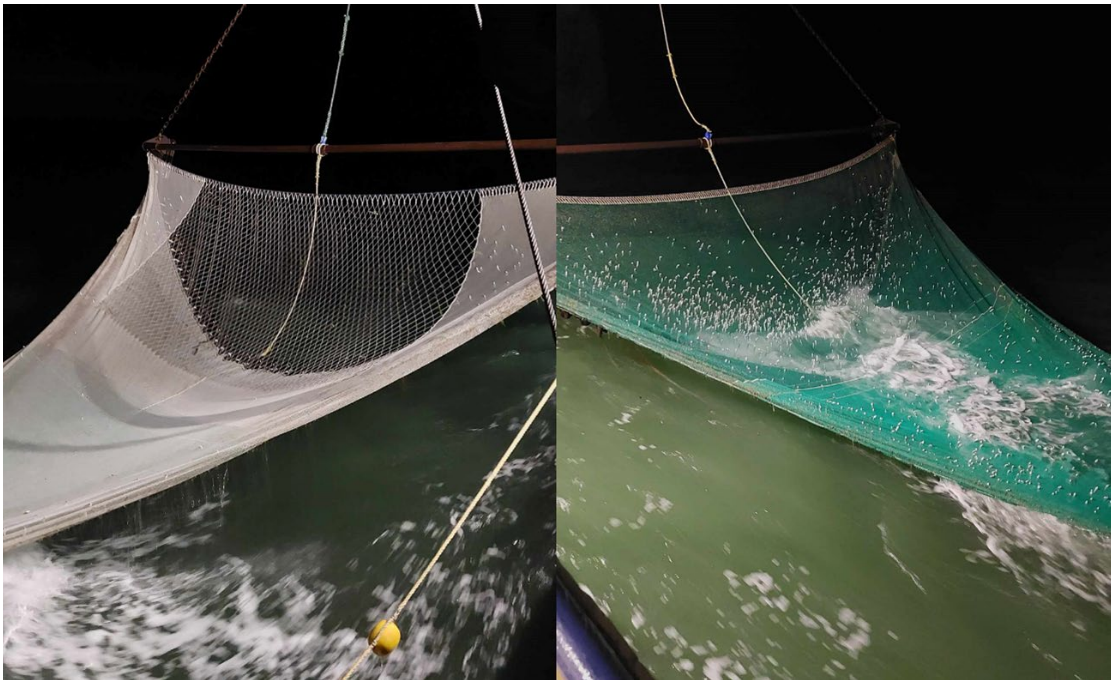


Figure 4.3.1. Trawl with large mesh panel (left) and a typical trawl targeting brown shrimp when it encounters a shoal of small pelagic fish. Please note that during the catch comparison trial, two trawls identical to the left trawl were used, where on one side the panel was using a sheet of netting similar to the netting of the trawl in that section.

Figure 4.3.2. Example of pictures of the total catch from the codends with (left) and without (right) the panel taken by the fisher.

5. Development of new technologies

The development of technologies to improve commercial fishing is happening at a rapid rate. Technologies are being developed to provide better documentation of what is entering the gear during the fishing process, what is being caught, how fish react to the fishing gear and its components, as well as to reduce the gear's impact on the environment.

These technologies aim to address many of the same issues as the technical measures, such as the specification of fishing gear, aim to address. Namely, the reduction of unwanted catches, unnecessary seabed impact and carbon emissions.

Technology	Aim	Application	Fact sheet
Multi-species methods	Improved size selectivity for several species simultaneously	Mixed fisheries	Annex 2A-C
Tech-based precision fisheries	Detect cod in a real-time setup	Demersal trawl fisheries	Annex 2D
New data streams for selectivity	Using new data streams from cameras for improved insights into selectivity	All trawl fisheries	Annex 2E-F
Potential of fully digitalized fisheries for fisheries management	How real-time fully documented fisheries could transform the fisheries management framework.	All fisheries	Annex 5
Fish behaviour and split beam acoustics	Monitor efficiency of trawl modifications due to changes in fish responses	All trawl fisheries	Annex 3
Reducing seabed contact	Reduce fuel consumption and seabed impact	Demersal trawl fisheries	Section 5.6.

5.1. Multi-species methods

The majority of Danish demersal trawl fisheries target several different species simultanously. The exact combination of species targeted, depends, among other things, on the quota portfolio of the vessel, auction price, and the abundance of species on the fishing grounds. Some species encountered by the trawl are therefore considered target species while the capture of other species should be avoided or at least minimized. One such mixed-species fishery is the demersal trawl fishery in the Baltic Sea targeting flatfish species such as plaice and flounder. In this fishery, the capture of cod is of concern due to dwindling populations. Therefore, in recent years, a focus has been on developing gear solutions that address the mixed-species challenge of having an effective fishery after the targeted flatfish species while avoiding or at least minimizing capture of cod.

In this project we aimed at increasing the basic understanding of the mechanics of size selection in a trawl codend. A gear with a perfect size selection will retain all fish above a certain size and release every single fish below. In real life, variation in the selection process leads to a more inaccurate selection and a significant part of this variability has theoretically been attributed to variation in the openness of the meshes during the fishing process. However, the contribution from the variation in mesh openness had so far not been quantified experimentally. Understanding how the meshes in the codend affects the size selection of different species, might lead to better control over what sizes of different species can escape, if we can make the meshes behave in a more predictable manner.

Figure 5.1.1: Picture of the constructed codend with fixed meshes.

Selectivity of codends with fixed mesh configurations (Fig. 5.1.1) were compared with normal codends with similar mesh size (**Annex 2A**). For cod, the traditional diamond-mesh codend was found to have 45% more variation in size selection than the codend with fixed mesh at a 40° opening angle (Bak-Jensen, et al., 2022).

For cod, we also demonstrated that the standard square-mesh codend had significantly larger variability in size selection compared to the fixed diamond-mesh codend (Bak-Jensen et al., 2023). Thereby, the results demonstrate that the use of standard square-mesh codends is not sufficient to reduce variability in codend size selection. For flatfish, we also found the sharpest size selectivity with fixed mesh geometry, indicating that variability in mesh openness also affects the selectivity of flatfish. We further found that the retention risk for undersized flatfish tends to increase with increasing mesh opening angle (**Annex 2B**). Thereby, having the smallest size at 50 % retention probability for flatfish in a fixed square mesh (FS), the second lowest in a diamond mesh with 60° opening angle (OA60) and the largest when the opening angle is reduced to 40° (OA40).

The results from these sea trials are summarized in Fig. 5.1.2. in the three codends above the curly bracket. The FS retains both large and smaller flatfish while the roundfish morphology is better suited for escape and the larger and smaller individuals both escapes. In the OA60 the larger individuals of both roundfish and flatfish are retained but the smaller individuals escape. In the OA40 the large and smaller sized flatfish escapes while both large and smaller individuals are retained. In the Baltic Sea the aim is to catch only the large individuals of flatfish. Therefore, a codend with a large square mesh where the mesh size was adapted to the minimum landing size (MLS) for plaice was developed (FS140). Using a 140mm nominal mesh size instead of the previous tested 110mm mesh size, we expected that this would favor the release of cod of both larger and smaller size and flatfish below MLS. This while still retaining the target flatfish. In addition, it was considered if the large mesh size would give benefits for other species to escape.

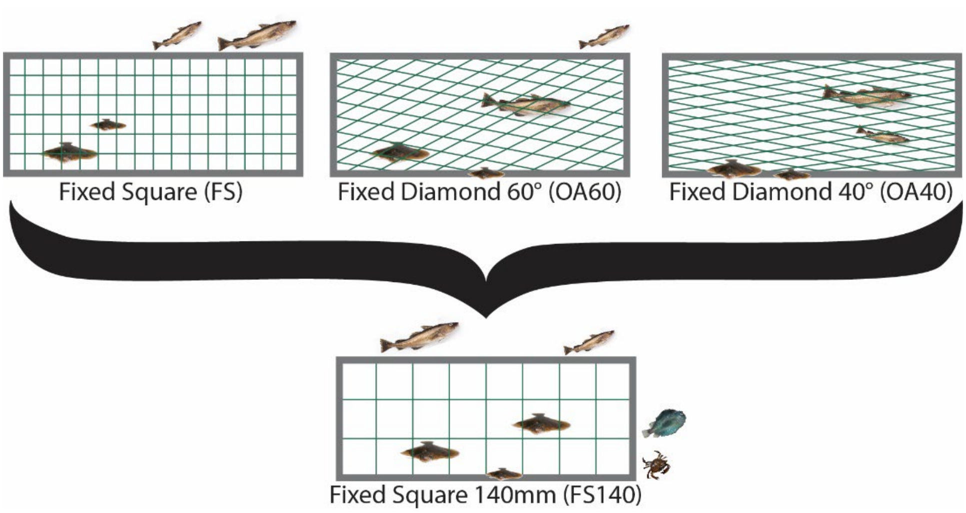


Figure 5.1.2: Picture the development of the Fixed Sqaure 140mm codend.

Next up was to investigate the effect of bottom trawling in Baltic Sea on the species community. In this sea trial the FS140 codend was tested and for comparison an Ultracross© knotless with a nominal mesh size of 125 mm. The trial was again carried out onboard *Solea* the German research vessel from Thünen Institute. A total of 38 valid hauls were made, of these 21 hauls with the FS140 and 17 hauls with the Ultracross© knotless. In combination with selectivity data for the species of interest, count numbers and weight of all species caught in the codend or cover larger than 1cm^3, was collected (**Annex 2C**). The species numbers and weight were used to quantify the impact of the trawl both on commercial species and on species, that have not so far been of investigated e.g. due to lack of commercial interest. The analysis and therefore the result of this trial is still under preparation. However, preliminary analysis shows that the FS140 retains the targeted flatfish while releasing large parts of the undersized flatfish and cod. The size selectivity data showed no significant difference in for cod and whiting between the two codends. For plaice and dab the SR was significantly higher for the flexible Ultracross compared to the FS140. For flounder the L50 was significantly higher using the FS140.

All these trials showed a more controlled size selection using fixed meshes. However, the construction used is not suitable for commercial use. Development of a design that has fixed mesh shape and at the same time possible to handle onboard a fishing vessel could benefit to a more sustainable fishery.

5.2. Tech-based precision fisheries

Commercial trawling is today fundamentally challenged by an extensive ecological, societal and economical drive to improve sustainability. Commercial trawling is an effective fishing practice, however, it is mainly conducted in the blind and fishers have little to no information of what species and sizes that are being caught, and when and where it happens. We have therefore developed artificial intelligence-based solutions (i.e. deep-vision models based on machine learning) that provide fishers with detailed information on the ongoing catch process and composition, which enables them to react to catches of unwanted species and sizes.

More specifically, a cod-detector has been trained based on an extensive image library (dataset) collected at sea during this project. The cod-detector takes in the real-time video stream from an underwater trawl camera, co-developed by DTU-Aqua and automatically informs the fisher when cod enter the codend (92% mean average precision) The cod-detector visually displays an interactive "heat-map" of hot spots of cod catches (**Annex 2D**). Using the stereo function of the camera, we have been able to extract length estimates of the individual cod and with further work, we will be able to show an accumulated catch structure for the ongoing haul. We can automatically process the information in real-time with realistic computer power (hardware) available to commercial vessels.

This work will enable the fishers to monitor and evaluate catches of cod, allowing for the interruption and reallocation of the fishing operation if catches are unfavorable. Thereby, transforming the fishing operation from a blind process to a transparent, informed decision-making process, giving the operator more control over the ongoing process.

5.3. New data streams for selectivity

The objective of this work package was to document the fish entering the trawl codend with video data from in-trawl cameras and compare it to the actual catches documented by electronic monitoring cameras. By analyzing this data as paired gear data and comparing it to the typical data that is collected during selectivity experiments by using the paired gear method (Wileman et al., 1996), selectivity curves would be obtained automatically.

The experimental setup comprised of a twin-trawl where one side was mounted with a selective codend and an underwater camera, while a blinded codend was attached on the other side to sample the species populations. Atlantic cod (*Gadus morhua*) was the only species in the trial appearing in high enough quantity to provide usable selectivity curves. These were manually worked up onboard the fishing vessel, and subsequently attempted to be replicated using computer vision. To simulate a real catch scenario, catch items were allowed to overlap on the sorting belt. This proved to become a limiting factor, as our computer vision models were unable to accurately classify species and estimate lengths of overlapping fish and crustaceans. Especially the length estimations of occluded objects remain a challenge, that to this day, continues to occupy scientists across research fields.

To tackle this challenge, a series of exploratory studies on using allometric relationships as an alternative way to predict the lengths of occluded fish were conducted (**Annex 2E** and **Annex 2F**). Several trials were conducted as part of two separate studies, to collect and measure different morphometrics on Atlantic cod. Firstly, an exploratory study investigating 34 allometric relationships was conducted to assess the applicability of using these for total length estimation from EM videos (**Annex 2E**). This was followed up by a study investigating the robustness of the seven most promising allometric relationships across four seas in the Northern European waters (**Annex 2F**). The investigation of allometric relationships was also used to address the fact that some cod in the underwater footage from the in-trawl camera were only partly visible, as they either swam close to the camera or swam in and out of the periphery of the camera's field of view.

The next steps are to combine everything – from documenting the fish that enters the trawl's codend to improving the computer vision models to tackle the current challenges with obtaining species and length measurements of occluded catches.

5.4. Potential of fully digitalized fisheries for fisheries management

Recent advancements in acoustics and camera technologies together with the power of Artificial Intelligence (AI) and especially computer vision allow for the collection and analysis of detailed catch information in real time that can revolutionize fisheries management frameworks (Sokolova et al., 2022). Indeed, the human-like cognitive functions rooted in computer systems of Machine learning (ML) can learn and adapt to draw inferences from patterns in complex data.

Electronic Monitoring (EM) combined with AI technology serves the potential for providing Fully Documented Fisheries (FDF). In other words, AI-assisted EM systems can process the video data to automatically generate fishing reports that contains essential information such as catch composition and length information of the catch items. Therefore, utilization of EM allows for delivering the catch information for FDF with minimizing the risk of data tampering. However, it does not allow for real-time decision making that can influence catch rates and compositions since EM takes place after the catch is brought on the deck of the fishing vessel. The monitoring of catches in real-time using underwater cameras or acoustics mounted in the trawl (Real-Time Monitoring, RTM) introduces the possibility for fishers to make informed decisions to actively avoid unwanted catches and more efficiently target species of interest. Indeed, more precise targeting of species can reduce the carbon footprint and seabed disturbance associated with fisheries (Sokolova et al., 2022; Krag et al., 2023).

In a system with robust control and enforcement, e.g. where all catches are documented, the significance of gear-based technical measures diminishes. This can lead to various subsequent changes and adaptations in management and the way stocks are harvested, presented in **Annex 5** We present in Table 5.4.1. how the emerging technologies for real-time fully documented fisheries (with camera or acoustics technologies) could transform the fisheries management framework.

Table 5.4.1. For each conservation measure, we present what it regulates in fisheries management, and what would happen under a real-time fully documented fishery (FDF): not necessary anymore in grey, to be adapted in orange, still necessary (same as now) in green.

Conservation measure	Regulates…	Output of Real-time FDF	Adaption in the management framework	Points of attention
Technical specifications	how the stocks can be fished	In a system with robust control and enforcement, e.g. where all catches are documented, the significance of gear-based technical measures diminishes	Free or more flexible gear choice	Gears with e.g. reduced impact on the seabed may need support from legislation to be implemented.
Temporal and spatial closure	when and where the stocks can be fished	Real-time information of high quality can optimize the extent of the area, the onset, and the duration of the closure.	More accurate spatiotemporal data could allow for more flexibility in the extent of the area, the onset, and the duration of the closure.	Many species are not yet detectable by AI. Until this is possible, more footage will require more workup effort (time).
Fishing efforts limitations	the amount of time spent fishing	The impacts on target stocks are controlled for by counting regulated catch against the quota.	The impacts on the wider ecosystem would normally be regulated by controlling for fishing effort, but RTM in the trawl can reduce the time needed to catch the quota and increase pressure on non-quota species.	Many species are not yet detectable by AI and new commercial e.g. climate change species may be missed in an FDF.
Harvest limits and quota systems	what and how much can be caught and retained (an issue of increased importance under the Landing Obligation)	More accurate catch registration will ease quota control, while recording fishing operations e.g. sorting time may be of relevance for high survival exemption to discard under the landing obligation.	No change. Improved data stream on catches to support the stock assessment.	Many species are not yet detectable by AI. Until this is possible, more footage will require more time for workup.
Catch composition	what species are not allowed to be caught (vulnerable and prohibited species)	Better information on catch composition both with regards to species and sizes.	No change.	Many species are not yet detectable by AI. Until this is possible, more footage will require more time for workup.
Minimum Conservation Reference Sizes	the sizes of fish allowed to be caught and sold for human consumption		No change.	Automatic size measurements are still challenging for many species.

5.5. Fish behaviour and selectivity

Fishing gears are originally designed to maximise catch rates. Any changes to the gears, for example to reduce seabed impact or improve selectivity, are likely to influence the catchability and selectivity of the wanted and/or unwanted species and sizes. For example, the efficacy of a selective device in a trawl depends on fish actively using the escape opportunities provided by the device. While the probability of escaping based on the morphology of fish relative to the geometry of the escape route can be quantified and modelled, the predictability in the fish behaviour leading to escapement is still poor. The low understanding of fish behaviour in relation to active fishing gears is linked to limitations in three important areas: (i) methods obtaining detailed observations of fish behaviour during the fishing process, (ii) tools for extracting and quantifying large amount of observational data, and (iii) understanding how the interactions between different stimuli present in a trawl during fishing influence on fish behaviour.

We investigated how recent developments in high frequency acoustic equipment and associated analytical tools can be used to obtain detailed and quantitative data on fish behaviour. Experiments were first conducted in a controlled environment in the laboratory, then during fishing at sea. In the laboratory, we investigated the effects of selected sensory stimuli presented as a single stimulus and in a combination of two stimuli using both acoustic and optic observation technologies. The selected stimuli were of relevance for trawl fisheries and aimed to get a better understanding of how behaviours can be influenced to obtain the desired catch composition when modifying trawl gears. At sea, we investigated fish response to a square mesh panel using split-beam acoustic observation.

5.5.1. Using acoustics and optics to track fish in the laboratory (Annex 3)

The laboratory experiments were conducted in a large quarantine tank at Nordsøen Oceanarium (**Annex 3**). The tank was 18 m long, 5.5 m wide and 3.5 m deep (Fig. 5.5.1.).

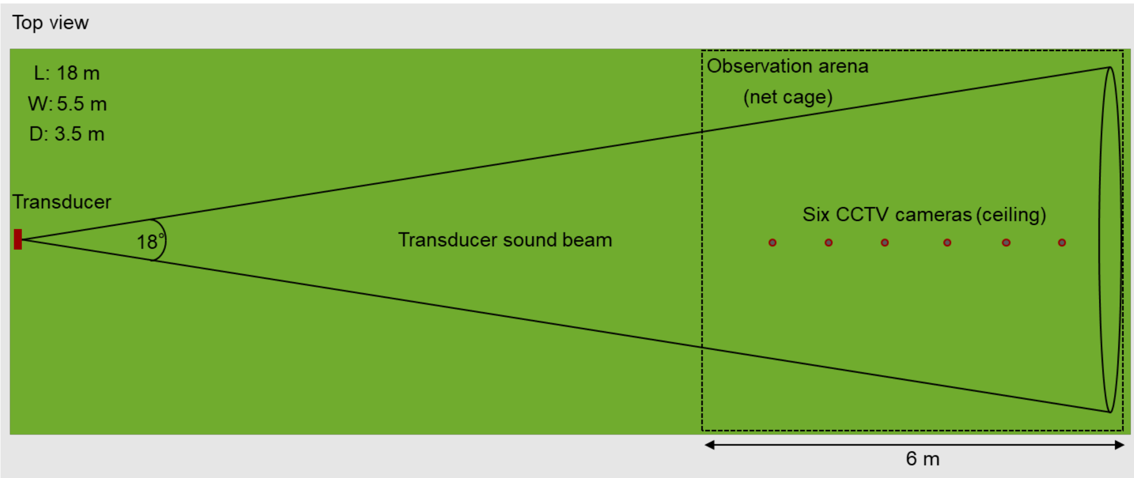


Fig. 5.5.1. Top view of the experimental tank illustrating the net cage constituting the observation arena, placement of the split-beam transducer and the extent of its sound beam, and the placement of the six CCTV cameras for simultaneous optic observation.

In this setup, cod were tracked by use of both the acoustics and images to monitor their reactions to two simulated trawl stimuli in the laboratory: i) vibration stimulus and ii) the presence of movement and LED light stimuli. Tracks from individual cod were visible in the split-beam data

(Fig. 5.5.2). The movement device created distinct acoustic noise as it was moved across the arena (Fig. 5.5.3). The video recordings revealed periods where the group of fish was dispersed and periods where they were closely together. Due to the limited time frame of the project, the collected data have not been analyzed. It is expected that both acoustic and optic tracking will reveal how their reaction is related to the stimuli tested.

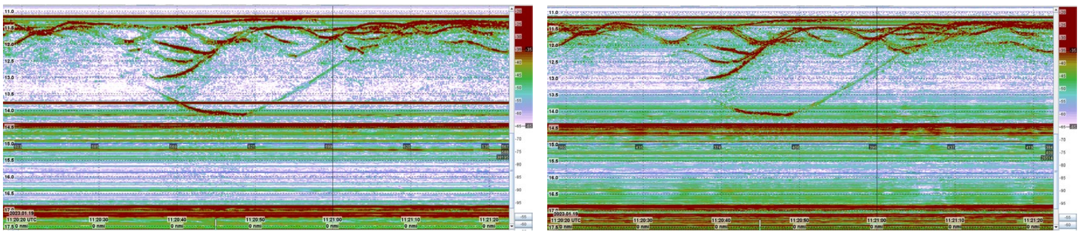


Fig. 5.5.2. Echograms of a fish group of eight individuals being stimulated by vibrations observed by the 70 (55-90) kHz transducer (left) and 120 (100-155) kHz transducer (right).

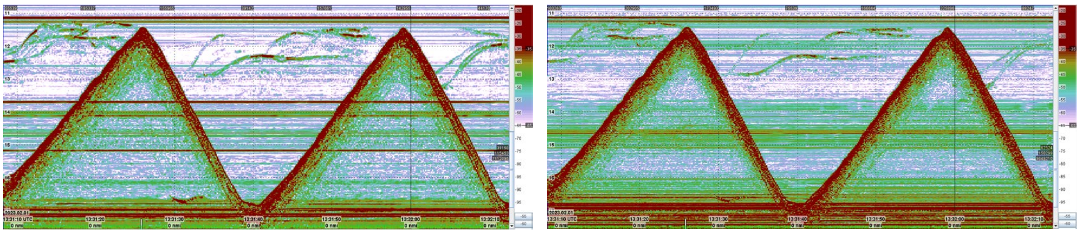


Fig. 5.5.3. Echograms of a fish group of eight individuals being stimulated by a combination of movement and light stimuli observed by the 70 (55-90) kHz transducer (left) and 120 (100-155) kHz transducer (right). The distinct noise tracks creating two peaks are created by the movement device as it was moved along the observation arena.

5.5.2. Tracking fish during fishing

The ability to track individual fish using split-beam observation technology was not only tested in the laboratory, but also during fishing where information on how fish respond to bycatch reduction devices and other gear modifications was collected. While the species and sizes of the fish are known in the laboratory, this is often difficult to identify from acoustic data at sea, and catch data is used to ground truth the acoustic data. Also, only some of the present individuals are expected to be possible to track due to high fish densities. On the other hand, there is typically less acoustic noise at sea.

The experiment was conducted using an 80 mm PET whitefish trawl. The 90 mm PET codend had a 3 m long 300 mm square mesh panel inserted in the top sheet (Fig. 5.5.10). A metal frame with a Simrad 18-degree split-beam transducer mounted inside the codend in the cross section 4 m behind the square mesh panel. The transducer was connected to a Simrad WBAT transceiver attached on the inside of the top sheet. The transducer transmitted pings at a nominal frequency of 70 kHz (range: 55-90 kHz). The start and end of the square mesh panel section was acoustically marked with small floats (Fig. 5.5.4).

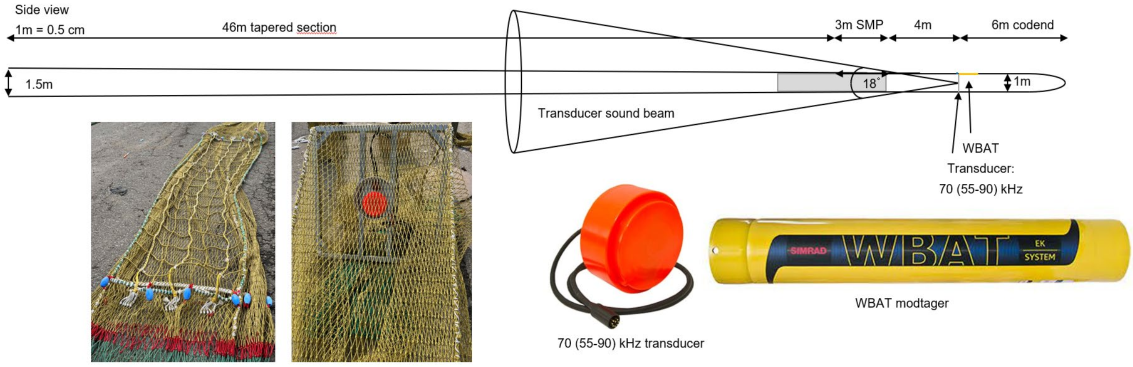


Fig. 5.5.4. The experimental set-up. Side-view of the trawl gear from the 1.5 m high trawl mouth to the codend. The split beam transducer was placed on a 1x1 m metal frame and mounted in the codend cross section 4 m behind the square mesh panel, so the circular 18-degree sound beam covers the whole gear section with the 300 mm square mesh panel. The blue floats marked the start and end of the square mesh panel section.

Data for acoustic tracking was collected during a sea trial with R/V Havfisken. The trawl gear with the square mesh panel and split-beam set-up (test gear) was fished in a twin rig with an identical gear without the square mesh panel and split-beam set-up (baseline). Ping settings and ping period were programmed into the WBAT mission planner prior to each haul.

In total, approximately 260 minutes of acoustic recordings were obtained from 7 hauls (Table 5.5.1). A review of the acoustic recordings in EK80 revealed paths from multiple fish individuals (Fig. 5.5.5).

Table 5.5.1. Station data for the sea trial with Havfisken during which acoustic data for fish tracking was collected.

Haul No.	Date	Time at start (UTC)	Duration (min)	Lat start	Long Start	Towing speed seabed (kt)	Depth (m)	Side of test	Wind direction	Wind speed (m/s)	Wave direction	Wave height (m)	WBAT (kHz)
1	31-08-2023	13:05	00:47	57.52.552 N	010.30.255 E	3.1	110	BB	NE	4	NE	0.5	70/120
2	31-08-2023	14:48	00:42	57.54.362 N	010.24.687 E	3.2	98	BB	NNE	4	E	0.2	70/120
3	01-09-2023	05:52		57.47.740 N	010.00.532 E		54	BB	WNW	5	WNW	0.5	70
4	01-09-2023	11:02	00:58	57.56.841 N	009.46.069 E	3.0	92	BB	N	3	W	0.3	70
5	05-09-2023	08:38	00:26	57.52.419 N	010.42.158 E	2.8	135	ST	W	14	W	1-2	70
6	05-09-2023	10:29		57.53.94 N	010.47.025 E	3.0	139	ST	W	15	W	1-2	70
7	05-09-2023	13:09	00:30	57.54.24 N	010.46.622 E	3.0	140	ST	W	16	W	1.5-2	70

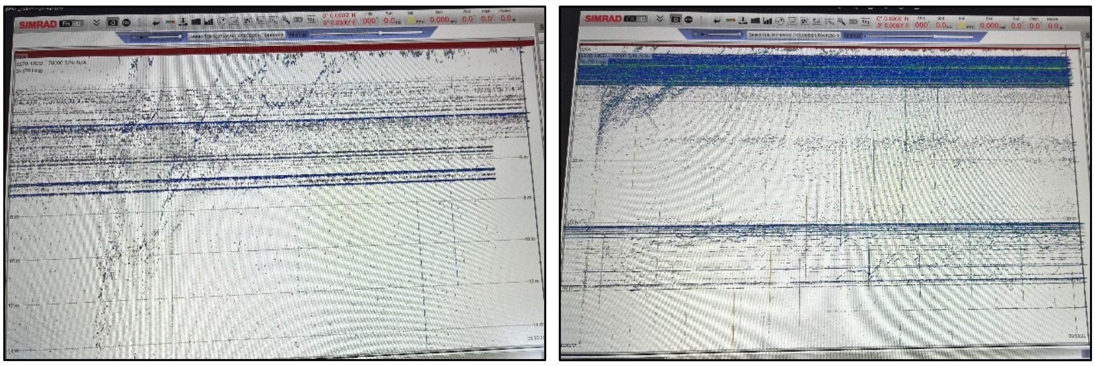


Fig. 5.5.5. Example echograms showing paths of movements from multiple fish individuals during a haul 0-14 m from the transducer showing the acoustic markings of the square mesh panel at 4 and 7 m (left) and 0-45 m from the transducer (right).

The catch data from all hauls were collected (Table 5.5.2). All roundfish caught in the test and baseline gears were length measured. This data of known fish species and fish lengths are used to ground truth the acoustic data. Furthermore, from the data, the number of fish escapes by species and lengths are estimated and used in the interpretation of the fish responses observed in the acoustic data.

Table 5.5.2. Catch data from the test and baseline gear.

Haul No.	Test catch (n)					Baseline catch (n)				
	Total catch	Cod	Haddock	Hake	Whiting	Total catch	Cod	Haddock	Hake	Whiting
1	176	17	136	3	20	348	27	247	17	57
2	245	29	157	12	47	503	39	314	19	131
3	230	111	47	20	52	419	117	95	37	170
4	492	41	391	7	53	657	44	509	3	101
5	75	6	68	1	0	314	8	297	3	6
6	441	33	405	2	1	488	26	457	1	4
7	240	33	200	2	5	600	45	543	0	12

Optic and acoustic technologies are complementary observation methods. While the focus on optic methods is increasing due to advancements in the use of artificial intelligence for identifying and tracking individuals, less emphasis has been placed on the potential of using acoustic methods. The acoustic split-beam data collected reveals distinct fish paths and so identifying fish tracks in future acoustic analysis is promising. The challenges and strengths of using split-beam acoustics will be evaluated against those faced by conventional optic tracking methods. Both observation methods are expected benefit from future automatic identification and tracking using deep learning methods.

5.6. Reducing seabed contact

Owing to both economic and environmental concerns, many modifications to trawl fishing gears have been tested to reduce the hydrodynamic drag and contact of demersal trawls with the seabed. These modifications can also affect the selective performance of a fishing gear by, for example, reducing its herding capacity, altering the swept area fished or by providing alternative escape routes.

A GUDP funded project, STEER (with the trawl door company MLD ApS), developed self-adjusting otter boards (SAO) for demersal fisheries, that can maintain a given distance above the seabed. The SAO have built-in altimeters and adjustable flaps that are controlled by an active Proportional-Integral-Derivative (PID) feedback system, which allows their position in the water column to be modified automatically by adjusting the flap openings via actuators, by comparing the altimeter data to a pre-set target height above the seabed during the fishing operation. Eighani et al. (2023) showed that when the target height was set at 1 m, the SAO contacted the seabed 16% of the time (at most), and that there was no seabed contact when the target height was set at 5 m. They also demonstrated that there were fuel savings of approximately 15%. Subsequent fishing trials in a demersal white fish fishery, demonstrated that raising otter boards off the seabed reduced the catches of haddock and whiting, however, this was not expected to affect the catches of species such as Norway lobster which are not herded by the doors and sweeps (Eighani et al., submitted).

Here we explore how these types of otter boards can be used to improve fuel efficiency, reduce seabed contact and reduce the bycatch of unwanted species while maintaining catches of target species in the Danish *Norway lobster* fishery.

To develop SAO for the Norway lobster fishery, MLD designed and manufactured otter boards that would be suitable for the slower speeds that Norway lobster trawls are usually towed. The design combines hydrodynamic and gravitational elements that ensures high steerability at low speeds and was verified in the flume tank in Hirtshals in June 2023. While the operation of these doors is based on many of the principles of the STEER doors, they also have innovative aspects and a patent application is in progress. In addition, the trawl doors were designed to be suitable for side hanging gallows (Fig. 5.6.1).

Figure 5.6.1. The prototype doors developed by MLD.

Trial 1 Havfisken: September 12th and 13th, 2023.
The prototype was installed successfully on the side of Havfisken, and the first test showed too much buoyancy which resulted in difficulties steering the doors down to the desired depth. Adjustments were made to reduce buoyancy, which allowed the doors to get to the target depth and spread the net as desired. However, there were still problems with the steerability, and it was concluded that some further design changes were needed that required structural modifications to the doors.

Trial 2 Havfisken: September 30th to October 2nd, 2023.
Following the first trial, the prototype was modified with improved steering capability and weight balance. Furthermore, the doors were fitted with adjustable front attachment points, allowing more rigging arrangements to be tested. While these modifications improved the original design, there were still problems. In particular, the spreading power of the doors was too large and the

doors were sensitive to changes of the water speed. Hence, given that there was still a need for further design development it was decided not to carry out the planned fishing trials.

Summary

While it was not possible to achieve the initial aim of carrying out fishing trials with the new doors, the developments were positive. The trials showed that the basic design principles were valid and are on the right track. There is a need to have better control of both the vertical and horizontal steering capability. The doors were also over-spreading, so it is likely that they could be made smaller, which would further reduce drag and improve fuel efficiency.

6. Discussion

Gears developed

A series of ideas on how to adjust catch composition with the aim of reducing bycatch while maintaining target species were presented to the project group. Following an evaluation of the concept and the fraction of the fleet that could benefit from the gear if it proves efficient, the large majority of these proceeded to further development and production at the netmaker. In some cases the concept had already been proven in other fisheries i.e. the T90 codend and was ready to move directly to a scientific trial. In other cases, the idea was novel and focus was therefore put on the development phase where the gear was tested in a commercial fishery, adjusted and tested again. When reaching catch / bycatch levels that reflected the expectations of the fisher, a period of self-sampling was initiated. Data from self-sampling is valuable when assessing the commercial potential of the gear and will justify a later scientific trial. Output of scientific trials are needed as input into the management system, where either their relative or absolute selectivity needs to be described. Due to the short life of the project, several trials are still ongoing and will require follow-up, especially the self-sampling trials where preliminary data have been collected.

Stakeholder engagement

One pillar of the project has been to develop and test fishing gears that could solve selective challenges in the Danish fishery. This was set up as a cooperation with the industry with an initial setup of the industry raising concerns or ideas that would highlight areas to focus on. Engagement of fishers throughout the project was therefore recognized as a central and important aspect in the project. However, getting input from the industry was more difficult than anticipated. Whether this was due to lack of time or low expectations to the chance that ideas could result in new gears being introduced in the fishery, is unknown.

DTU Aqua proposed a series of harbor meetings in the main fishing harbors throughout Denmark. This was met with hesitation from the PO's as they felt there would be limited participation from their members. The meetings were replaced with an article in Fiskeritidende, inviting fishers to come with ideas to improve the selectivity of their gears. This resulted in 4 incoming ideas which were included in the project. However, further ideas coming forward from the industry were lacking. The short duration of the project challenged the possibilities of conducting scientific trials at this late stage and it was decided to rethink the setup of trials; Ideas coming forward at this stage would need to be undertaken in a format, where participating fishers would be responsible for the collection of data following a self-sampling protocol. In total, 6 scientific trials and 6 commercial trials with self-sampling were conducted. On top of this, DTU Aqua organized a demonstration day in the flume tank in Hirtshals where 8 different gears were developed following a dialog with fishers, POs, and net makers. 50 participants from the industry participated and fishers in attendance were provided the opportunity to register their interest in testing the gears presented on the day.

Management system

The rigid EU fisheries management system makes it hard to address issues in the fisheries as they arise. For example, during the project's kick-off meeting participants were tasked with mapping the different steps in the gear development and approval process and the time required for each step. This showed that the gear development and implementation pipeline, from identification of the issue to potential introduction in regulation, takes between 2 and 3 years. Something which is far too long when considering the fluctuating nature of fish stocks, as has been the case for haddock in the Kattegat, where a large year class has entered the fishery and, to a high degree, been discarded as it hasn't been possible for fishers to implement selective improvement to their gears to avoid them. This rigidity means that the year class of haddock entering the fishery is decimated before actually being able to contribute to the spawning stock biomass and landings in the fishery.

Technology development

The technologies developed show promise in not only facilitating a reduction in catches of unwanted species but also improving catch rates of target species, reducing seabed impacts and carbon emissions, as well as improving the documentation of catches. This development is ongoing and will continue, for example, in both national and international projects.

7. Conclusions and recommendations for future work

The SELEKT project has served as a platform for gear development and testing as well as development of new technologies with application in Danish Fisheries. The tested gears showed promising results when it comes to reducing bycatches of different size groups of cod and other round fish. However, it has not been possible to have any of these implemented in legislation within the life of the project.

The long handling times required to have new gears implemented in legislation indicates that the framework needs to be revised. This could be, for example, by having the European Commission to give authority to regional groups (e.g. BALTFISH and the Scheveningen group) to implement gears, consequently expediting the process. Alternatively, ICES WGFTFB could take on a more proactive role when it comes to the approval process of having gears implemented. This could be in the form of a ToR at the annual meeting, where promising solutions are reviewed prior to being sent to STECF. A form of pre-approval process to make it easier for evaluation by STECF. A further alternative to expedite the use of more selective gears is through the use of electronic monitoring.

Electronic monitoring (EM), enables the registration of all fish caught, consequently rendering some details in the technical regulations unnecessary (van Helmond et al., 2019).

Certain aspects of the technical conservation measures are in place due to limitations in control and enforcement. Under the current regime, it is not possible to control all fishing events (Gullestad et al., 2015; Borges, 2021). Consequently, certain technical conservation measures aim to limit what can be extracted from the ecosystem. For example, the technical characteristics of fishing gears, aim to ensure that unwanted catches are limited. With an increase in digitalisation within control and enforcement, such as EM and the possibility to document entire catches, and not just landings, certain technical conservation measures could become less prescriptive, since what is of importance to management is knowing what is extracted from the available resources rather than the technical specifications of the gears used to fish those stocks and the subsequent catch compositions obtained. Therefore, the shift towards a more detailed control and enforcement can potentially facilitate a more flexible and simple management frameworks. However, for EM to be successful in helping to improve compliance and reporting of catches, incentives need to be provided that motivate fishers to take such technologies on board. Therefore, removing certain technical measures, such as the technical specifications of fishing gears, for fleet segments with EM will potentially incentivise fishers to take the technology on board, as they would be better able to tailor catch profiles to the quota combinations they have available. Tailoring of catch profiles to better match the quota combination available is something that can also be achieved through the adoption of real-time monitoring of catches.

Being able to observe what is entering the gear during fishing, and the subsequent catch rates and compositions, allows fishers to make informed decisions about the fishing process. For example, fishing could be ceased if catches of unwanted species, e.g. cod, are too high, or if catches of target species, e.g. Norway lobster, are too low. Such information can help to reduce the impact fishing has on the marine environment by reducing unnecessary seabed impact and carbon emissions, as well as improving the economy in the fishery. Supporting the adoption of such technologies by the fishing industry will help move fisheries in a more sustainable direction.

Danish fisheries, especially trawl fishing, are facing perhaps the most significant change in their history. A future-proof and viable fishing industry must be both ecologically and economically sustainable. This can be achieved through the development of more efficient, precise, gentle, and controlled fishing. The development of selective, gentle, and fuel-efficient fishing gear, along with new technologies, including the digitization of the fishing process, can largely address the challenges faced by Danish fisheries today. However, a national focus on this development, including a clear national plan, is crucial for its success and the extent of its development over time.

References

Avsar, E., Feekings, J. P., & Krag, L. A. (2023). Estimating catch rates in real time: Development of a deep learning based Nephrops (Nephrops norvegicus) counter for demersal trawl fisheries. *Frontiers in Marine Science*, *10*, 1129852.(https://www.frontiersin.org/articles/10.3389/fmars.2023.1129852/full)

Bak-Jensen, Zita, et al. "Fixed mesh shape reduces variability in codend size selection." *Canadian Journal of Fisheries and Aquatic Sciences* 79.11 (2022): 1820-1829. (https://cdnsciencepub.com/doi/pdf/10.1139/cjfas-2022-0049)

Bak-Jensen, Z., Herrmann, B., Santos, J., Melli, V., Stepputtis, D., & Feekings, J. P. (2023). The capability of square-meshes and fixed-shape meshes to control codend size selection. *Fisheries Research*, *264*, 106704. (https://www.sciencedirect.com/science/article/pii/S0165783623000978)

ICES (2023). Baltic Fisheries Assessment Working Group (WGBFAS). ICES Scientific Reports. Report. https://doi.org/10.17895/ices.pub.23123768.v1

Karlsen, Junita D., et al. "One Mesh Does Not Fit All: A Dual Compartment Codend Provides Flexible Selectivity Opportunities to Manage Mixed Fisheries." Ocean and Coastal Management, vol. 247, Elsevier Ltd, 2024, p. 106890

Krag, L.K., Savina, E., Lyngby, M.S. & Frandsen, R. (2023). Real-time camera observation in the trawl fisheries (Technofish). Final report. DTU Aqua Report no. 421-2023. National Institute of Aquatic Resources, Technical University of Denmark, 29 pp.

Palder, O.J., Feekings, J.P., Fraser, S., & Melli, V. (2023). Approaching single-species exclusion in mixed demersal trawl fisheries. *Ocean & Coastal Management*.

Sokolova, M., O'Neill, F.G., Savina, E., Krag, L.A. (2022). Test and development of a sediment suppressing system for catch monitoring in demersal trawls. Fisheries Research 251, 106323. https://doi.org/10.1016/j.fishres.2022.106323.

Sokolova, M., Thompson, F., Mariani, P., Krag, L.A. (2021). Towards sustainable demersal fisheries: NepCon image acquisition system for automatic Nephrops norvegicus detection. PLoS ONE 16. https://doi.org/10.1371/journal.pone.0252824.

Stepputtis, D., Santos, J., Zimmermann, C., (2020) Technical approaches to avoid cod catches in Baltic Sea trawl fisheries. Thünen Institute of Baltic Sea Fisheries, Rostock, Germany 37 pp

Svantemann, M. M., Savina, E., Krag, L. A. (Submitted). Improving escape efficiency in selective devices with the use of a dark tunnel. *Canadian Journal of Fisheries and Aquatic Sciences.*

van Helmond, A.T.M., Mortensen, L.O., Plet-Hansen, K.S., Ulrich, C., Needle, C.L., Oesterwind, D., Kindt-Larsen, L., Catchpole, T., Mangi, S., Zimmermann, C., Olesen, H.J., Bailey, N., Bergsson, H., Dalskov, J., Elson, J., Hosken, M., Peterson, L., McElderry, H., Ruiz, J., Pierre, J.P., Dykstra, C., Poos, J.J. (2020). Electronic monitoring in fisheries: Lessons from global experiences and future opportunities. Fish and Fisheries 21, 162–189. https://doi.org/10.1111/faf.12425.

Annexes

Annex 1: Twelve factsheets on gear developments

Annex 2: Six factsheets on technological developments

Annex 3: Laboratory report on experiments with tracking fish using acoustics

Annex 4: Scientific publications

Annex 5: Potential of fully digitalized fisheries for fisheries management

Annex 1. Twelve factsheets on gear developments

1A: Large meshes (800 mm) in the upper panel of a trawl to reduce catches of cod in a flatfish fishery

1B: Size selectivity for plaice (*Pleuronectes platessa*) in a 110 mm codend + SELTRA 300 for a vessel below 10 m in Kattegat

1C: Large diamond opening as an alternative to SELTRA 300

1D: Compare the selectivity of Roofless to the large meshes (800 mm) in the upper panel of the trawl

1E: A bottom escape window outperform the SELTRA270 in the *Nephrops*-directed fishery

1F: Two-codend Excluder for the Nephrops directed mixed fishery

1G: Improving escape efficiency in selective devices with the use of a dark tunnel

1H: 120 mm T90 codend in the Danish Anchor Seine Fishery

1I: Does the real-time observation set-up affects catch efficiency?

1J: Comparing 120 mm T90 vs. T0 Diamond Mesh Codends in Skagerrak and the North Sea

1K: Comparing a 120 mm T90 codend vs. a 105 mm diamond mesh with a 140 mm SMP codend

1L: Large mesh panel in the trawl's upper section to reduce fish bycatch in the brown shrimp fishery

Large meshes (800 mm) in the upper panel of a trawl to reduce catches of cod in a flatfish fishery

AIM
Reduce catches of cod while retaining commercially important flatfish species

TARGET SPECIES
Plaice (*Pleuronectes platessa*)
Flounder (*Platichthys flesus*)
Dab (*Limanda limanda*)
Cod (*Gadus morhua*)

AREA, VESSEL
Baltic Sea (ICES subdivision 22)
Stern trawler (17 m, 221 kW)

GEAR TRIALS
Two trawls were fished in parallel for a month in March and April 2023. Both trawls were mounted with BACOMA 120 mm codends. One of the trawls had a section of large meshes (800 mm) mounted in the upper panel of the trawl. Data were collected by the crew on the vessel.

RESULTS
Catches of cod during the trial were low (752 kg), counting for only 3.6 % of total catches. When fishing with large meshes in the upper panel, cod catches were reduced by 38 % while catches of flatfish were reduce by 9-11 %.

Species	Weight <MCRS Test	Weight >MCRS Test	Weight <MCRS Bacoma	Weight >MCRS Bacoma	Total weight/ species	Reduction Total	Reduction <MCRS	Reduction >MCRS
Cod	0	288	1	463	752	38%	100%	38%
Dab	307	681	386	768	2142	14%	20%	11%
Flounder	99	1639	106	1840	3684	11%	7%	11%
Plaice	1063	5415	1197	5935	13610	9%	11%	9%
Total	1469	8023	1690	9006	20188	11%	13%	11%

FURTHER INFORMATION
Jordan Feekings (jpfe@aqua.dtu.dk)

SKIPPERS COMMENTS
The trawl worked well under fishery and resulted in a clean flatfish fishery

DTU
European Union
European Maritime and Fisheries Fund
HAV & FISK

Annex 1A

Size selectivity for plaice (*Pleuronectes platessa*) in a 110 mm codend + SELTRA 300 for a vessel below 10 m in Kattegat

AIM

Estimate the size selectivity for plaice (*Pleuronectes platessa*) in a 110 mm codend with mandatory SELTRA 300 panel in Kattegat for a vessel under 10 m.

AREA, VESSEL

Kattegat, commercial 1-man trawler (<10 m) targeting plaice with a single otter trawl

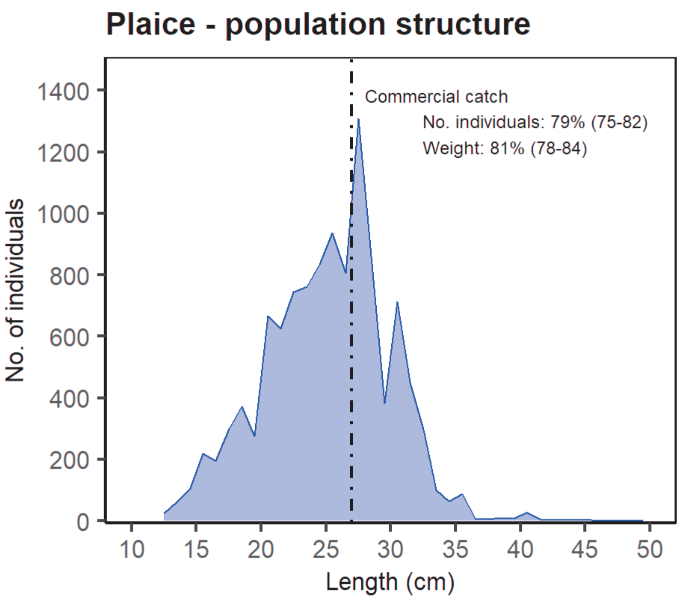
TRIAL DESCRIPTION

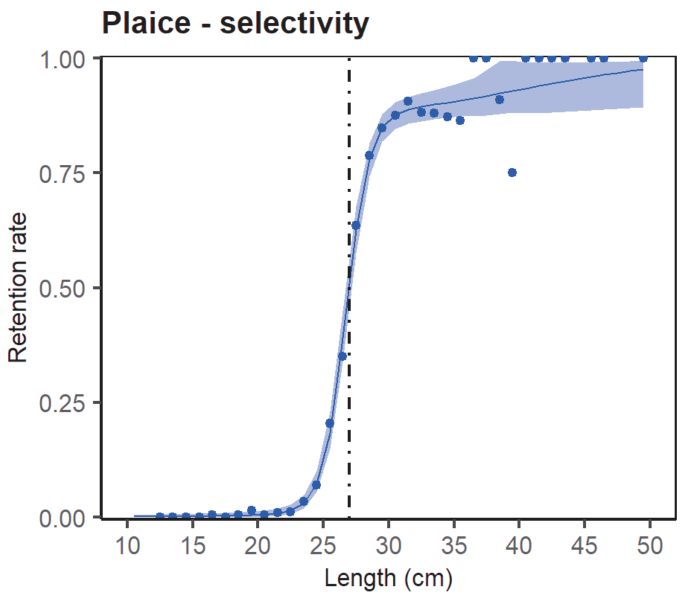
The covered codend method was used to estimate absolute selectivity for plaice with participation from DTU Aqua onboard

RESULTS

A strong dataset containing 20 hauls and a high number of individuals in the selective area of the tested codend + SELTRA 300 was collected.

The selection curve shows that some losses of marketable catch (MCRS > 27 cm) occur due to the codend mesh size (110 mm) but additional losses of plaice above 30 cm can be attributed to the SELTRA 300 panel. In total, the gear lost on average 21% and 19% of the target catch, in number of individuals and weight, respectively.





CONCLUSION

There was an observed loss of about 20% for marketable sized plaice in the tested gear. A proportion of the observed loss occurred through the SELTRA 300 panel.

FURTHER INFORMATION

Ludvig Krag (lak@aqua.dtu.dk); Valentina Melli (vmel@aqua.dtu.dk)

DTU

European Union
European Maritime and Fisheries Fund

HAV & FISK

Annex 1B

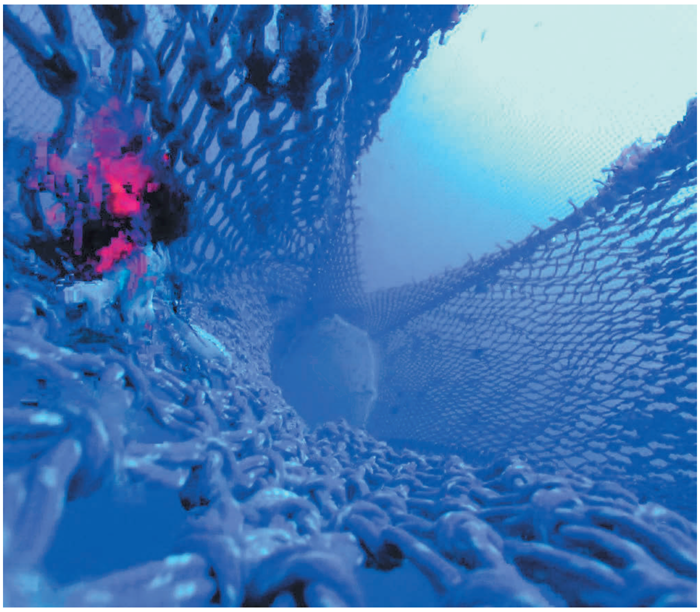
Large diamond opening as an alternative to SELTRA 300

AIM
Reduce catches of cod and haddock while retaining commercially important flatfish species and Norway lobster

TARGET SPECIES
Cod (*Gadus morhua*)
Haddock (*Melanogrammus aeglefinus*)
Norway lobster *(Nephrops norvegicus)*
Plaice (*Pleuronectes platessa*)
Whiting (*Merlangius merlangius*)

AREA, VESSEL
Kattegat (ICES subdivision 21)
Stern trawler (16 m, 128 kW)

GEAR TRIALS
Two trawls were fished in parallel for a month in September and October 2023. One of the trawls was mounted with a SELTRA 300 codend while the other was mounted with a large diamond opening. Data were collected by the crew on the vessel.



RESULTS
Catches of cod were lower in the diamond codend than the SELTRA 300. However, catches were low (31 kg), counting for only 1.5 % of total catches. Catches of haddock accounted for 14 % of total catches and were slightly higher in the diamond codend (18 %). Catches of plaice and Norway lobster were similar in both codends.

Species	Weight <MCRS SELTRA 300	Weight <MCRS Diamond	Weight >MCRS SELTRA 300	Weight >MCRS Diamond	Total weight SELTRA 300	Total weight Diamond	Reduction Total	Reduction <MCRS	Reduction >MCRS
Cod	17,1	13,9			17,1	13,9	-19	-19	
Haddock	137	161			137	161	18	18	
Nephrops	457	468	867	910	1324	1378	4	2	5
Plaice	259	261			259	261	1	1	
Whiting	172	136			172	136	-21	-21	
Total	1042,1	1039,9	867	910	2390,1	2535,9	6	0	5

FURTHER INFORMATION
Jordan Feekings (jpfe@aqua.dtu.dk)

SKIPPERS COMMENTS
Little to no improvement in catches were observed.

Compare the selectivity of Roofless to the large meshes (800 mm) in the upper panel of the trawl

AIM
Reduce catches of cod while retaining commercially important flatfish species

TARGET SPECIES
Plaice (*Pleuronectes platessa*)
Flounder (*Platichthys flesus*)
Dab (*Limanda limanda*)
Cod (*Gadus morhua*)

AREA, VESSEL
Baltic Sea (ICES subdivision 24)
Stern trawler (17 m, 221 kW)

GEAR TRIALS
Two trawls were fished in parallel for a month in October 2023. Both trawls were mounted with BACOMA 120 mm codends. One of the trawls had a section of large meshes (800 mm) mounted in the upper panel of the trawl and the other had Roofless mounted in the extension piece. Data were collected by the crew on the vessel.

RESULTS
When fishing with Roofless, cod catches were reduced by 52 % when compared to the large mesh panel. However, catches of cod during the trial were low (156 kg), counting for only 1.1 % of total catches. For flatfish, catches were reduced by 10 - 26 % (10 % for flounder, 17 % for plaice and 26 % for dab).

Species	Weight <MCRS Bacoma 120 + 800 mm in the upper panel	Weight >MCRS Bacoma 120 + 800 mm in the upper panel	Weight <MCRS Bacoma 120 + Roofless	Weight >MCRS Bacoma 120 + Roofless	Total weight/ species	Reduction total	Reduction <MCRS	Reduction >MCRS
Cod	32	74	5	46	156	52%	84%	39%
Dab	5	228	4	169	405	26%	20%	26%
Flounder	127	2280	108	2060	4575	10%	15%	10%
Plaice	1195	3739	886	3222	9042	17%	26%	14%
Total	1359	6321	1003	5496	14178	15%	26%	13%

FURTHER INFORMATION
Jordan Feekings (jpfe@aqua.dtu.dk)

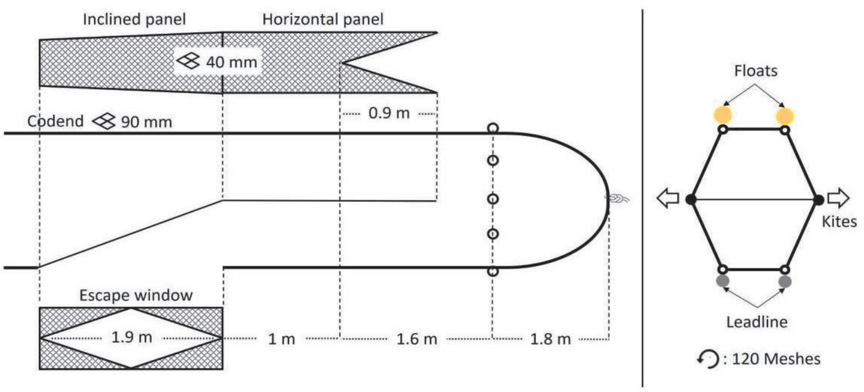
SKIPPERS COMMENTS
The trawl worked well under fishery and resulted in a clean flatfish fishery

DTU
HAV & FISK
European Union
European Maritime and Fisheries Fund

A bottom escape window outperform the SELTRA270 in the *Nephrops*-directed fishery

AIM

To avoid cod (*Gadus morhua*) catches while retaining other valuable target species like *Nephrops* (*Nephrops norvegicus*), plaice (*Pleuronectes platessa*) and haddock (*Melanogrammus aeglefinus*).

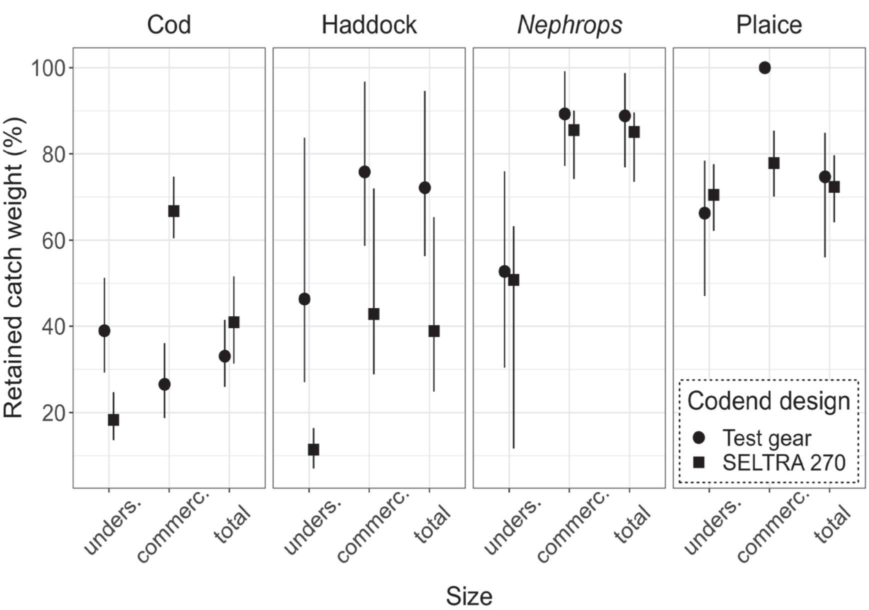


AREA, FISHERY

Skagerrak *Nephrops*-directed fishery with mixed demersal fish.

TRIAL DESCRIPTION

21 hauls (June 2022) onboard R/V Havfisken equipped with twin-rigged Combi trawls, one with the bottom escape window (Test gear) and one with a non-selective codend (Control)



RESULTS

The bottom escape window achieved the desired objective, with cod being the only species consistently escaping though the opening. The effect was length-dependent with higher escape rate for larger cod.

When comparing the performance of the bottom escape window with previous data from the SELTRA270, the most used legal gear in the fishery, the results show higher retention of commercial plaice (100%) and haddock (76%), as well as equal retention of *Nephrops*.

CONCLUSION

The design was a prototype adapted from a similar concept tested in the Shetland's whitefish fishery. The promising performance warrant further developments of the design, to simplify it and facilitate its commercial implementation.

FURTHER INFORMATION

Valentina Melli (vmel@aqua.dtu.dk)

Link to scientific publication: https://doi.org/10.1016/j.ocecoaman.2023.106672

DTU

European Union European Maritime and Fisheries Fund

HAV & FISK

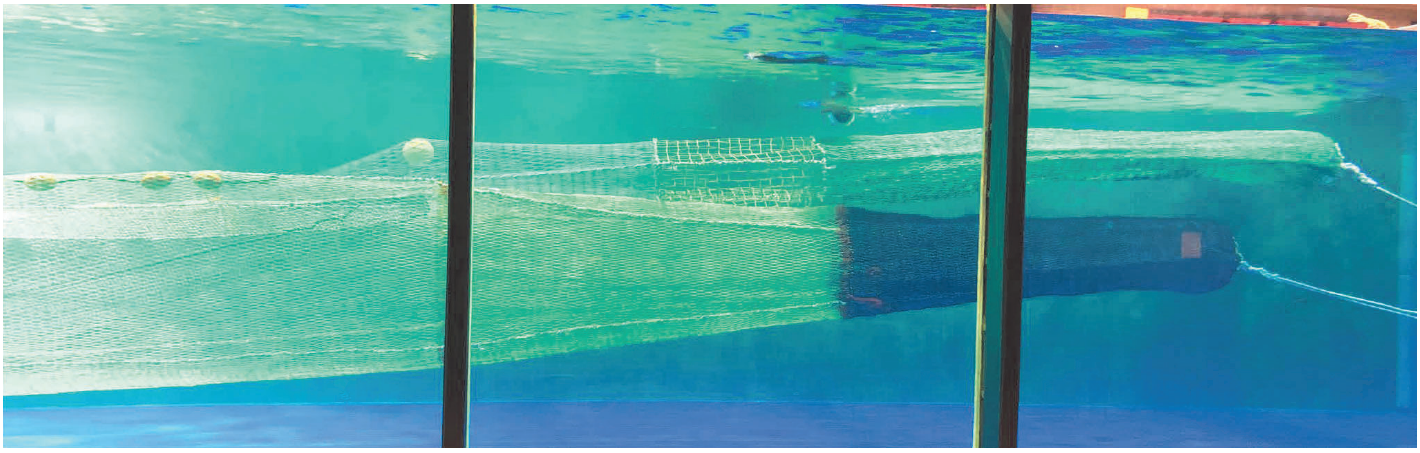
Annex 1E

Two-codend Excluder for the Nephrops directed mixed fishery

AIM
Improve the sizes selectivity for fish in the *Nephrops (Nephrops norvegicus)* directed demersal trawl fishery in Skagerrak using TORMO Trawl's newly developed two-codend Excluder.

AREA, VESSEL
Experimental fishing is conducted in Skagerrak. The vessel is operating a twin-trawl system where two similar trawls are towed in parallel.

TRIAL DESCRIPTION
The two-codend Excluder is tested in a catch comparison experiment onboard a 23.9 m trawler. The Excluder is tested against a 90mm codend with a mandatory SELTRA panel. The Excluder separate the catch of *Nephrops* from the catch of fish into two codends with different mesh sizes (90mm and 120mm)



RESULTS
The trial is ongoing but initial results *indicate*:

- **No loss of *Nephrops***
- **30-60% reduction in of round-fish (haddock, whiting and cod)**
- **Good separation between fish and *Nephrops***
- **Improved quality of the fish caught**

CONCLUSION
Based on the initial results on the Excluders selective performance and the increased quality of the catch, other vessels in the *Nephrops* directed fishery have shown interest in using the Excluder in Skagerrak.

FURTHER INFORMATION
Ludvig Krag (lak@aqua.dtu.dk)

Annex 1F

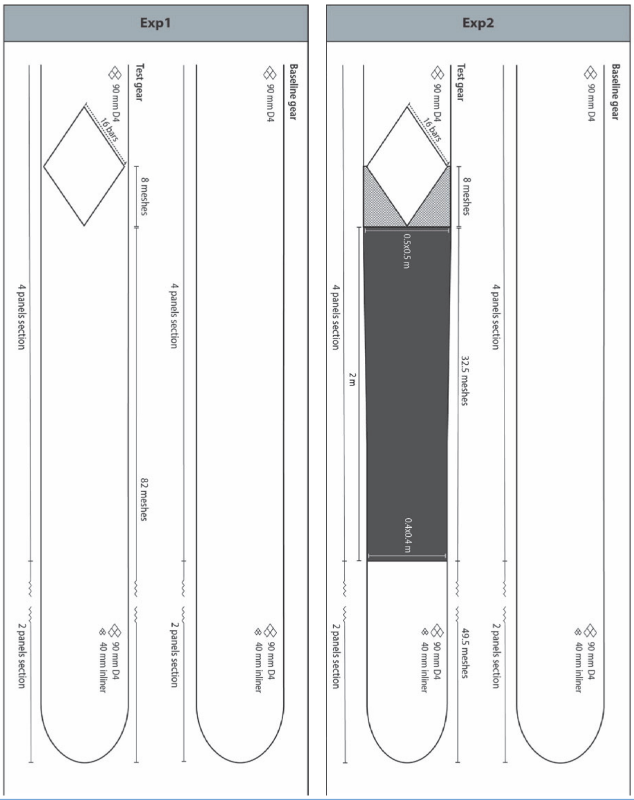
Improving escape efficiency in selective devices with the use of a dark tunnel

AIM
To explore the selective potential of a large escape opening placed in the aft of the trawl (Exp1), and whether the addition of a dark tunnel behind the escape opening can increase the escape efficiency of fish by triggering a station-holding behavior (Exp2).

RESEARCH SPECIES
Atlantic cod (*Gadus morhua)*, haddock (*Melanogrammus aeglefinus*), witch flounder (*Glyptocephalus cynoglossus*), and *Nephrops* (*Nephrops norvegicus*)

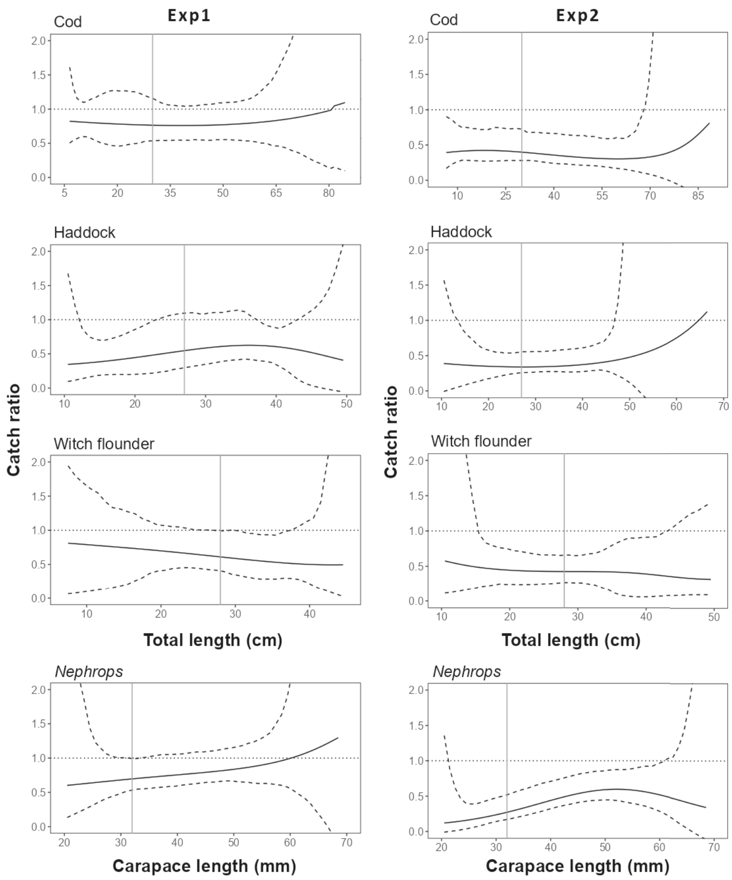
AREA, VESSEL
Kattegat and Skagerrak (ICES Division III)
RV Havfisken (17 m LOA, 373 kW)

FURTHER INFORMATION
Mette M. Svantemann (msvly@aqua.dtu.dk)



METHOD
The modified gears (test) were compared to a standard gear (baseline) in a twin-rig setting and the collected data analysed using the catch comparison approach.

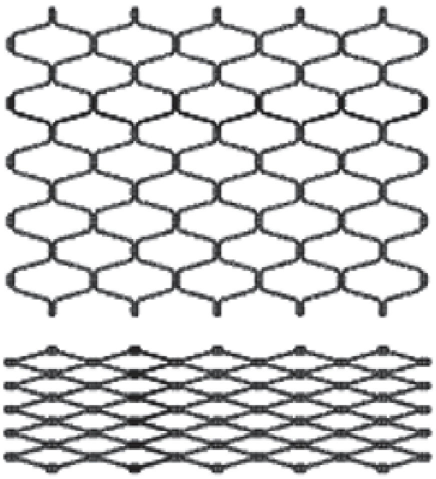
RESULTS
The results showed limited escapement through the large escape opening. However, escapement was significant for narrow length ranges of some species. Adding the black tunnel significantly increased the escapement for all analysed species, with escapement up to 70 (40-83)% for roundfish and 63 (8-93)% for flatfish. A loss of *Nephrops* up to 85 (60-96)% highlighted the importance of optimising the integration of the dark tunnel in demersal trawls.



Annex 1G

120 mm T90 codend in the Danish Anchor Seine Fishery

AIM
Reduce catch of smaller sizes of haddock (*Melanogramus aeglefinus*) while maintaining catch of plaice (*Pleuronectes platessa*) in the Danish Anchor seine fishery in Skagerrak.



AREA, VESSEL
19 m Danish Anchor seine vessel (218 kw) operating in Skagerrak.

TRIAL DESCRIPTION
The experimental 120mm T90 codend was compared with a legal 120mm diamond codend. The T90 codend was constructed following the specifications in the technical legislation given for the Baltic Sea.
Due to the nature of Danish seining, the two codends were fished alternately. Catches in the different codends are therefore not necessarily fished on the same population structure and therefore not directly comparable.
Catch data was collected by the crew onboard the fishing vessel.

RESULTS
A total of 48 tows were made, 14 with the 120mm diamond codend and 34 with 120mm T90 codend.

According to the Skipper of the vessel, the 120mm T90 codend efficiently removes the catch of smaller round-fish and in particular haddock while improving the retention on the smaller sizes of marketable plaice.

CONCLUSION
The tested 120mm T90 codend is today a legal gear in the Baltic Sea to improve the sizes selectivity of cod.

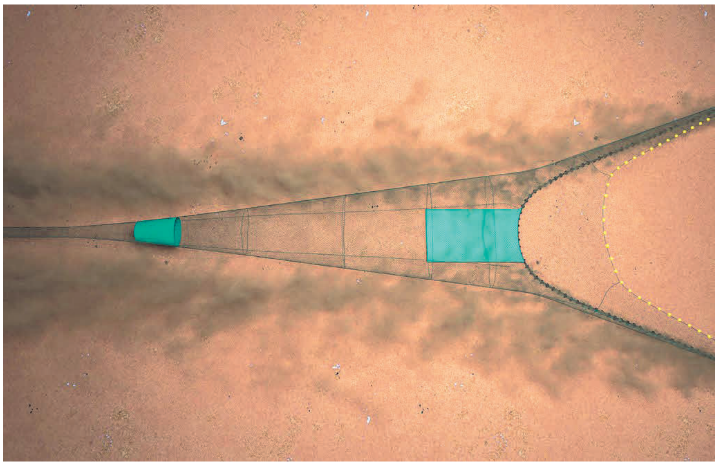
FURTHER INFORMATION
Ludvig Krag (lak@aqua.dtu.dk)

European Union
European Maritime and Fisheries Fund
HAV & FISK

Does the real-time observation set-up affects catch efficiency?

AIM

To investigate if the set-up developed in SMARTFISH for real-time observations of catches, has an effect on the catch efficiency of the trawl.
The set-up includes a sediment suppressor sheet in the forward part of the trawl and a 2-m long observation section, both made of tarpaulin material. The camera is cable-connected to the vessel.

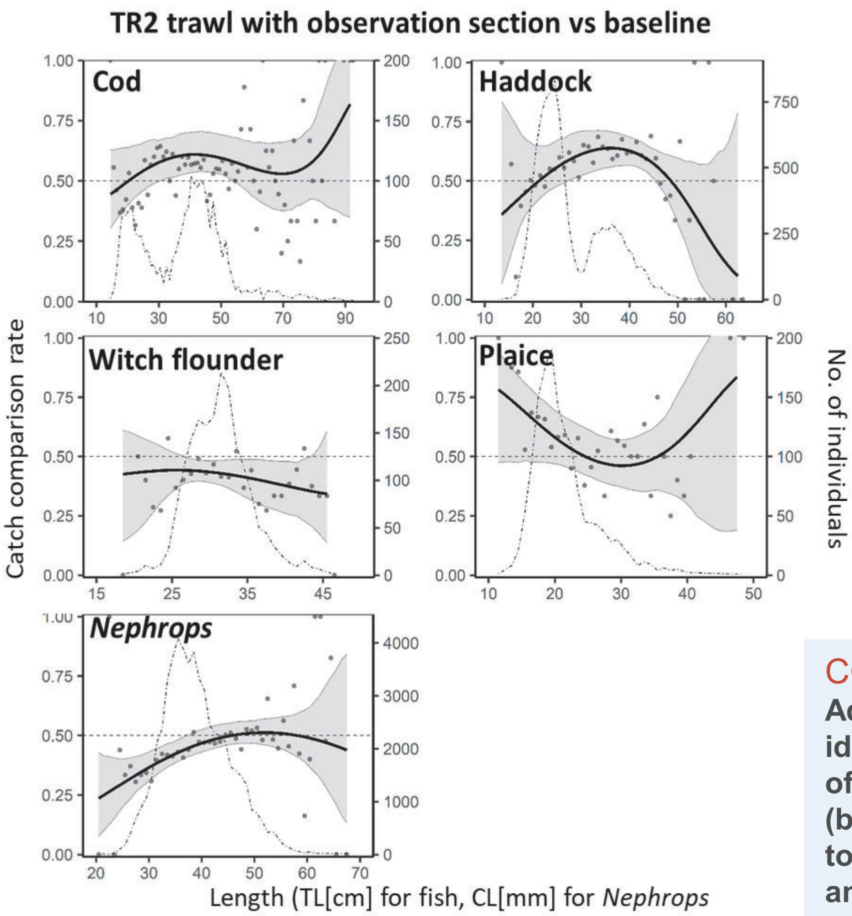


AREA, VESSEL

Skagerrak, commercial trawler targeting *Nephrops* (*Neprops norvegicus*) and mixed demersal fish.

TRIAL DESCRIPTION

12 hauls (May 2023) with twin-rigged Combi trawls with SELTRA panel (200 mm, square) and 90 mm diamond, double 4 PE codends.



RESULTS

We observed an increase in catch efficiency for commercial cod (Gadus morhua) and haddock (Melanogrammus aeglefinus); consistent with previous observation of higher headline height caused by the camera's cable.
There was no effect on plaice (Pleuronectes platessa) but partial loss of witch flounder (Glyptocephalus cynoglossus) and loss of *Nephrops* up to 39 mm CL.
These results are consistent with observations of catch accumulation ahead of the observation section.

CONCLUSION

Additional developments required to identify optimal rigging and handling of the real-time observation set-up (both cable and observation section) to prevent changes in gear geometry and catch accumulation ahead of the tarpaulin section.

FURTHER INFORMATION

Valentina Melli (vmel@aqua.dtu.dk); Mette Svantemann (msvly@aqua.dtu.dk)

DTU
European Union
European Maritime and Fisheries Fund
HAV & FISK

Comparing 120 mm T90 vs. T0 Diamond Mesh Codends in Skagerrak and the North Sea

AIM
Document the effect on catch efficiency for different fish species of turning the mesh orientation in the codend by 90° (T90).

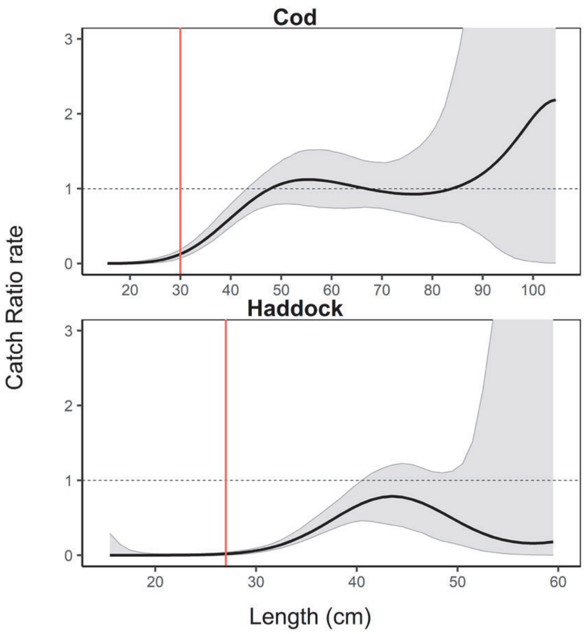
AREA, VESSEL
Skagerrak and North Sea; commercial trawler targeting demersal fish (17 m, 224 kW)

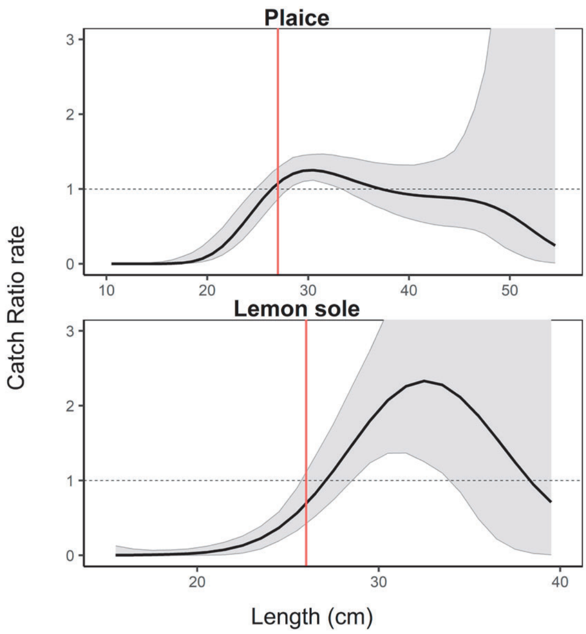
TARGET SPECIES
Cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), plaice (*Pleuronectes platessa*) and lemon sole (*Microstomus kitt*).

RESULTS
For all 4 species investigated, using T90 meshes reduced the catch efficiency for lengths under MCRS (red vertical line). For cod and haddock, a loss was found for individuals below 43 and 40 cm, respectively. For flatfish, a moderate increase of catch for some length classes of the smaller commercial sizes was also found.

GEAR TRIALS
Two identical codends differing only on the orientation of the meshes (T90 vs T0) were compared in a twin-rig setting and the collected data analysed using the catch comparison approach.

FURTHER INFORMATION
Tiago Malta (timat@aqua.dtu.dk)





Comparing a 120 mm T90 codend vs. a 105 mm diamond mesh with a 140 mm SMP codend

AIM

Compare catch efficiency of a T90 codend with 120 mm mesh (top) against the currently standard codend used with 105 mm diamond mesh with a 140 mm square mesh panel (bottom).

TARGET SPECIES

Cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), plaice (*Pleuronectes platessa*) and lemon sole (*Microstomus kitt*).

AREA, VESSEL

Skagerrak and North Sea; commercial trawler targeting demersal fish (17 m, 224 kW)

GEAR TRIALS

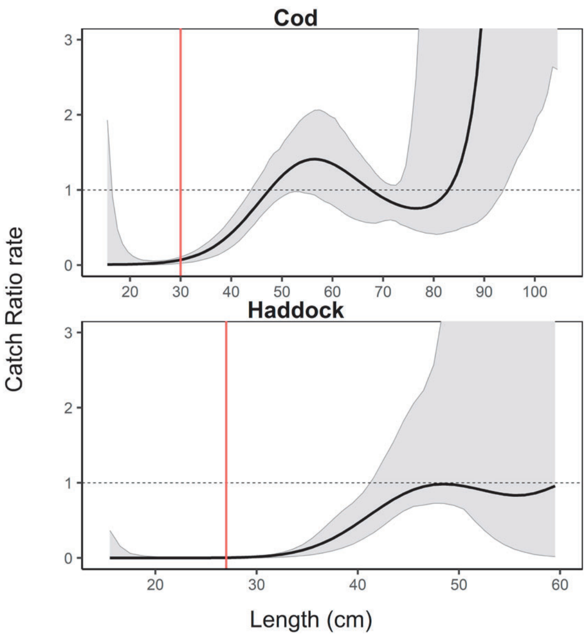
The two codends described in the aim section were compared in a twin-rig setting and the collected data analysed using the catch comparison approach.

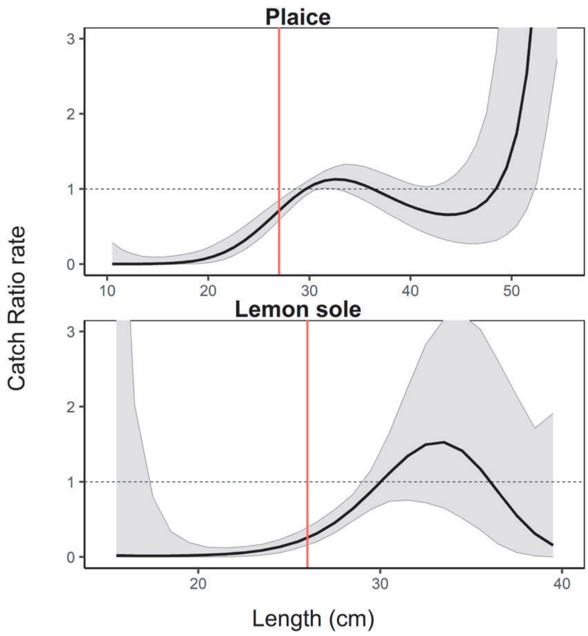
RESULTS

When compared to the standard codend, the T90 caught significantly less fish below MCRS for all species. A loss of small marketable fish was found for cod (30-43 cm), haddock (28-40 cm), plaice (27-28 cm) and lemon sole (26-28 cm). No difference in catch efficiency was found for the larger commercial-sized individuals.

FURTHER INFORMATION

Tiago Malta (timat@aqua.dtu.dk)





DTU

HAV & FISK

European Union
European Maritime and Fisheries Fund

Annex 1K

Large mesh panel in the trawl's upper section to reduce fish bycatch in the brown shrimp fishery

AIM

Use of a top panel with large meshes in the trawl mouth to reduce bycatch of small pelagic species while maintaining catch efficiency for brown shrimp. A secondary aim was to reduce hydrodynamic drag of the gear to reduce fuel consumption.

TARGET SPECIES

Brown shrimp (*Crangon crangon*)

AREA, VESSEL

North Sea (ICES area IVb) coastal area outside Thyborøn and northwest of Esbjerg; commercial beam trawler with two 10 m beams (22 m, 121 kW)

FURTHER INFORMATION

Tiago Malta (timat@aqua.dtu.dk)

GEAR TRIALS

Catch comparison of a standard trawl vs a trawl with a large mesh (200 mm) panel on the upper panel of the trawl mouth. In 29 hauls data on total catch, sorting time, amount of bycatch and total weight of cooked shrimp was collected by the skipper of the vessel as self-sampling data.

RESULTS

Preliminary results found no significant difference in terms of total catch, weight of cooked shrimp, sorting time and fish bycatch, although for bycatch, larger reductions were observed when larger amounts of herring, sprat or whiting were encountered by the gear. Further analyses need to be conducted on these data.

Effect of panel on (%):

	Total catch	Cooked shrimp	Bycatch	Sorting time
Average	-7,51	1,74	-19,61	-15,22
(±SD)	±11,65	±18,03	±38,83	±10,07

SKIPPERS COMMENTS

The skipper is happy with the gear, he believes the panel will not lead to any significant loss of brown shrimp, while it will reduce the fuel consumption due to drag and sorting time reduction.

Annex 2. Six factsheets on technological developments

2A: Fixed mesh shape reduces variability in codend size selection

2B: Size selectivity trawl codends fishing for flatfish

2C: Species selectivity and biodiversity measures in a Baltic trawl fishery

2D: A new tool for mitigation of bycatch and choke-species levels in demersal trawl fisheries through machine learning-based detection and tracking

2E: Using allometric relationships for total length prediction of Atlantic cod in EM videos

2F: Robustness of allometric relationships across different populations of Atlantic cod

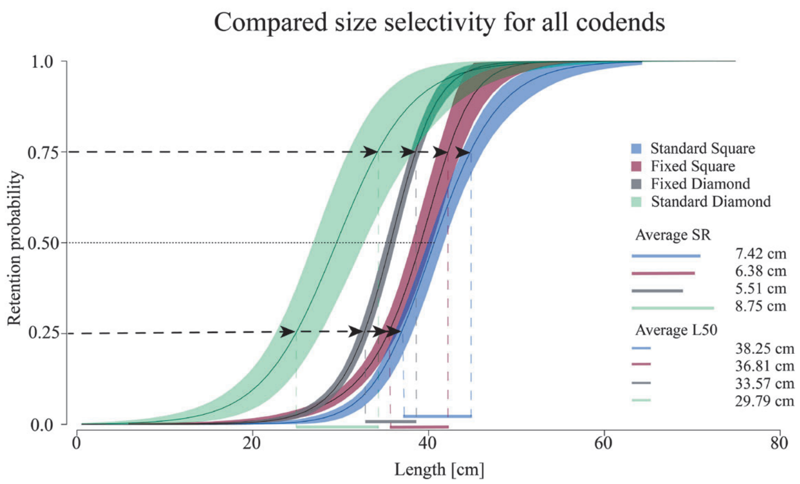
Fixed mesh shape reduces variability in codend size selection

AIM
To investigate the impact of variation of opening angle in meshes on the selectivity of cod (*Gadus morhua*) in the search for a sharper discrimination of sizes.




AREA, FISHERY, TIME
Baltic Sea
Flatfish-directed fishery with mixed demersal fish.
September 2021 and June 2022

TRIAL DESCRIPTION
56 hauls onboard the German vessel *R/V Solea* equipped with a TV300/60 bottom trawl, using the covered-codend method. A total of 4 110 mm codends were tested where three were fixed in mesh openness 60° and 90°, respectively, and the last two were a standard diamond-mesh and square-mesh codend.



RESULTS
Using Atlantic cod (Gadus morhua) as a case study, we demonstrated that the codends with fixed mesh codends have significantly sharper discrimination of sizes compared to the standard diamond-mesh codend. In comparison with the standard square mesh codend the fixed codends were also sharper in discrimination of size, however, not significantly for the fixed square mesh.

CONCLUSION
Though the codends tested have no commercial application, the outcome confirms theoretical predictions and may guide research toward codend designs with more well-defined size selection properties.

FURTHER INFORMATION
Zita Bak-Jensen (zitba@aqua.dtu.dk)
Link to scientific publication: https://doi.org/10.1139/cjfas-2022-0049
https://doi.org/10.1016/j.fishres.2023.106704

DTU

European Union
European Maritime and Fisheries Fund

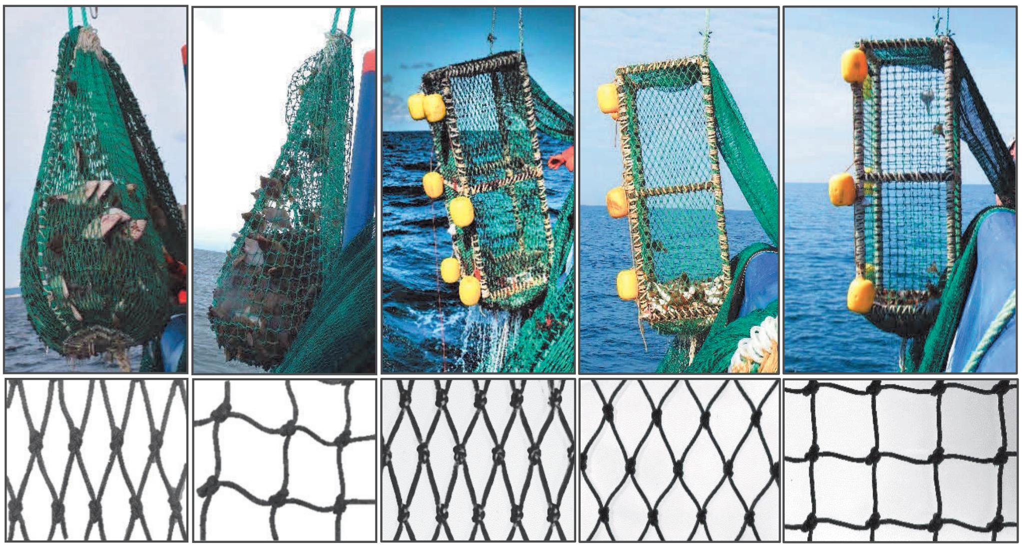
HAV & FISK

Annex 2A

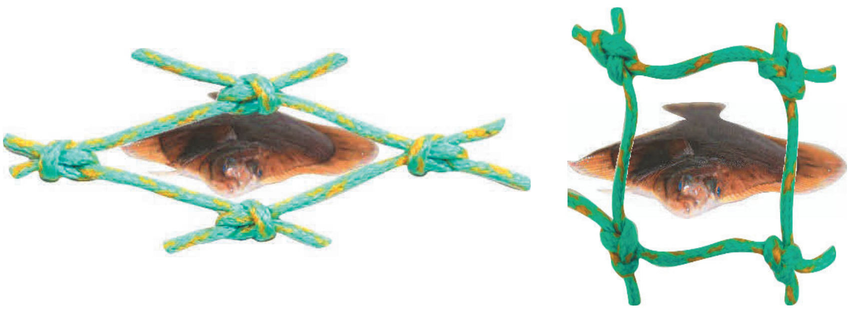
Size selectivity trawl codends
Flatfish

AIM
To investigate the size selectivity of flatfish and how it is affected by mesh shape and openness.

AREA, FISHERY, TIME
Baltic Sea
Flatfish-directed fishery with mixed demersal fish. September 2021 and June 2022



TRIAL DESCRIPTION
94 hauls onboard the German vessel *R/V Solea* equipped with a TV300/60 bottom trawl, using the covered-codend method. Three codends were tested where meshes were fixed 40°, 60° and 90° configuration. For comparison, a standard diamond mesh and a square mesh codend were tested too.



RESULTS
The most accurate size selectivity was found with fixed mesh geometry, indicating that variability in mesh openness affects the selectivity of flatfish.

Our results further demonstrated that the retention risk for undersized flatfish tends to increase with increasing mesh opening angle in diamond-mesh codends.

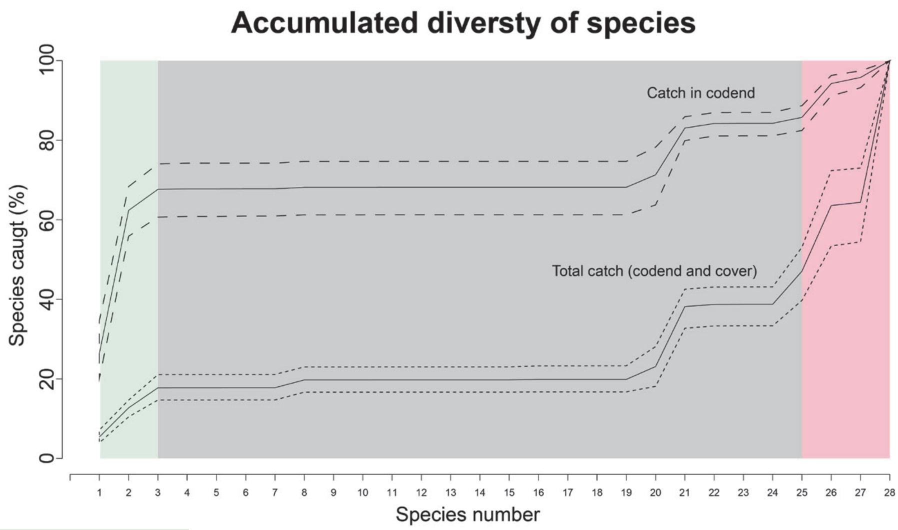
CONCLUSION
The results shows an increasing retention probability with higher opening angle, this means that a square-mesh would be good for retaining flatfish but would release large roundfish like Atlantic cod.

FURTHER INFORMATION
Zita Bak-Jensen (zitba@aqua.dtu.dk)

Species selectivity and biodiversity measures in a Baltic trawl fishery

AIM

To investigate the effect of bottom trawling in Baltic Sea on the species community by counting not only species of interest but <u>all</u> species being retained or released during fishing.



Index	Common Name	Latin
S1	Plaice above MLS	Pleuronectes platessa
S2	Flounder above MLS	Platichthys flesus
S3	Dab	Limanda limanda
S4	Turbot	Scophthalmus maximus
S5	Brill	Scophthalmus rhombus
S6	Sole	Solea solea
S7	Ameriacn Plaice	Hippoglossoides platessoides
S8	Hering/Sprat	Clupeidae
S9	Common mackerel	Scomber scombrus
S10	Haddock	Melanogrammus aeglefinus
S11	Lumpsucker	Cyclopterus lumpus
S12	Twait Shad	Alosa fallax
S13	Grey gurnard	Eutrigla gurnardus
S14	European eelpout	Zoarces viviparus
S15	Hooknose	Agonus cataphractus
S16	Scorpius	Myoxocephalus scorpius
S17	long-spined sea-scorpion	Taurulus bubalis
S18	Four-bearded rockling	Rhinonemus cimbrius
S19	Gobiidae	Gobiidae
S20	Common Jellyfish	Aurelia aurita
S21	Mussels	Bivalia
S22	Seastars	Asterias
S23	Crab	Brachyura
S24	Swimming crab	Portunidae
S25	Whiting	Merlangius merlangus
S26	Plaice under MLS	Pleuronectes platessa
S27	Flounder under MLS	Platichthys flesus
S28	Cod	Gadus morhua

TRIAL DESCRIPTION

39 hauls onboard the German vessel *R/V Solea* equipped with a TV300/60 bottom trawl, using the covered-codend method. A 140mm codend was tested where meshes were fixed in square configuration.

AREA, FISHERY, TIME

Baltic Sea
Flatfish-directed fishery with mixed demersal fish. June 2023

RESULTS

The species counts for the fixed 140mm square mesh showed release of unwanted catch of unwanted species (colored red) while retaining the target species (green).

CONCLUSION

Further conclusions will follow as the remaining analysis is finalized.

FURTHER INFORMATION

Zita Bak-Jensen (zitba@aqua.dtu.dk)

DTU

European Union
European Maritime and Fisheries Fund

HAV & FISK

Annex 2C

A new tool for mitigation of bycatch and choke-species levels in demersal trawl fisheries through machine learning-based detection and tracking

AIM

To provide fishers with a new technology-based solution for mitigating bycatch levels in demersal trawl fisheries and to improve the sustainable of such practices.

We have developed and tested a bycatch detector, i.e., cod-detector, in the *Nephrops* (*Nephrops norvegicus*) directed fisheries in Kattegat and Skagerrak, where bycatch of cod (*Gadus morhua*) challenge the fishery. The cod-detector can via real-time catch descriptions provide the fishers with more spatial and temporal knowledge on the distribution of the bycatch species and allow fishermen to monitor catch volumes and compositions continuously.

TARGET SPECIES

Cod (*Gadus morhua*)

AREA, VESSEL

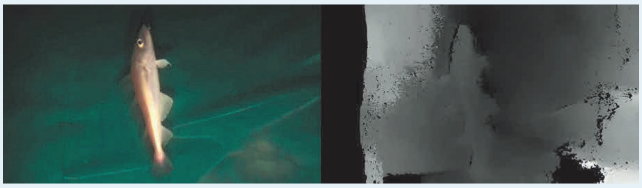
Skagerrak (ICES IIIa)

Havfisken (17 m, 373 kW)

METHOD

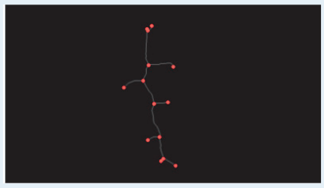
We applied machine learning and deep-vision methods to detect, track and count each individual cod. Subsequently, we extracted masks of each cod detection for length estimation. Finally, we connected the timestamps of the detections with the vessel's position to display the spatial distribution of cod.

EXAMPLE OF COD DETECTION

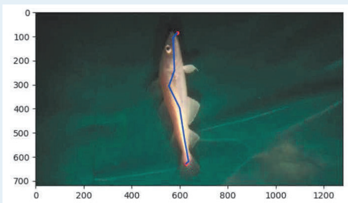


Raw data; image and depth map (stereovision)

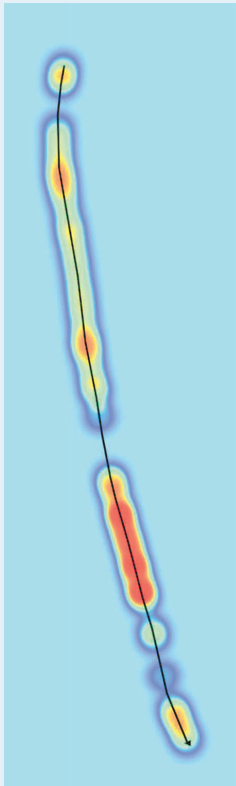
Binary mask from segmentation



Skeleton and nodes



Length estimation



Heatmap of cod catches during a haul, Skagerrak

FURTHER INFORMATION

Mette M. Svantemann (msvly@aqua.dtu.dk)

European Union
European Maritime and Fisheries Fund

Annex 2D

Using allometric relationships for total length prediction of Atlantic cod in EM videos

AIM

To investigate the potential of allometric relationships for total length estimation of occluded (partly visible) individuals of Atlantic cod (*Gadus morhua*) in electronic monitoring videos.

TARGET SPECIES, AREA

Atlantic cod (*Gadus morhua*), Skagerrak

METHOD

In a pre-trial, a total of 35 measurements (incl. total length) were taken on 117 specimens of Atlantic cod.
Of these measurements, seven allometric relationships were found suitable for total length prediction and were further validated in a new trial with 428 specimens of Atlantic cod and finally remeasured via EM videos.

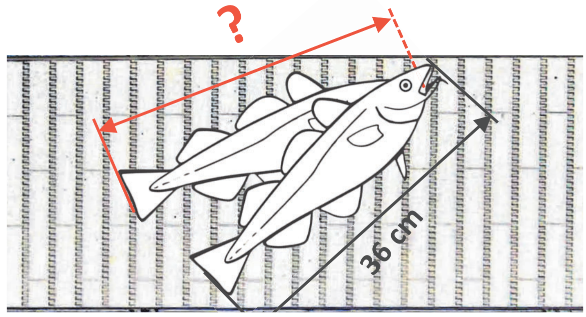
Finally, the accuracy of allometric relationships obtained from EM videos to predict total lengths were calculated both individually and combined.

RESULTS

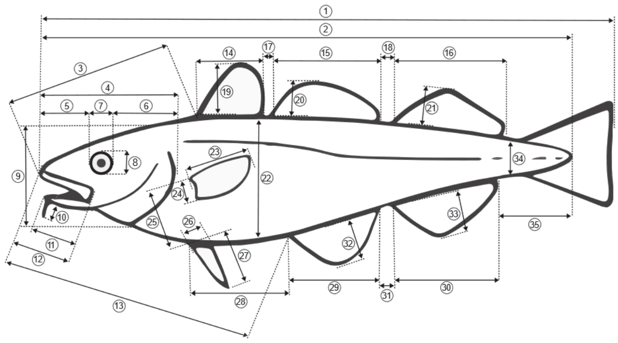
Linearity was observed for all 34 allometric relationships with r^2-values ranging from 0.782 to 0.999.
For the seven allometric relationships found suitable for total length prediction r^2-values ranged from 0.873 to 0.991.

The allometric relationships were chosen based on e.g., the relative ease of measuring them in EM videos, the strength of the relationships, and the location of the measurement along the body of the fish.

The predictive performance for the chosen allometric relationships, is summarized in the table on the right using Root Mean Squared Error, RMSE.



Occluded catch on a sorting belt



Allometric relationships tested for total length prediction

ID	Suitable morphometric measures	RMSE (in cm)
4	Head length	2.47
5	Pre-orbital length	4.11
6	Post-orbital length	2.47
7	Horizontal eye diameter	6.69
23	Pectoral fin length	2.69
24	Pectoral fin width	4.45
34	Caudal peduncle height	2.71
4 + 5 + 6 + 7	ID 4-7 in all combinations	2.27 – 2.43
23 + 24	Combination of Pectoral fin length and width	2.58

FURTHER INFORMATION

Martin Mathias Nielsen (mmani@aqua.dtu.dk)

DTU

European Union
European Maritime and Fisheries Fund

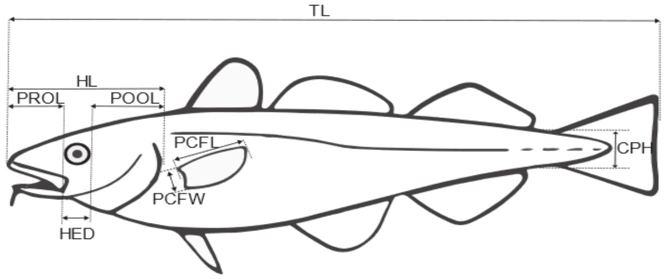
HAV & FISK

Annex 2E

Robustness of allometric relationships across different populations of Atlantic cod

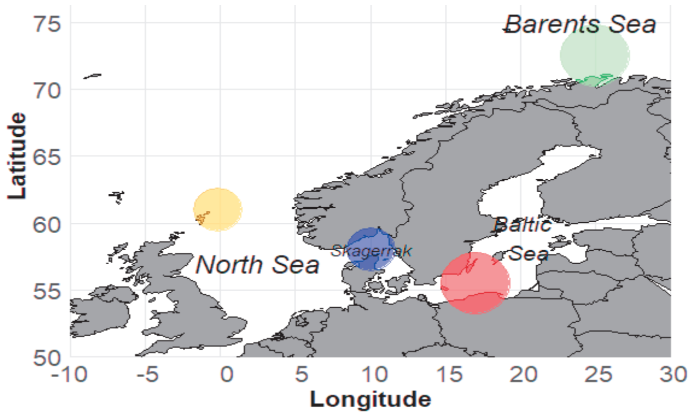
AIM

To evaluate the robustness of seven allometric relationships in Atlantic cod across four areas in the Northeast Atlantic. The goal was to determine which relationship would be more suitable for predicting the total length of occluded cod on EM videos across areas.



RESEARCH SPECIES

Atlantic cod (*Gadus morhua*)



AREAS

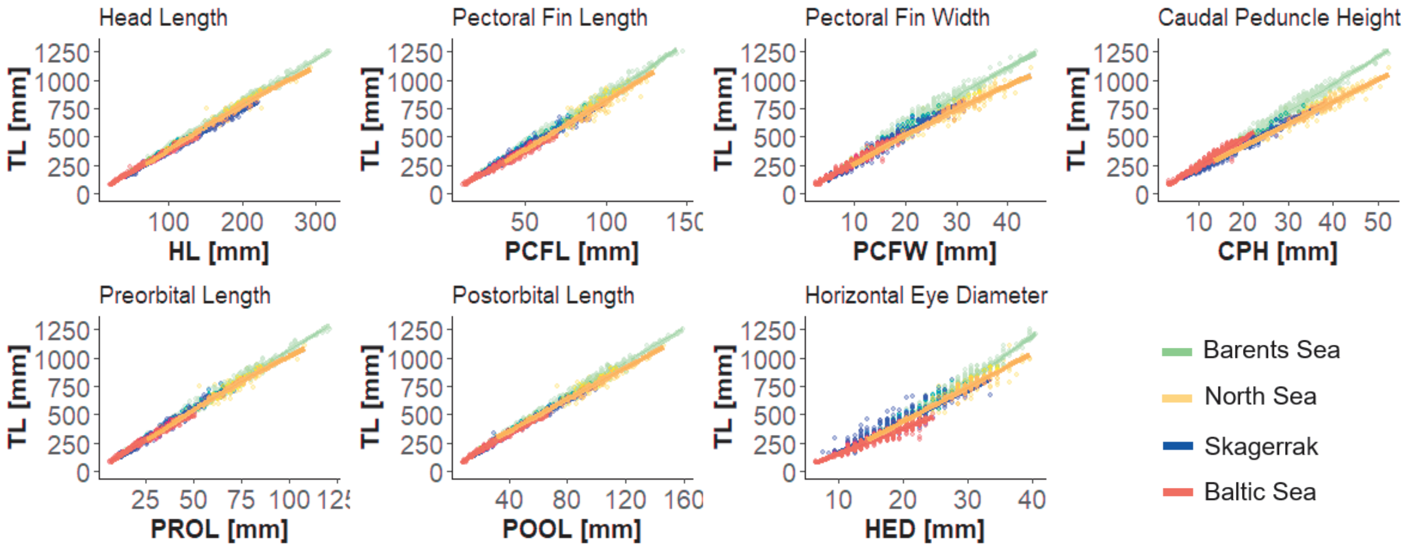
Barents Sea (n = 430)
North Sea (n = 200)
Skagerrak (n = 427)
Baltic Sea (n = 421)

METHOD

In total, 1478 cod were caught and measured across all four geographic areas. The total length (TL) and seven additional morphometric measurements were taken on each cod to build the allometric relationships.

RESULTS

All allometric relationships were affected by regional bias for one or more of the four areas. HL, PCFL and PROL, and POOL, however, were identified as suitable to predict total length across areas. See location of measures on drawing above.



FURTHER INFORMATION

Sissel Kolls Bertelsen (skobe@aqua.dtu.dk)

DTU

European Union
European Maritime and Fisheries Fund

HAV & FISK

Annex 2F

Annex 3. Laboratory report on experiments with tracking fish using acoustics

Acoustic split-beam technology

Sonar (SOund NAvigation and Ranging) is an acoustic technique used to detect and identify objects with the use of sound waves. Echosounders are a type of sonar. In contrast to optic observation techniques (cameras), acoustic observation techniques are independent of the ambient light level and water clarity. An echosounder system consists of a computer with echosounder software, a transceiver, and a transducer. The software is used to specify the characteristics of the transmitted pings and convert the recorded echoes into data that can be visualized and analyzed, the transceiver transmits the specific ping signal to the transducer, which converts the ping from an electric to an acoustic signal and vice versa for the received ping echo. Split-beam transducers are divided into four quadrants. The received echoes are processed separately for each quadrant and compared. This enables positioning of the fish, and so forms a basis for tracking individuals. This technology therefore has potential for observing how fish responds to any changes in fishing gears, for example new bycatch reduction devices, or changes to reduce seabed impact in towed fishing gear.

Tracking fish under controlled conditions

The ability to track individual fish using split-beam observation technology was tested under controlled conditions in the laboratory where fish species and fish sizes are known. The investigations consisted of three steps: i) finding the optimal test conditions in the laboratory; ii) conducting a stress test of the tracking algorithm and make an evaluation in comparison to optic tracking, and iii) use the tracking in a test of fish responses to selected stimuli relevant for trawl fishing.

Split-beam observation system

The observation system consisted of a Simrad WBT Tube transceiver connected to a computer running the Simrad EK80 echo sounder software and two split-beam transducers. This set-up allowed real-time observations and control of the tranceiver settings. One of the two transducers emitted pings at a normal frequency of 70 kHz with a frequency range of 55-95 kHz (Simrad ES70-18CD). The other transducer emitted pings at a normal frequency of 120 kHz with a frequency range of 100-155 kHz (Simrad ES120-18CDK). Each transducer produced a circular sound beam with a width of 18-degree, which corresponds to an 18 degree field-of-view.

Experimental set-up

The experiments were conducted in a large quarantine tank at Nordsøen Oceanarium. The tank was 18 m long, 5.5 m wide and 3.5 m deep (Fig. 5.5.1). The concrete walls were covered with a green canvas tarp. The tank was connected to the recirculation system of the aquarium. Sea water was added to the tank subsurface to prevent production of air bubbles causing acoustic noise. The water circulated anti-clockwise at the tank bottom. The transducers were placed in one end of the tank and the observation arena in the other where the transducer sound beams covered a larger area. The observation arena consisted of a 5.5 m X 6 m nylon net cage in which the fish were enclosed during the experiments. An alternative, optic observation system consisting of six CCTV cameras were mounted along the middle of the tank above the observation arena 0.65 m from the arena wall and 0.95 m between cameras. Real-time monitoring and control of the equipment occurred from a platform away from the tank to avoid disturbing the fish during experiments.

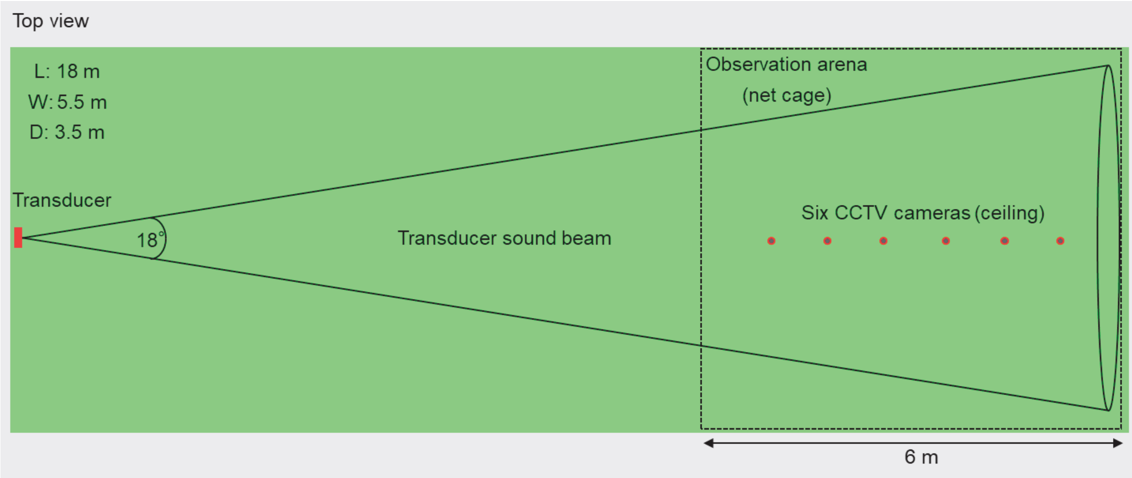


Fig. 5.5.1. Top view of the experimental tank illustrating the net cage constituting the observation arena, placement of the split-beam transducer and the extent of its sound beam, and the placement of the six CCTV cameras for simultaneous optic observation.

Calibration

The EK80 was calibrated following the calibration function in the software and using a calibration sphere with a known target strength (TS) and specifically produced for calibrating echosounder equipment from Simrad. The Simrad 38.1 mm tungsten calibration sphere was mounted on a fishing rod and moved around in the sound beams of the transducers until the calibration was successfully obtained. The water environment was measured for estimation of the sound velocity and absorption coefficient in EK80 (Table 5.5.1).

Table 5.5.1. Water environment measurements for transducer calibration.

Temperature	Salinity	Acidity	Sound velocity	Absorption coefficient
13.9°C	31.54 ppm	8	14.9 m/s	0.0255 dB/m

Optimal settings under laboratory conditions

The sound signals emitted by the split-beam transducers are being reflected by the walls, floor, and water surface of the laboratory tank. The optimal settings of the sound signal and transducer set-up were therefore tested to minimize the noise created by such reflections. The following tests were conducted:

i) Ping settings
ii) Transducer depth
iii) Transducer angle
iv) Transducer distance to observation arena

The transducers were mounted on a metal plate that allowed changing the angle of the transducers. The metal plate was fixed to a stick for lowering the transducers to the desired depth in the water column. The stick was then attached to a moveable metal bridge placed across the tank. The different transducer set-ups tested are shown in Table 5.5.2). When the transducers were in the water, the ping type was set to FM, i.e. frequency modulated sweeps transmitted across a range of frequencies called “chirps”. The different ping settings tested were ping interval (i.e., duration in ms between two pings), power (dB), duration (ms), and ramping (i.e., if the output level of each ping increases from 0 V to the maximum power level defined in a fast or slow manner) (Table 5.5.2).

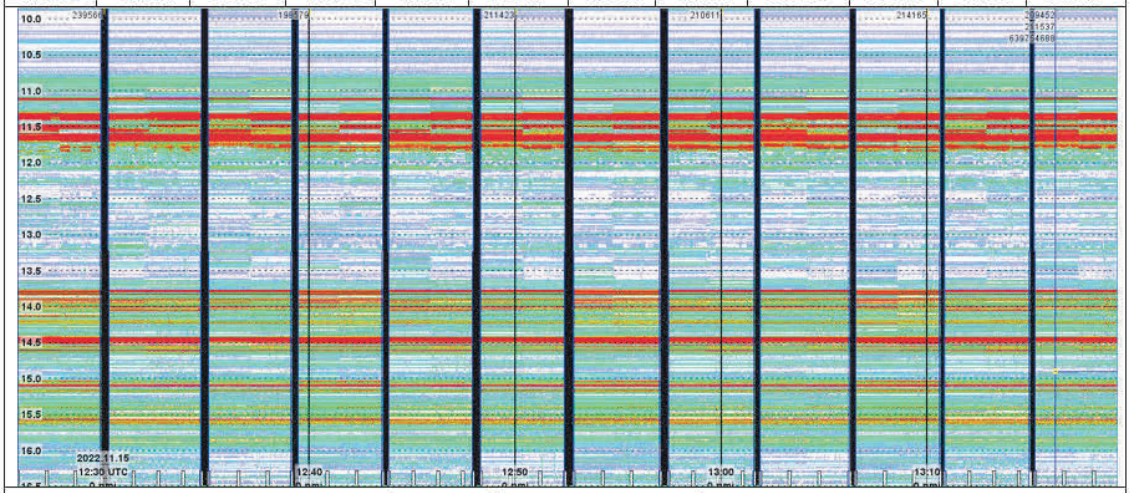
Table 5.5.2. Tested ping settings and transducer set-ups.

Transducer (kHz)	Ping type	Ping interval (ms)	Power (dB)	Ping duration (ms)	Ramping	Transducer depth (m)	Transducer angle (deg)	Transducer distance (+/- m)
70 (55-90)	FM	150 200 500 1000	60 90 120 150	512 1024 2048	fast slow	1.60 1.65 1.70 1.75 (mid) 1.80	66 69 72 75 78 81 84 87 90	18.0 16.4 16.0 15.7 15.4
120 (100-155)	FM	150 200 500 1000	60 90 120 150	512 1024 2048	fast slow	1.60 1.65 1.70 1.75 (mid) 1.80	66 69 72 75 78 81 84 87 90	18.0 16.4 16.0 15.7 15.4

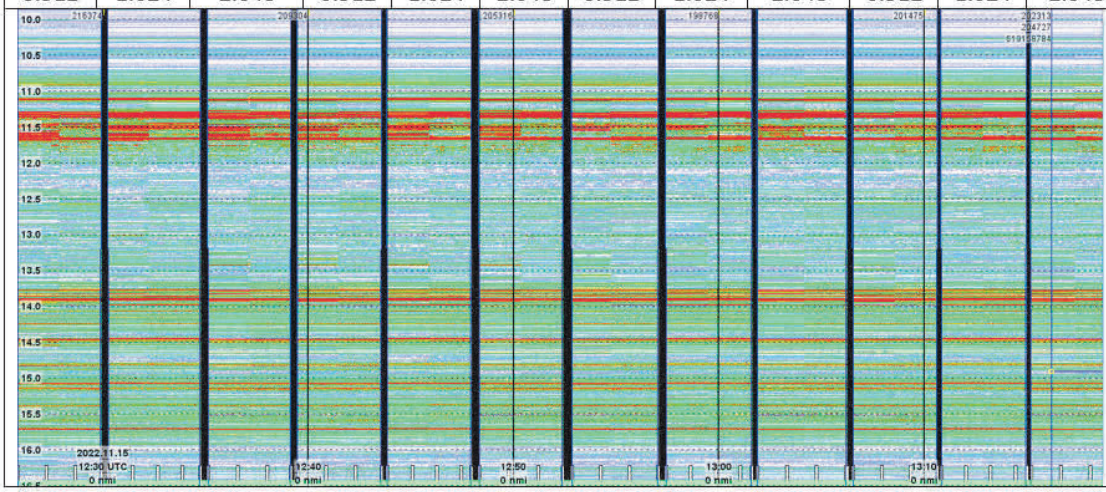
When testing the ping settings, the ping interval of 150 ms gave the best results for both transducers with less noise than the 80 ms interval. Higher ping intervals reduced the resolution of the data. A power of 60 W and ping duration of 0.512 ms gave the most optimal results (Table 5.5.3).

Table 5.5.3. Echograms of different ping power, and duration at ping interval 150 and 200 ms.

70 (55-90) kHz – Ping interval 150 ms											
60			90			120			150		
0.512	1.024	2.048	0.512	1.024	2.048	0.512	1.024	2.048	0.512	1.024	2.048

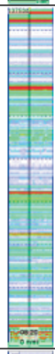
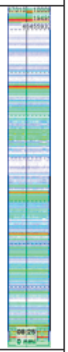


120 (100-155) kHz – Ping interval 150 ms											
60			90			120			150		
0.512	1.024	2.048	0.512	1.024	2.048	0.512	1.024	2.048	0.512	1.024	2.048



When testing the effect of transducer depth and angle, placing the transducer at 1.80 m, which was slightly deeper than midwater, and at 90 degrees angle gave the least noise (Table 5.5.4).

Table 5.5.4. Echograms of different transducer depths (m) and angles (degrees) for ping power 60W, interval 150ms, duration 0,512ms and fast ramping.

Depth	Angle								
	66	69	72	75	78	81	84	87	90
1.65									
1.75									
1.80									

As the noise reduced with increasing angle, angles larger than 90 degrees were also tested for two different pulse durations. It confirmed that the 90-degree angle and 0.512 ms pulse durations were the optimal choices (Table 5.5.5). The last test aimed at reducing the noise by changing the placement of the noise by changing the distance between the transducers and the end wall. Placing the transducers 16 m from the end wall was considered the best option (Table 5.5.6). There was less noise in the observation arena. This was chosen at the expense of increased noise close to the end wall. The final ping settings and transducer set-ups are given in Table 5.5.7.

Table 5.5.5. Echograms of different transducer angles and ping durations for the 70 (55-90) kHz and 120 (100-155) kHz transducers.

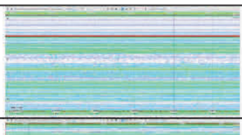
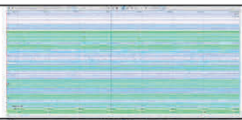
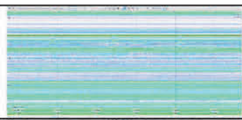
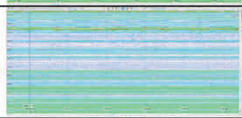
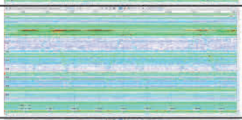
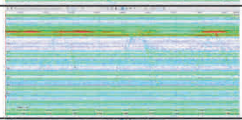
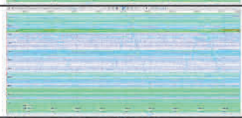
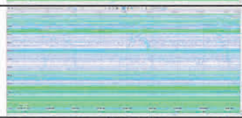
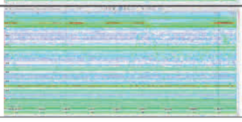
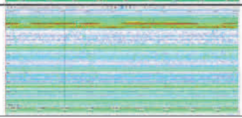
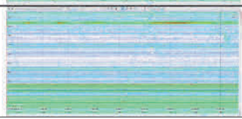
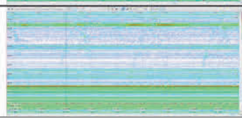
Angle	70 (55-90) kHz		120 (100-155) kHz	
	0.512	1.024	0.512	1.024
9				
10				
11				
12				

Table 5.5.6. Echograms of different transducer distances (m) from the observation arena and tank end wall. At 16.0 and 16.4 m temporary noise is seen at 13-15 m from the transducers.

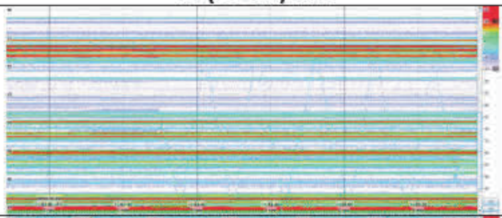
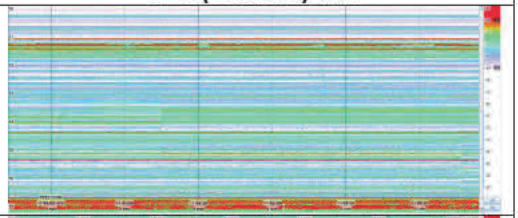
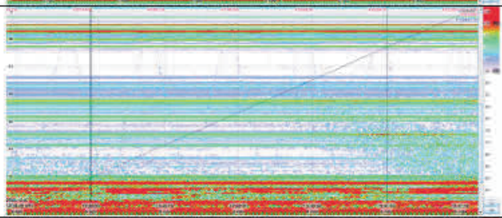
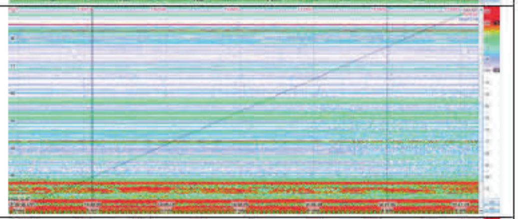
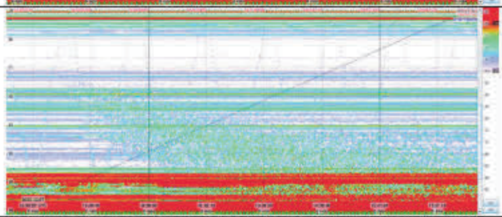
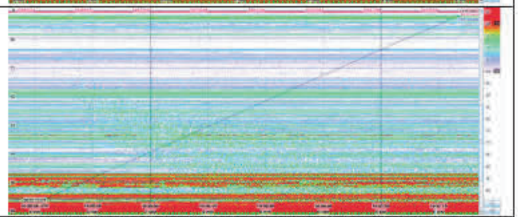
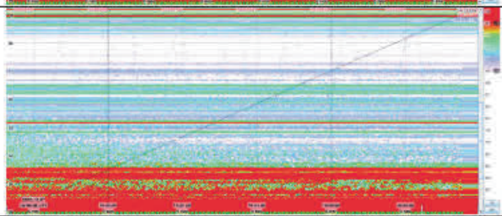
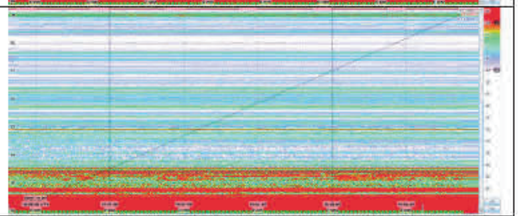
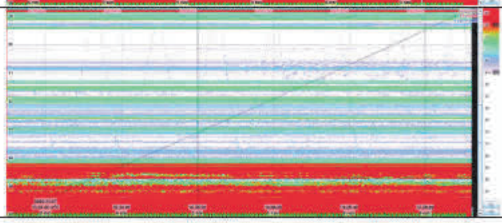
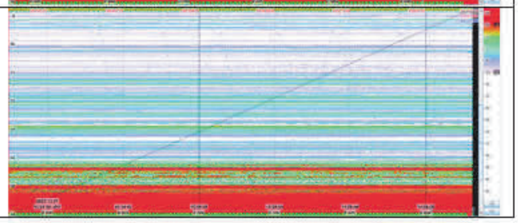
Dist.	70 (55-90) kHz	120 (100-155) kHz
18.0		
16.4		
16.0		
15.7		
15.4		

Table 5.5.7. Final ping settings and transducer set-up for the 18-degree transducers.

Transducer, 18 deg (kHz)	Ping type	Ping interval (ms)	Power (dB)	Ping duration (ms)	Ramping	Transducer depth (m)	Transducer angle (deg)	Transducer distance (+/- m)
70 (55-90)	FM	80	60	0.512	slow	1.8	90	+2
120 (100-155)	FM	80	60	0.512	slow	1.8	90	+2

There was considerable noise in many of the tested settings and set-ups. Highly noisy areas (stripes) corresponded with the distance from the transducer where the sound beam reflected from the water surface as well as when the sound beam reflected off the side and end walls (Fig. 5.5.2). Acoustic data recorded with optimal ping settings and transducer set-up were tested with the tracking algorithm in the software LSSS. This revealed that the echoes from the fish were masked by the noise generated by the sound beam reflections and so tracking individual fish was not possible. The two 18 degrees transducers were therefore replaced by two transducers with the same frequency specifications, but with 7-degree sound beams. This reduced the noise considerably (Fig. 5.5.3). With these transducers, the ping interval could be set to 80 ms (Table 5.5.8). The power was increased to 75 W. To reduce the extra noise of the 120 kHz transducer relative to that of the 70 kHz transducer, the power was set to 50 W.

Table 5.5.8. Final ping settings and transducer set-up for the 7-degree transducers.

Transducer, 7 deg (kHz)	Ping type	Ping interval (ms)	Power (dB)	Ping duration (ms)	Ramping	Transducer depth (m)	Transducer angle (deg)	Transducer distance (+/- m)
70 (55-90)	FM	80	75	0.512	slow	1.8	90	+2
120 (100-155)	FM	80	50	0.512	slow	1.8	90	+2

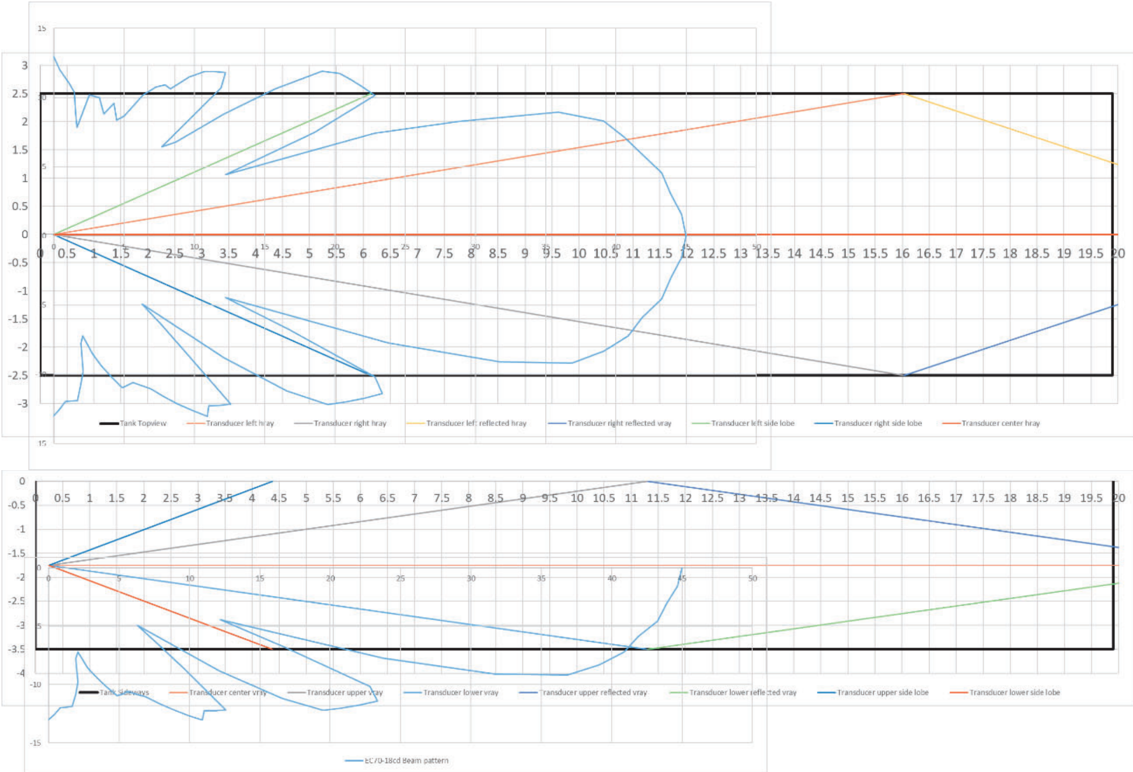


Fig. 5.5.2. The sound beam (blue line) of the 70 kHz transducer superimposed on the experimental tank and showing where the main sound lobe will reflect (straight lines on each side of the mid-line) from the side walls (top view in upper panel) and tank floor and water surface (side view in lower panel). (Figure made by Bo Lundgren.)

Experimental animals

The experiments in the lab were conducted under the animal welfare approval 2022-15-0201-01300. Atlantic cod (*Gadus morhua*) were captured off the coast of Hirtshals and transported to the quarantine tank facilities at Nordsøen Oceanarium. Here they were acclimated in a large holding tank (Ø: 4 m, D: 3.5 m, 44.000 L) for at least two weeks prior to the experiments. During the acclimation, the fish were inspected and fed ad libitum with sandeels (*Ammodytes* spp.) or blue mussels (*Mytilus edulis*) daily. In addition, the water quality variables temperature, oxygen, salinity, and ammonia or acidity were measured (Table 5.5.9).

Table 5.5.9. Water quality variables.

Variable	Holding tank 1	Holding tank 3	Obs arena
Temperature (°C)	13.5 (13.0-14.2)	13.5 (13.1-14.2)	13.5 (12.9-14.2)
Oxygen (%)	96.1 (95.7-97.2)	92.8 (89.0-95.7)	93.5 (89.0-96.6)
Ammonia	0.0-0.2	0.0-0.2	Not measured
Acidity	Not measured	Not measured	8 (8-8)
Salinity	31.3 (31.0-31.5)	31.3 (31.0-31.5)	31.4 (31.0-31.5)

Tracking algorithm stress test

The ability of the acoustic tracking algorithm to track individual fish is likely to change with increasing fish density. This is due to the increased crossings of individual tracks, shadow effects when fish are located behind each other, or difficulties of discerning individuals from each other when they are located close to each other. In a fishing situation, several fish are likely to be present simultaneously in a section of the trawl gear. A test was therefore performed in the laboratory to determine how the tracking algorithm would perform under different fish densities. As optic cameras are commonly used method for observing fish responses, recordings from the six CCTV cameras mounted in the ceiling were obtained in addition to the split-beam recordings to make a comparison of the performances of the two technologies (Table 5.5.10). The echoes from individual cod in the observation arena gave clear acoustic paths in the echogram (Fig. 5.5.3). Examples from the CCTV camera recordings are given in Fig. 5.5.4.

Table 5.5.10. Acoustic split-beam and video recording data (in minutes) at different fish densities.

No. of cod	Split-beam		Video (min)
	70 kHz (min)	120 kHz (min)	
3	20	20	30
4	20	20	30
6	15	15	25
8	15	15	25
10	15	15	25
14	15	15	25

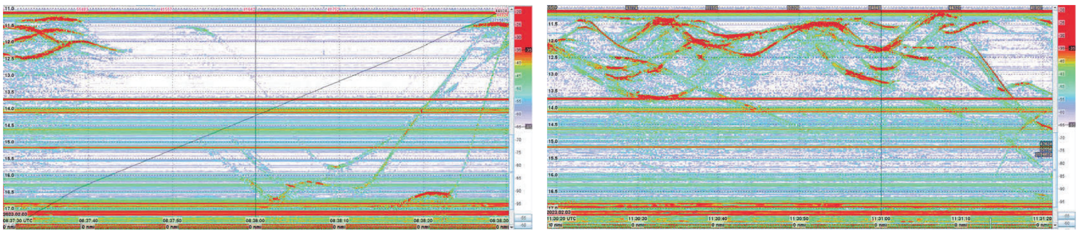


Fig. 5.5.3. Echograms from the algorithm stress test showing the fish group of four individuals (left) and ten individuals (right) observed by the 70 (55-90) kHz transducer.

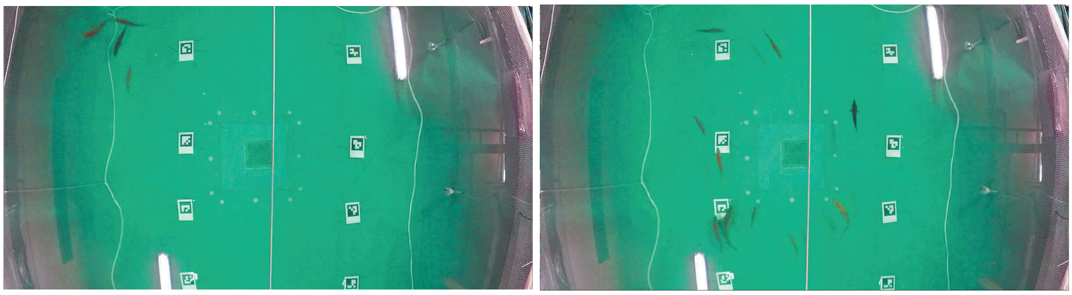


Fig. 5.5.4. Photo from the CCTV recordings (camera 3) during the algorithm stress test showing the fish group of four individuals (left) and ten individuals (right).

Effect of simulated trawl stimuli on fish response

Two experiments were conducted with simulated trawl stimuli in the laboratory: i) vibration stimulus and ii) the presence of movement and LED light stimuli. The vibration was created by a vibrator. The vibrator was mounted above the water surface on a wire descending to a second wire placed ca. 30 cm above the arena bottom. This bottom wire was tensioned between two pillars (Fig. 5.5.5). When the vibrator was turned on, the vibrations were transferred into the water to the tensioned bottom wire. The movement stimulus was a circular frame with trawl netting that was lowered close to the arena bottom. It was attached to a roller on a wire tensioned above the observation arena and moved through the water in the middle of the arena (Fig. 5.5.6). The continuous green LED lights tested simultaneously with the movement stimulus, were attached close to the arena bottom at three different places along on of the arena net walls in front of the tank wall (Fig. 5.5.6).

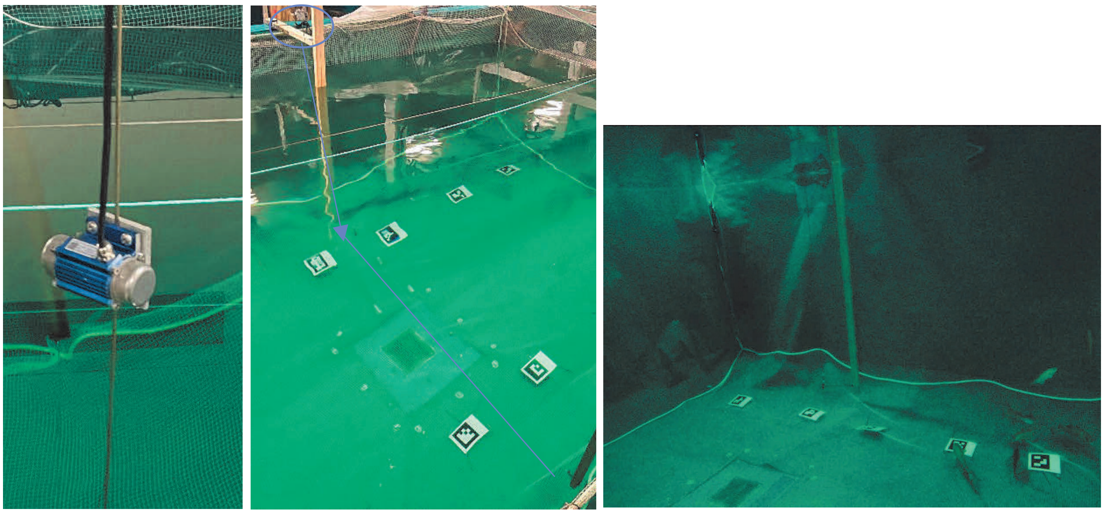


Fig. 5.5.5. The set-up for the vibration stimulus. The vibrator mounted onto the descending wire (left photo and encircled in the middle photo). The descending wire (right of red arrow) was attached to the tensioned bottom wire (right of the red line, middle photo). The cod response to the vibrations were recorded (right photo).

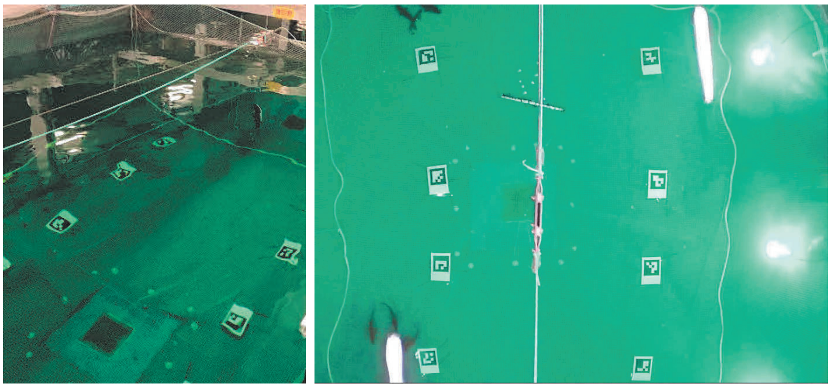


Fig. 5.5.6. The set-up for the movement and LED light stimuli. A circular frame with trawl netting was moved along a tensioned wire across the observation arena (left photo). Simultaneously, green LED lights mounted above the tank bottom on the arena netting was turned on (right photo).

The stimuli experiments were each conducted on five groups of eight cod. In total, 2.5 hrs of split-beam recordings and 3.75 hrs of video recordings were collected (Table 5.5.11). The recordings included an acclimation period, periods with stimuli and control periods without stimuli. Tracks from individual cod were visible in the split-beam data (Fig. 5.5.7). The movement device created distinct acoustic noise as it was moved across the arena (Fig. 5.5.8). The video recordings revealed periods where the group of fish was dispersed and periods where they were closely together (Fig. 5.5.9). Analysis will reveal how this is related to the stimuli tested.

The acoustic cod paths from the algorithm stress test, vibration stimulus and the combined movement and light stimuli will be tracked in the software LSSS. The cod in the CCTV videos will be tracked in the software Ethovision v. 17. These two software programs are commonly used to analyze fish behaviors from acoustic and video data, respectively. The tracks will then be quantified and compared between the two technologies extracting variables such as amount of time tracked, swimming speed, and swimming direction.

Table 5.5.11. Recording times for split-beam and video observation technologies for the five experimental groups of cod. For the split beams, the recording times were the same for the 70 kHz and 120 kHz transducers, and for the optic observation, the recording times were the same for the six CCTV cameras covering different parts of the observation arena.

	Vibration		Movement/LED light	
No of cod	Split-beam (70/120) (min)	Video (1-6) (min)	Split-beam (70/120) (min)	Video (1-6) (min)
8	30	45	30	45
8	30	45	30	45
8	30	45	30	45
8	30	45	30	45
8	30	45	30	45

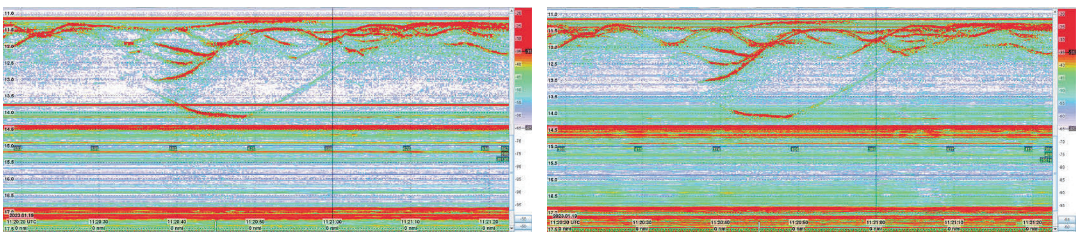


Fig. 5.5.7. Echograms of a fish group of eight individuals being stimulated by vibrations observed by the 70 (55-90) kHz transducer (left) and 120 (100-155) kHz transducer (right).

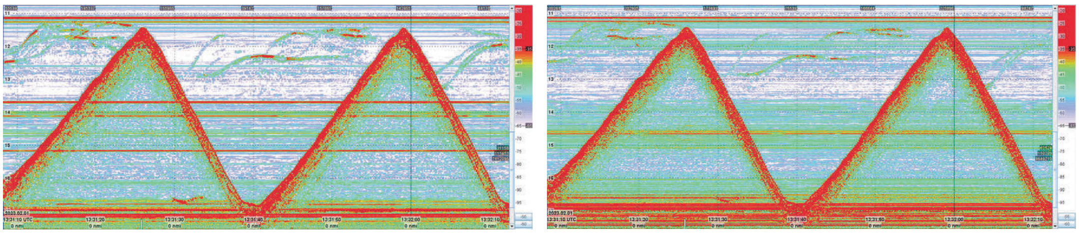


Fig. 5.5.8. Echograms of a fish group of eight individuals being stimulated by a combination of movement and light stimuli observed by the 70 (55-90) kHz transducer (left) and 120 (100-155) kHz transducer (right). The distinct noise tracks creating two peaks are created by the movement device as it was moved along the observation arena.

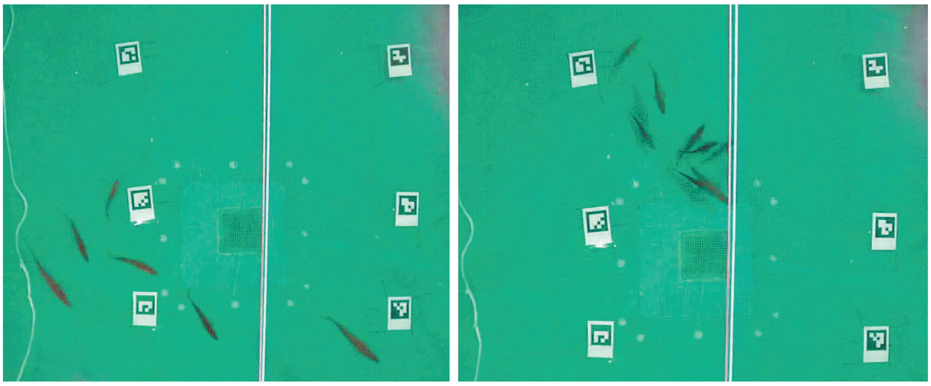


Fig. 5.5.9. Photos from CCTV video recordings showing dispersal (left) and grouping (right) of cod.

Annex 4. Scientific publications

- Bak-Jensen, Zita, et al. "Fixed mesh shape reduces variability in codend size selection." *Canadian Journal of Fisheries and Aquatic Sciences* 79.11 (2022): 1820-1829. (https://cdnsciencepub.com/doi/pdf/10.1139/cjfas-2022-0049)

- Bak-Jensen, Z., Herrmann, B., Santos, J., Melli, V., Stepputtis, D., & Feekings, J. P. (2023). The capability of square-meshes and fixed-shape meshes to control codend size selection. *Fisheries Research*, *264*, 106704. (https://www.sciencedirect.com/science/article/pii/S0165783623000978)

- Avsar, E., Feekings, J. P., & Krag, L. A. (2023). Estimating catch rates in real time: Development of a deep learning based Nephrops (*Nephrops norvegicus*) counter for demersal trawl fisheries. *Frontiers in Marine Science*, *10*, 1129852. (https://www.frontiersin.org/articles/10.3389/fmars.2023.1129852/full)

- Palder, O. J., Feekings, J. P., Fraser, S., & Melli, V. (2023). Approaching single-species exclusion in mixed demersal trawl fisheries. *Ocean & Coastal Management*, *242*, 106672. (https://www.sciencedirect.com/science/article/pii/S0964569123001977?via%3Dihub)

- Svantemann, M. M., Savina, E., Krag, L. A. (Submitted). Improving escape efficiency in selective devices with the use of a dark tunnel. *Canadian Journal of Fisheries and Aquatic Sciences.*

Annex 5. Potential of fully digitalized fisheries for fisheries management

Digitalization opens for a real-time catch data stream
Digitalization is the process of integrating digital technologies into various practices where traditionally collected information and knowledge are transformed into computer-based language (Rowan, 2022a). This transformative process not only improves efficiency and accessibility but also has the potential to restructure fisheries management frameworks, making them more agile and responsive. Globally, existing fisheries management frameworks face significant challenges due to overfishing, environmental degradation, and the need for sustainable resource management. Digitalization is changing the way fisheries are managed worldwide by allowing fishers to streamline fishing operations, improve real-time decision-making processes, and enhance overall sustainability.

Technological development has always been a strong driver of innovation in fishing gear technology, starting with acoustics in the 20th century (MacLennan, 2017). Despite the existence of technologies that aid fishers in enhancing their fishery performance by locating fish, describing gear geometry, and offering basic catch size information, the act of fishing remains relatively blind regarding understanding catch rates and compositions. It is only after the catch is landed on the vessel that this information becomes available, offering no opportunity for real-time decision-making. The 21st century has seen a rapid increase in new digital technologies that are now available for use in fisheries. Recent advancements in acoustics and camera technologies together with the power of Artificial Intelligence (AI) and Machine Learning (ML) are allowing for the collection and analysis of detailed catch information in real time that can revolutionize fisheries management frameworks (Sokolova et al., 2022).

Decision support and operational management impacts of digital transformation
Fisheries at-sea observer programs are one of the most reliable and accurate monitoring and surveillance methods used to collect data on bycatch and discards by scientifically trained staff (Ewell et al., 2020; Suuronen & Gilman, 2020). While at-sea observer programs are well-known and accepted (industry outreach), they are also costly, and thus challenged by their ability to cover a representative sample of fishing vessels for the monitoring program to be informative due to high variability in catches between and within vessels (James et al., 2019; Bellido et al., 2020; Suuronen & Gilman, 2020).

To increase the coverage of fisheries monitoring programmes, some countries have successfully implemented electronic monitoring (EM) on vessels to record the fishing process (Bartholomew et al., 2018). If EM can improve the efficiency and capacity of data collection, observer programmes are still used for complex catch sampling operations and the collection of biological samples (van Helmond et al., 2020). The video material recorded by the EM system can be reviewed at a later stage by trained video observers to obtain catch information, such as species composition, numbers, volume, and lengths (van Helmond et al., 2019; Gilman et al., 2020). However, the manual analysis of the video material is a labour intensive and time-consuming process (Needle et al., 2015; Van Helmond et al., 2020), motivating the development of a computer vision system designed to analyse the footage automatically (French et al., 2020; Wibisono et al., 2022). EM combined with AI technology serves the potential for providing fully documented fisheries (FDF).

While EM has overview over what is caught, and therefore delivering catch information for control purposes, it does not allow for real-time management since EM takes place after the catch is brought on the deck of the fishing vessel. The monitoring of catches in real-time using underwater cameras mounted in the trawl or acoustics introduces the possibility for fishers to make informed decisions to actively avoid unwanted catches and more efficiently target species of interest. It also gives the opportunity to the industry to be able to monitor the performance of their gear and reduce their environmental footprint (Krag et al., 2023). Indeed, more precise targeting of species can reduce the carbon footprint and seabed disturbance associated with fisheries (Sokolova et al., 2022).

Documenting catch compositions and catch sizes at the haul level in a continuous data stream that can thus account for variability between vessels, seasons, and areas dramatically changes our ability to manage fisheries stocks by reducing estimation bias when assessing fishing mortality and stock number estimates, but also developing custom gears and operational tactics with a better understanding of how the fish react to the gear and selectivity devices during the catch process. Real-time catch data could even be automatically entered and amended when values are incorrect using Distributed Ledger Technology (DLT) e.g., blockchain.

Towards a more agile and responsive fisheries management framework

Current fisheries management frameworks are complex and multifaceted systems that involves a combination of international agreements, national policies, regulations, and regional management organizations. They are designed to address the sustainable use and conservation of aquatic resources, including fish stocks and marine ecosystems. Digitalized fisheries technology could, as such, enhance efficient mechanisms to enable near-real-time responses allowing for a more comprehensive and detailed control of catches, and potentially facilitate a simpler and more flexible management framework.

Various conservation measures are implemented to protect ecosystems and reduce bycatch (Bellido et al., 2020). In the European Union (EU) for example, fishers' choice of gear is governed by the Technical Measures regulation (EU regulation 2019/1241). This regulation stipulates specific gear requirements for different sea basins and fisheries, offering only a limited number of approved options (Eliasen et al., 2019). However, in a system with robust control and enforcement, e.g. where all catches are documented, the significance of gear-based technical measures diminishes. This can lead to various subsequent changes and adaptations in management and the way stocks are harvested (Johnsen, 2014). We present in Table 5.4.1. (**see report**) how the emerging technologies for real-time fully documented fisheries (with camera or acoustics technologies) could transform the fisheries management framework.

Challenges to implementing digital technologies in commercial fisheries management

Despite the efficiency and effectiveness of these recent technologies and their potential to address gaps in fisheries management, the implementation of fully digitalized fisheries remains more of an exception than the rule (Bradley et al., 2019). Digital data technologies may work best in fisheries, which voluntarily intend to demonstrate their compliance to laws, management rules, and consumer demands (Probst, 2020).

Our capacity to analyse large volumes of complex data still challenges the effective use of the new technologies (Malde et al., 2020; Ditria et al., 2022). Techniques from deep learning have the potential to better model complex adaptive systems, but it is not sufficient to accumulate vast amounts of data. All data are not created equal, and careful design of data collection remain important. Also, deep-learning methods can give unpredictable results on unfamiliar data, and careful monitoring of performance and subsequent adjustments will always be necessary.

There are several challenges emerging due to the nature of the deep learning methodologies. For instance, they typically require high amounts of data for efficient training of the models. This is a critical problem for the applications where data collection is a demanding task such as fisheries, e.g. occluded individuals, variable illumination. Another challenge is the computational load associated with the deep learning models. In other words, making real-time predictions using deep learning models requires usage of specific hardware powerful enough to produce results in a short time. This in turn causes an extra problem related to power consumption which may be challenge in remote areas with limited energy resources. These are most critical points that the digitalization of fisheries facing today, and more research effort should be put on developing resource-efficient deep learning models (Ditria et al., 2022; Li et al., 2022; Rubbens et al., 2023).

The European Union Digital Decade 2030 policy programme aims at stimulating the broad (companies and the public sector) uptake of digital solutions, such as AI and cybersecurity, to help reduce carbon emissions. We present in **Table 5.4.2.** an assessment of EM and RTM with AI using the categories developed for assessing European Digital Innovation Hubs supporting the European Union Digital Decade 2030 policy programme (Rowan et al, 2022b).

Table 5.4.2. Ranking of the EM and RTM systems for Digital using a classification adapted from the assessment criteria of European Digital Innovation Hubs supporting the European Union Digital Decade 2030 policy programme. Green: Commercially available and implemented in the industry, Yellow: under development, Red: Still a challenge, Grey: not assessed (no documentation).

Category	Description	EM (deck)	RTM (trawl)
Intelligence (AI)	AI used for decision making both understand and adjust to specific circumstances (optimisation)	EM may allow for enhanced transparency and compliance together with discard reduction. Accurate data collection for AI methods is still a challenge (van Helmond et al., 2019; Goethel et al., 2023).	Deep learning requires computationally powerful hardware consuming high energy while real-time requires fast processing of the data, which is challenging due to the resource-constraint environment on the vessel. Models with optimized computational load and deployable on edge devices are needed for practical implementations (Avsar et al., 2023).
Connectivity	Seamless internet connection, secure data transmission and storage, and synchronization of camera data with the other sensors in the vessel.	EM should be implemented within a vessel monitoring plan to collect data only from the required sections of the vessel and to process this data considering GDPR. Also, data should not be tampered with and saved securely (see guidelines from the European Fisheries Control Agency).	Currently available systems establish connection between the camera (underwater) and the processing system (on the vessel) through long wires. This is an expensive solution that can be replaced by wireless data transmission and in-trawl processing via embedded hardware.
Flexibility	The ability to adapt and customise the system to specific needs at affordable, mass-production prices.	EM equipment is fully implemented (scaled-up at commercial prices) in some fisheries.	The RTM is still expensive, especially for the demersal fleet. An economic analysis would be an interesting documentation for the industry (fuel price reduction).
Automation	Can repetitive task be automated in a reliable way?	Current challenges for automation of catch data are the length and species estimation of occluded individuals and variable illumination (Bartholomew et al., 2018).	
Sustainability	Is the product produced in a sustainable manner?	A Life Cycle Analysis to include the “digital” cost would be interesting.	
Social	Are fishers motivated, engaged, and empowered to carry out their work in an autonomous manner when working within the new systems?	Still under debate in the fishery (industry reluctancy) (van Helmond et al., 2019; Goethel et al., 2023).	Real-time information in the trawl during the fishing operation can empower fishers to make informed decisions regarding their catches.
Legal	Is it currently integrated in legislation?	Implementation in Kattegat	Using the camera is legal, but it is not legally integrated in the management framework.

References

Avsar, E., Feekings, J. P., & Krag, L. A. (2023). Estimating catch rates in real time: Development of a deep learning based *Nephrops* (*Nephrops norvegicus*) counter for demersal trawl fisheries. Frontiers in Marine Science, 10, 1129852. https://doi.org/10.3389/fmars.2023.1129852

Bartholomew, D.C., Mangel, J.C., Alfaro-Shigueto, J., Pingo, S., Jimenez, A., Godley, B.J. (2018). Remote electronic monitoring as a potential alternative to on-board observers in small-scale fisheries, Biological Conservation, Volume 219, Pages 35-45, ISSN 0006-3207. Doi: https://doi.org/10.1016/j.biocon.2018.01.003.

Bellido, J. M., Sumaila, U. R., Sánchez-Lizaso, J. L., Palomares, M. L., & Pauly, D. (2020). Input versus output controls as instruments for fisheries management with a focus on Mediterranean fisheries. Marine Policy, 118. https://doi.org/10.1016/j.marpol.2019.103786.

Bradley, D., Merrifield, M., Miller, K.M., Lomonico, S., Wilson, J.R., Gleason, M.G. (2019). Opportunities to improve fisheries management through innovative technology and advanced data systems. Fish and Fisheries 20, 564–583. https://doi.org/10.1111/faf.12361.

Ditria, E. M., Buelow, C. A., Gonzalez-Rivero, M., & Connolly, R. M. (2022). Artificial intelligence and automated monitoring for assisting conservation of marine ecosystems: A perspective. Frontiers in Marine Science, 9, 918104. https://doi.org/10.3389/fmars.2022.918104

Eliasen, S.Q., Feekings, J., Krag, L., Veiga-Malta, T., Mortensen, L.O., Ulrich, C. (2019). The landing obligation calls for a more flexible technical gear regulation in EU waters – Greater industry involvement could support development of gear modifications. Marine Policy 99, 173–180. https://doi.org/10.1016/j.marpol.2018.10.020.

EU. European Council Regulation No 1380. (2013). European Parliament and of the Council of 11 December on the Common Fisheries Policy, amending Council Regulations EC No 1954/2003 and EC No 1224/2009 and repealing Council Regulations EC No 2371/2002 and EC No 639/2004 and Council Decision 2004/585/EC. Off. J. Eur. Union 2013, L354, 22–61.

Ewell, C., Hocevar, J., Mitchell, E., Snowden, S., & Jacquet, J. (2020). An evaluation of Regional Fisheries Management Organization at-sea compliance monitoring and observer programs. Marine Policy, 115, 103842. https://doi.org/10.1016/j.marpol.2020.103842

French, G., Mackiewicz, M., Fisher, M., Holah, H., Kilburn, R., Campbell, N., Needle, C. (2020). Deep neural networks for analysis of fisheries surveillance video and automated monitoring of fish discards. ICES Journal of Marine Science 77, 1340–1353. https://doi.org/10.1093/icesjms/fsz149.

Gilman, E., Legorburu, G., Fedoruk, A., Heberer, C., Zimring, M., & Barkai, A. (2019). Increasing the functionalities and accuracy of fisheries electronic monitoring systems. Aquatic Conservation: Marine and Freshwater Ecosystems, 29(6), 901–926. https://doi.org/10.1002/aqc.3086.

Goethel, D. R., Omori, K. L., Punt, A. E., Lynch, P. D., Berger, A. M., de Moor, C. L., … Methot, R. D. (2023). Oceans of plenty? Challenges, advancements, and future directions for the provision of evidence-based fisheries management advice. Reviews in Fish Biology and Fisheries, 33(2), 375–410. https://doi.org/10.1007/s11160-022-09726-7

James, K. M., Campbell, N., Viðarsson, J. R., Vilas, C., Schreiber Plet-Hansen, K., Borges, L., … Ulrich, C. (2019). Tools and technologies for the monitoring, control and surveillance of unwanted catches. European Landing Obligation, 363–383. https://doi.org/10.1007/978-3-030-03308-8_18

Johnsen, J.P. (2014). Is fisheries governance possible? Fish and Fisheries 15, 428–444. https://doi.org/10.1111/faf.12024.

Krag, L.K., Savina, E., Lyngby, M.S. & Frandsen, R. (2023). Real-time camera observation in the trawl fisheries (Technofish). Final report. DTU Aqua Report no. 421-2023. National Institute of Aquatic Resources, Technical University of Denmark, 29 pp.

Li, J., Xu, W., Deng, L., Xiao, Y., Han, Z., & Zheng, H. (2023). Deep learning for visual recognition and detection of aquatic animals: A review. Reviews in Aquaculture, 15(2), 409–433. https://doi.org/10.1111/raq.12726

MacLennan, D.N. (2017). Reflections on technology and science in fishery research, *ICES Journal of Marine Science* 74 (8), 2069–2075, https://doi.org/10.1093/icesjms/fsx045.

Malde, K., Handegard, N. O., Eikvil, L., Salberg, A-B. (2020). Machine intelligence and the data-driven future of marine science. ICES Journal of Marine Science 77 (4), 1274–1285, doi:10.1093/icesjms/fsz057.

Needle, C. L., Dinsdale, R., Buch, T. B., Catarino, R. M. D., Drewery, J., & Butler, N. (2015). Scottish science applications of Remote Electronic Monitoring. Ices Journal of Marine Science, 72(4), 1214–1229. https://doi.org/10.1093/icesjms/fsu225

Probst, W. N. (2020). How emerging data technologies can increase trust and transparency in fisheries. ICES Journal of Marine Science, 77 (4), 1286–1294, doi:10.1093/icesjms/fsz036.

Rowan, N. J. (2022a). The role of digital technologies in supporting and improving fishery and aquaculture across the supply chain – Quo Vadis?, Aquaculture and Fisheries, https://doi.org/10.1016/j.aaf.2022.06.003.

Rowan, N.J., Murray, N., Qiao, Y., O'Neill, E., Clifford, E., Barceló, D., Power, D.M. (2022b). Digital transformation of peatland eco-innovations (‘Paludiculture’): Enabling a paradigm shift towards the real-time sustainable production of ‘green-friendly’ products and services, Science of The Total Environment, Volume 838, Part 3, 156328, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2022.156328.

Rubbens, P., Brodie, S., Cordier, T., Destro Barcellos, D., Devos, P., Fernandes-Salvador, J. A., … Irisson, J. O. (2023). Machine learning in marine ecology: an overview of techniques and applications. Ices Journal of Marine Science, 80(7), 1829–1853. https://doi.org/10.1093/icesjms/fsad100

Sokolova, M., O’Neill, F.G., Savina, E., Krag, L.A. (2022). Test and development of a sediment suppressing system for catch monitoring in demersal trawls. Fisheries Research 251, 106323. https://doi.org/10.1016/j.fishres.2022.106323.

Suuronen, P., & Gilman, E. (2020). Monitoring and managing fisheries discards: New technologies and approaches. Marine Policy, 116. https://doi.org/10.1016/j.marpol.2019.103554.

van Helmond, A.T.M., Mortensen, L.O., Plet-Hansen, K.S., Ulrich, C., Needle, C.L., Oesterwind, D., Kindt-Larsen, L., Catchpole, T., Mangi, S., Zimmermann, C., Olesen, H.J., Bailey, N., Bergsson, H., Dalskov, J., Elson, J., Hosken, M., Peterson, L., McElderry, H., Ruiz, J., Pierre, J.P., Dykstra, C., Poos, J.J. (2020). Electronic monitoring in fisheries: Lessons from global experiences and future opportunities. Fish and Fisheries 21, 162–189. https://doi.org/10.1111/faf.12425.

Wibisono, E., Mous, P., Firmana, E., & Humphries, A. (2022). A crew-operated data recording system for length-based stock assessment of Indonesia’s deep demersal fisheries. Plos One, 17(2), e0263646. https://doi.org/10.1371/journal.pone.0263646

Technical
University
of Denmark

DTU Aqua
Willemoesvej 2
DK-9850 Hirtshals

www.aqua.dtu.dk