THÜNEN

Stellnetzfischerei-Lösungsansätze

STELLA

Projekt-Abschlussbericht

Uwe Krumme, Steffi Meyer, Isabella M. F. Kratzer, Jérôme C. Chladek,
Fanny Barz, Daniel Stepputtis, Harry V. Strehlow, Sarah B. M. Kraak,
Christopher Zimmermann

Thünen Report 97

Bibliografische Information:
Die Deutsche Nationalbibliothek verzeichnet diese Publikationen in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet unter www.dnb.de abrufbar.

Bibliographic information:
The Deutsche Nationalbibliothek (German National Library) lists this publication in the German National Bibliography; detailed bibliographic data is available on the Internet at www.dnb.de

Bereits in dieser Reihe erschienene Bände finden Sie im Internet unter www.thuenen.de

Volumes already published in this series are available on the Internet at www.thuenen.de

Zitationsvorschlag – *Suggested source citation:*
Krumme U, Meyer S, Kratzer I, Chladek J-C, Barz F, Stepputtis D, Strehlow HV, Kraak SBM, Zimmermann C (2022) STELLA - Stellnetzfischerei-Lösungsansätze : Projekt-Abschlussbericht. Braunschweig: Johann Heinrich von Thünen-Institut, 220 p, Thünen Rep 97, DOI:10.3220/REP1662104969000

Thünen Report 97

Herausgeber/Redaktionsanschrift – Editor/address

Johann Heinrich von Thünen-Institut
Bundesallee 50
38116 Braunschweig
Germany

thuenen-report@thuenen.de
www.thuenen.de

ISSN 2196-2324
ISBN 978-3-86576-244-3
DOI:10.3220/REP1662104969000
urn:nbn:de:gbv:253-202209-dn065274-0

THÜNEN

Stellnetzfischerei-Lösungsansätze

Projekt-Abschlussbericht

STELLA

Uwe Krumme, Steffi Meyer, Isabella M. F. Kratzer, Jérôme C. Chladek,
Fanny Barz, Daniel Stepputtis, Harry V. Strehlow, Sarah B. M. Kraak,
Christopher Zimmermann

Thünen Report 97

Abschlussbericht 2020
Zuwendungsempfänger: Thünen-Institut für Ostseefischerei (OF)
Zuwendungsgeber: Bundesamt für Naturschutz (BfN)
Förderkennzeichen: 3516821300
Vorhabenbezeichnung: STELLA
Laufzeit des Vorhabens: 01.11.2016–31.01.2020
Berichtszeitraum: 01.11.2016–31.01.2020
(für Promovierende durch OF verlängert bis 31.07.2020)
Fertigstellung des Abschlussberichts: 31.03.2022

Adresse der Autorinnen und Autoren:
Thünen-Institut für Ostseefischerei (OF)
Alter Hafen Süd 2
18069 Rostock

Fachbetreuung im BfN: Christian Pusch, Katrin Prinz, Janos Hennicke, Henning von Nordheim

Anmerkung der Verfasser: Die in diesem Abschlussbericht geäußerten Ansichten und Meinungen sind die der

Thünen Report 97

Rostock/Germany, September 2022

Inhaltsverzeichnis

Abbildungsverzeichnis

1 Zusammenfassung

Das Projekt STELLA (STELlnetz-Lösungs-Alternativen) zielte darauf ab, **Lösungen für die Mitigation** unerwünschter Beifänge von Seevögeln und Meeressäugern und damit für den Ausgleich der Konflikte **zwischen Naturschutzinteressen und den Interessen der Küstenfischerei in der Ostsee zu finden**. Das Projekt wurde vom Thünen-Institut für Ostseefischerei (OF) von November 2016 bis Januar 2020 aus Mitteln des Bundesministeriums für Umwelt, Naturschutz und nukleare Sicherheit in Kooperation mit dem Bundesamt für Naturschutz durchgeführt. Von Februar bis Juli 2020 wurden noch ausstehende Arbeiten aus Mitteln des Thünen-Instituts fortgeführt.

Die Ziele des Projektes wurden **in fünf Arbeitspaketen (AP) bearbeitet**: AP1 zielte auf eine verbesserte Erhebung von Aufwands- und Fangdaten aus der Stellnetzfischerei; AP 2 fokussierte auf die technische Verbesserung von Stellnetzen, um unerwünschte Beifänge zu reduzieren; AP3 widmete sich Verbesserungen an zwei Alternativen zum Stellnetz, der Fischfalle und der Hebereuse; das sozialwissenschaftliche AP4 befasste sich mit der fischereilichen Handlungspraxis in Bezug auf die Vermeidung unerwünschter Beifänge. AP5 schließlich bildete aus den Ergebnissen der APs 1 bis 4 die Synthese und leitete Handlungsempfehlungen für die Politik ab.

AP1 analysierte die **Struktur der deutschen Flotte der kleinen Stellnetzfischerei in der Ostsee** (Aktivität, Fangmuster, Fangzusammensetzung) und konnte acht distinkte, zeitlich stabile Gruppen identifizieren. Die Identifizierung dieser Fischereigruppen ist essentiell, um angepasste Lösungen zu finden, denn einen universellen Ansatz zur Weiterentwicklung dieser Fischerei kann es bei der Heterogenität der Stellnetzflotte nicht geben. Außerdem wurden in diesem AP **Möglichkeiten der Datenerfassung verbessert**. Insbesondere **Aufwandsdaten**, die aus diesem Fischereisegment bisher nicht verlässlich vorliegen, können mit Hilfe der im Projekt entwickelten Smartphone-Applikation „Mofi“ („mobile fisheries log“) einfach und valide erhoben werden. Ein mehrmonatiger Test in der kommerziellen Fischerei verlief erfolgreich. Die „Mofi“-App wird kontinuierlich für weitere Anwendungen fortentwickelt, z.B. für die Erfassung unerwünschter Beifänge oder die Dokumentation von Netzschäden durch Kegelrobben, um ihre Nutzung für die Fischerei attraktiver zu machen.

Nach einer gründlichen Analyse des Kenntnisstandes zu Beginn des Projektes durch eine umfangreiche Recherche fokussierte **AP2** auf die **Verbesserung der akustischen „Sichtbarkeit“ von Stellnetzen**. Um zu verhindern, dass sich Schweinswale in Stellnetzen verfangen und ertrinken, wurden Acrylperlen als kleinstmögliche, neutral schwebfähige Körper identifiziert, die durch eine Resonanzfrequenz für den sich akustisch orientierenden Schweinswal wie viel größere Objekte wirken. Diese Perlen, die in die Maschen der Stellnetze geklebt wurden, könnten das Netz für Schweinswale akustisch wahrnehmbar („sichtbar“) machen. Um die Wirksamkeit dieser Netzmodifikation zu überprüfen, wurde das „Perlennetz“ in einer kommerziellen Fischerei getestet, die bekannt ist für erhöhte Beifangraten an Schweinswalen (Stellnetzfischerei auf Steinbutt im Schwarzen Meer). Die Versuche ergaben Hinweise auf eine Reduzierung der Beifänge, der statistisch signifikante Nachweis steht aufgrund der insgesamt geringen Beifangraten während des Experiments jedoch noch aus.

Das ebenfalls technische **AP3 entwickelte Fischfallen und eine Ponton-Hebereuse als Alternative zu Stellnetzen weiter**. Fischfallen und Hebereusen reduzieren den Beifang von Seevögeln und Meeressäugern erheblich, sind aber bislang deutlich weniger fängig für die fischereilichen Zielarten. Sie sind ferner aufwändiger in der Handhabung als Stellnetze und werden daher derzeit in der deutschen Ostseefischerei kaum eingesetzt. Es ist gelungen, die Fängigkeit der Fischfallen zu erhöhen und die Hebereuse an die besonderen Gegebenheiten in der deutschen Fischerei (z. B. Einsatz in exponierten Flachwassergebieten, unterschiedliches Zielarten-spektrum) anzupassen. Der Anstieg der Anzahl an Kegelrobben in deutschen Gewässern der Ostsee und die durch diese Art verursachten steigenden Fangverluste und Netzschäden werden den Einsatz von alternativen

Fanggeräten – wie Reusen – in naher Zukunft erforderlich machen, um sowohl den Fang der Fischer vor Beschädigung durch die Robben als auch Robben vor dem Ertrinken in den Fanggeräten zu schützen.

AP4 verfolgte den Ansatz, mit Hilfe von sozialwissenschaftlichen Methoden, Wissen für ein angepasstes Beifang-Management zu generieren. In der Forschung zum Fischereimanagement wird seit Jahren gefordert, bei der Entwicklung von Managementinstrumenten den Menschen zu berücksichtigen, da erfolgreiches Management auf Verhaltensreaktionen der Fischer gegenüber auferlegten Maßnahmen beruht. Es wurden **drei Fischertypen und zwei verschiedene Einstellungen zum Thema Beifang identifiziert.** Ein Expertenworkshop erarbeitete mögliche Managementansätze, die Beifang vermeiden können. Diese Ergebnisse wurden vor dem Hintergrund der Fischertypen und der Einstellung der Fischer zu Beifängen analysiert und Schlussfolgerungen gezogen, welche Fischertypen mit welchen Managementinstrumenten am besten erreicht werden können, um ihr regelkonformes Verhalten (Compliance) zu fördern. Gleichzeitig wurde die Änderung der Einstellung von Fischern zu Beifangereignissen als eine der Hauptmaßnahmen identifiziert. Bislang ist unter den Fischern ein Diskurs vorherrschend, der Beifang von Seevögeln zum großen Teil als ein Teil der täglichen Routine beschreibt. Erhebliche Fortschritte in der Transformation der Fischerei zur Reduzierung der Umweltauswirkungen erfordern einen Diskurswandel, gefördert z. B. durch Co-Management-Prozesse.

STELLA konnte auf einer Reihe wichtiger Arbeitsfelder wesentliche Grundlagen zur Mitigation der Beifänge von Seevögeln und Meeressäugern durch die Stellnetzfischerei in der westlichen Ostsee schaffen. Die Arbeiten werden überwiegend nahtlos fortgeführt, auch im Rahmen von Folgeprojekten, so dass die Umsetzung in der Fischerei in absehbarer Zukunft erfolgen könnte. Wissenslücken bestehen nach wie vor vor allem bei Aspekten, die für die Vermeidung von Seevogelbeifängen erforderlich sind. Hier ist insbesondere das Verhalten von Seevögeln in Bezug zu Stellnetzen zu untersuchen und zu verstehen. Diese Aspekte konnten im Rahmen des Projektes nicht addressiert werden, vor allem weil Erkenntnisse zum Verhalten der Seevögel fehlen, die wiederum Grundlage für die systematische Entwicklung von beifangvermeidenden Techniken sind. Entsprechende Untersuchungsansätze zum Verhalten von Seevögeln (in Zusammenarbeit mit dem FTZ Büsum) konnten nicht weiterverfolgt werden, da die dafür notwendigen Datenlogger (Tags) technische Probleme aufwiesen. Dementsprechend wurde entschieden, sich bei AP2 (Stellnetzmodifikationen) auf die Vermeidung von Schweinswalbeifang zu konzentrieren. Die Reduktion von Seevogelbeifang wurde nachwievor durch die Entwicklung alternativer Fanggeräte (AP3) adressiert.

Die Ergebnisse des Projektes zeigen, dass Aufwandsdaten flächendeckend und hochaufgelöst auch auf kleinsten Fischereifahrzeugen erhoben werden können. Mit Hilfe der in STELLA entwickelten Smartphone-Applikation „Mofi“ ist dies so einfach und kostengünstig möglich, dass wir **empfehlen**, zügig die erforderlichen Anreize oder eine gesetzliche Regelung für diese Datenaufnahme zu schaffen. Zeitlich versetzt – nach der unbeeinflussten Aufnahme von Basis-Aufwandsdaten – sollte mit der Erfassung und Verifizierung von Beifängen geschützter, bedrohter oder empfindlicher Arten mit Hilfe von elektronischen Monitoringsystemen begonnen werden. Für diese Datenerhebung sollten Anreize geschaffen werden, die spezifisch für die Bedürfnisse der identifizierten Fischereigruppen der deutschen Stellnetzfischerei sein können; Quotenzuschläge und Zugangserleichterungen erscheinen dabei als ein stärkerer Anreiz als monetäre Beihilfen. Für die einzelnen identifizierten Fischereigruppen sollten daher maßgeschneiderte Lösungen entwickelt werden, wie einerseits eine wirtschaftlich tragfähige deutsche Küstenfischerei sichergestellt werden kann und andererseits deren negativen Umweltauswirkungen reduziert werden können. Hierfür ist die zeitnahe Entwicklung einer Gesamtstrategie erforderlich. Technische Lösungen bei bereits eingeführten Fanggeräten sind – wenn verfügbar – vergleichsweise schnell und konfliktarm einführbar, weil sie nur moderate Verhaltensänderungen bei der Fischerei erfordern. Je nach Lösung sollte eine verpflichtende Einführung (wie im Falle des „Perlennetzes“) oder eine mit Anreizen flankierte freiwillige Einführung (bei alternativen Fangtechniken) vorgesehen werden. Wenn technische Lösungen (noch) nicht vorhanden sind, müssen rechtliche Möglichkeiten zur Reduzierung der Beifänge ergriffen werden. Sozialwissenschaftliche Aspekte sollten bei der Konzeptionierung und Durchführung von Maßnahmen zur Reduzierung der

Umweltauswirkungen der Fischerei von Anfang an mit einbezogen werden; und für jede Maßnahme sollte eine umfassende Beteiligung aller Akteure vorgesehen werden (Co-Management). Das Schaffen sorgfältig auf die spezifische Zielgruppe zugeschnittener Anreize ist wegen der großen Heterogenität der deutschen Stellnetzflotte erforderlich. Es hilft ferner zu verdeutlichen, dass die Maßnahmen auch im Interesse der Fischerei liegen.

Schlagwörter: Stellnetzfischerei, Flottensegmentierung, Fanggerätemodifikation, Beifangreduzierung, Beifang-Diskurs, Fischerinterviews, Fischertypen, Fischereipraxis, Anreize, Fischereimanagement, sozialwissenschaftliche Fischereiforschung, westliche Ostsee, Smartphone-Applikation, Seevögel, Schweinswale

2 Summary

The project STELLA (Gillnet-Solution-Approaches) aimed at finding finding solutions for the mitigation of unwanted by-catches of sea birds and marine mammals, and thus reconcile nature conservation interests and the interests of coastal fisheries in the Baltic Sea. The project was carried out by the Thünen Institute of Baltic Sea Fisheries (OF) from November 2016 to January 2020, funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety in cooperation with the Federal Agency for Nature Conservation. From February to July 2020, pending work was continued with funds of the Thünen Institute.

The objectives of the project were **executed in five work packages (WP)**: WP1 aimed to improve data collection from the gillnet fishery; WP 2 focused on technical modifications of gillnets to reduce unwanted by-catches; WP3 addressed improvements to two alternatives to the gillnet, the fish trap and the pontoon trap; the social-science WP4 dealt with the fishing practice in relation to the avoidance of undesirable by-catches. Finally, WP5 synthesised the results of WPs 1 to 4 and derived recommendations to policy makers.

WP1 analyzed the **structure of the German small-scale gillnet fleet in the Baltic Sea** and was able to identify eight distinct groups, similar in terms of activity and fishing pattern, that were stable over time. The identification of these fishing groups is essential in order to find tailored solutions, because there can be no uniform approach to the transformation of the gillnet fleet given its heterogeneity. In addition, **means of data collection have been improved** in this WP. In particular, reliable, high-resolution **effort data** that have not yet been reliably available from this fishing segment can now be collected on vessels of all sizes using the smartphone application “Mofi” (“mobile fisheries log”) developed in the project. A test lasting several months in the commercial fishery was successful. The "Mofi-App" is continuously developed further to allow for e.g. the photographic documentation of unwanted bycatch or gear damage caused by grey seals in the area, aiming at making its use more attractive for fishers.

After a thorough review of the state of knowledge at the beginning of the project, WP2 focused on improving the acoustic "visibility" of gillnets. In order to prevent harbor porpoises from entangling and drowning in gill nets, acrylic beads were identified as the smallest possible neutrally buoyant bodies, which appear like much larger objects for the acoustically-oriented harbor porpoise due to a resonance frequency. These beads, which were glued into the meshes of the gill nets, could make the net acoustically perceivable (“visible”) for porpoises. In order to test the effectiveness of this net modification, the “beads net” was tested in a commercial fishery which is known for elevated bycatch rates of porpoises (gillnet fishery for turbot in the Black Sea). The experiments showed evidence of a reduction in by-catches, but statistically significant evidence is still pending due to the overall low by-catch rates during the experiment.

WP3, the second technical WP, **advanced fish traps and a pontoon trap** as an alternative to gill nets. Fish traps and pontoon traps are known to reduce the bycatch of seabirds and marine mammals considerably, but so far have a lower catchability for the target species; they are also more complex to handle than gill nets and are therefore rarely used in German Baltic Sea fisheries. It has been possible to increase the catchability of the fish traps and to adapt the pontoon trap to the special conditions in the German Baltic fisheries (e.g. use in exposed shallow-water areas, adaptation to the target-species spectrum). The increase in the number of grey seals in German Baltic waters and the increasing catch losses and damage to gill nets caused by this species will make the use of alternative fishing gear - such as fish traps - necessary in the near future. This could protect both the fishermen's catch from damage by the seals and the grey seals from drowning in the fishing gear.

WP4 took the approach of using social science to develop adapted bycatch management. Research on fisheries management has called for years for consideration of people in the development of management tools, since successful management is based on behavioral responses of fishermen to imposed measures. Three types of fishermen and two different attitudes toward bycatch were categorised within the German Baltic small-scale gillnet fishery. An expert workshop identified potential management approaches that could avoid bycatch.

These results were analysed in light of the types of fishers and their attitudes toward bycatch, and conclusions were drawn about which types of fishers could be targeted best with which management tools to promote their compliance. At the same time, changing fisher's attitudes toward bycatch events to understand the significance for a sustainable fishing was identified as one of the key actions. To date, a discourse has prevailed among fishers that describes seabird bycatch largely as a part of daily routine. Significant progress in transforming fisheries to reduce environmental impacts requires a change in discourse, fostered, for example, through co-management processes.

In a number of important areas of work, STELLA was able to lay the foundation for the mitigation of by-catches of seabirds and marine mammals by gillnet fishing in the western Baltic Sea. Most of the work will be continued seamlessly, including in the context of follow-up projects, so that it could be implemented in fisheries in the foreseeable future. Gaps in knowledge exist mainly in aspects that are necessary to avoid seabird by-catches. These could not be addressed within STELLA, mainly because basic knowledge on sea bird behaviour is lacking. Such insights are a prerequisite for a systematic development of technical bycatch mitigation.

The project results demonstrate that effort data can be recorded area-wide and in high resolution even on smallest fishing vessels, simple and cost-efficient using the smarthphone application “Mofi” developed within the Stella project. We therefore **recommend** to implement the required incentives or regulations to ensure a rapid start of such a data collection. With some time lag, needed for an unaltered determination of initial effort, by-catch data for endangered, threatened and protected (ETP) species should be systematically recorded and verified with the help of electronic monitoring systems. For their rapid uptake in the fishery, incentives should be created that can be specific to the needs of the identified fishing groups; quota additions and excemptions from closed areas appear to be a stronger incentive than monetary aids. For the individual identified fishing groups, tailor-made solutions should be developed, which on the one hand can ensure economically viable German inshore fisheries, and on the other hand reduce their environmental impact. This requires the timely development of an overall strategy. If available, technical solutions for fishing gear that are already in use can probably be introduced relatively quickly and with little conflict because they require little change in fisher’s behaviour. Depending on the solution, a mandatory introduction (like in case of the “beads net”) or a voluntary introduction with incentives (in case of alternative fishing techniques) should be provided. If technical solutions are (presently) not available, legal actions for the mitigation are required. Social-science aspects should be included from the very beginning when designing and implementing measures to reduce the environmental impact of fishing; and full involvement of all actors should be ensured for each measure (co-management). The creation of incentives carefully tailored to the specific target groups identified in this project is necessary because of the great heterogeneity of German gillnet fleet. This will help to convey that the measures are also in the interest of the fishery.

Keywords: gillnet fisheries, fleet segmentation, fishing gear modification, bycatch mitigation, bycatch discourse, fisher interviews, type of fishers, fishing practices, incentives, fisheries management; Social-science fisheries research, western Baltic Sea, apps, seabirds, harbour porpoise

3 Einleitung

3.1 Hintergrund

Die Fischerei mit Stellnetzen ist weltweit eine wichtige Fischfangmethode, die in der Binnenfischerei sowie im Meer vor allem im küstennahen Bereich von kleinen Booten aus eingesetzt wird. Die Nutzung von Stellnetzen hat eine ganze Reihe von Vorteilen: Die Anschaffungskosten sind gering und die Qualität der Fänge sowie die Energie- und Fangeffizienz sind hoch. Dabei bestimmt die gewählte Maschenöffnung das Entnahmefenster für die Zielarten, und der Einfluss auf den Meeresboden ist sehr gering. Die Fänge gewährleisten die lokale und regionale Versorgung mit (Frisch-)Fisch und sichern so Arbeitsplätze in oft strukturschwachen küstennahen Regionen. Ferner fördert die Fischerei die kulturelle Identität und den Tourismus an den Küsten.

Gleichzeitig treten in diesen Fanggeräten aber auch unerwünschte Beifänge von Meeressäugern, Seevögeln sowie anderen geschützten und/oder gefährdeten Arten auf, was für einzelne Populationen eine Gefährdung darstellen kann. Außerdem können Meeressäuger wie Kegelrobben die Fänge und das Fanggerät der Fischer beschädigen. Unerwünschte Beifänge und Schäden an Fang und Fanggeräten führen somit vorhersehbar zu Konflikten zwischen Fischerei und Naturschutz. Dieses Spannungsfeld betrifft in der Bundesrepublik Deutschland vor allem die Ostseeküste, da dort der Großteil der deutschen Stellnetzkutter operiert; die Lösung dieser Konflikte ist aber aufgrund der weltweiten Nutzung von Stellnetzen de facto von globaler Relevanz.

Wesentliche Probleme bei der Entwicklung von Ansätzen zur Mitigation der Konflikte zwischen Naturschutz- und Fischereiinteressen sind (1) keine oder zu ungenaue Aufwandsdaten, (2) Beifangereignisse sind hoch variabel, sie sind selten, aber u.U. für die betroffene Population relevant und (3) zugrundliegende Mechanismen, die das Eintreten von Beifangereignissen erklären könnten, sind in Teilen unverstanden und deshalb in Experimenten derzeit nicht kontrollierbar.

In der Bundesrepublik Deutschland sind v.a. das Bundesministerium für Landwirtschaft und Ernährung (BMEL) und das Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU) sowie ihre Facheinrichtungen Thünen-Institut (Thünen) und Bundesamt für Naturschutz (BfN) mit der Lösung dieser gesellschaftlichen Herausforderung befasst.

Das Projekt STELLA („Entwicklung von alternativen Managementansätzen und Fangtechniken zur Minimierung der Konflikte zwischen der Stellnetzfischerei und Naturschutzzielen und Schutzgütern in der deutschen AWZ der Ostsee“) ist ein wichtiger Baustein in der Umsetzung der Beschlüsse der Staatssekretäre des BMU und des BMEL vom 13.04.2015. Demnach soll die Entwicklung alternativer Fangtechniken eine zentrale Rolle bei der Minimierung der Konflikte zwischen Fischerei und den Schutzzielen in den Natura 2000-Gebieten in der deutschen Ausschließlichen Wirtschaftszone (AWZ) der Ostsee spielen.

Das Projekt STELLA leistet somit einen direkten Beitrag zur Umsetzung relevanter Naturschutzrichtlinien (insbesondere Flora-Fauna-Habitat (FFH)- und Vogelschutz-Richtlinie) sowie der Meeresstrategie-Rahmenrichtlinie (MSRL) durch die Entwicklung von Ansätzen für eine Erfassung von Beifängen geschützter Arten (insbesondere Seevögel und Meeressäugetiere) und deren Reduktion und Vermeidung durch operative und technische Maßnahmen in der Stellnetzfischerei in der deutschen AWZ der Ostsee. Die Umsetzung von geeigneten Managementmaßnahmen in den marinen Natura 2000-Gebieten in der deutschen AWZ ist eines der wesentlichen Instrumente, um das Erreichen eines günstigen Erhaltungszustands von Arten und Lebensräumen zu gewährleisten.

Das Projekt trägt damit bei zum Schutz des marinen Ökosystems der Ostsee und der Erreichung der für die betroffenen Gebiete in der deutschen AWZ festgelegten Schutz- und Erhaltungsziele, wie sie im

Bundesnaturschutzgesetz, gemäß der FFH- und Vogelschutz-Richtlinie, der Nationalen Biodiversitätsstrategie (NBS) sowie der MSRL zum Ausdruck kommen. Es handelt sich dabei auch um die Wahrnehmung von hoheitlichen Aufgaben im Rahmen der Zusammenarbeit im Helsinki-Übereinkommen (HELCOM). Vor diesem Hintergrund sind der hier gewählte Ansatz und die daraus resultierenden Ergebnisse nicht nur für die Lösung der Beifang-Problematik im Bereich der deutschen Ostsee von Bedeutung, sondern potentiell auch für Fortschritte im internationalen Kontext relevant.

3.2 Ansatz

Der Ansatz des STELLA-Projektes unterscheidet sich grundlegend von vorherigen, unter anderem auch vom Bundesamt für Naturschutz (BfN) geförderten nationalen Projekten zur Stellnetzfischerei und alternativen Fangmethoden. Bisherige Projekte zur Verbesserung der Datenerhebung aus der Küstenfischerei und der Reduzierung der negativen Umweltauswirkungen der Stellnetzfischerei haben keine wesentlichen Durchbrüche erzielt.

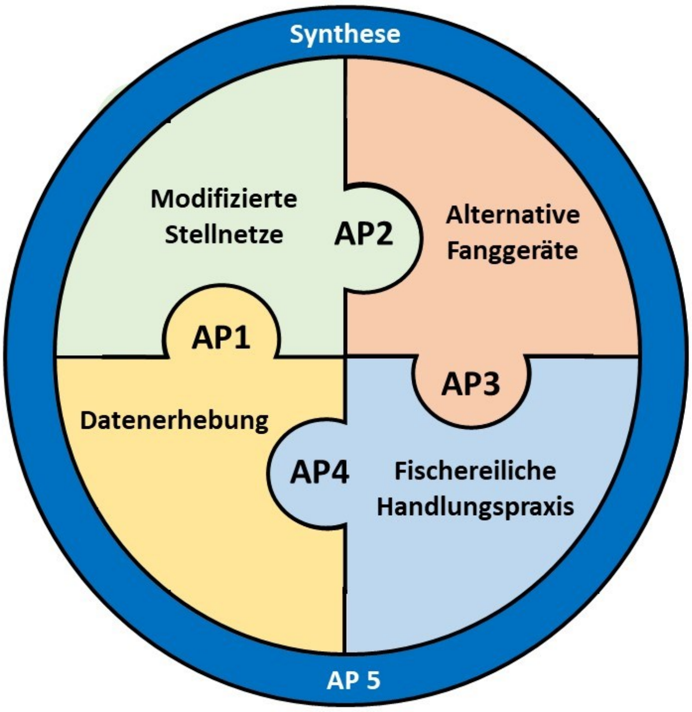
In STELLA folgen wir deshalb einem holistischen Ansatz, der mögliche Einflussfaktoren auf Beifangereignisse systematisch untersucht, indem wir verhaltensökologische, fischereitechnische, biologische und sozialwissenschaftliche Faktoren kombiniert und interdisziplinär untersuchen. Klare wissenschaftliche Vorgabe ist, dass die gewählte Methodik zwar dem speziellen Fall aus der Ostsee Rechnung trägt, aber darüber hinaus auch universelle Anwendbarkeit gewährleisten soll. Die methodischen Ansätze der einzelnen Arbeitspakete sind nachfolgend im Detail aufgeführt.

3.3 Struktur

Das STELLA-Projekt ist in die fünf Arbeitspakete (1) Datenerhebung, (2) Modifizierte Stellnetze, (3) Alternative Fanggeräte, (4) Fischereiliche Handlungspraxis und (5) Synthese unterteilt (Abbildung 1).

Gesamtziel dieses Vorhabens ist, zukunftsweisende Ansätze und signifikante Fortschritte auf dem Weg zur Lösung der bestehenden Konflikte zwischen den fischereilichen Aktivitäten der passiven Fischerei (v.a. der Stellnetzfischerei) und dem Schutz von Seevögeln und Meeressäugern in der deutschen AWZ der Ostsee zu erreichen. Dazu gehört eine verbesserte Kenntnis der passiven Fischereien und eine verbesserte Datenerhebung, Entwicklungen verbesserter Stellnetze und Alternativen zu Stellnetzen sowie ein besseres Verständnis des Handelns der Fischer, die die zentrale Rolle bei der Reduktion von ungewollten Beifängen spielen.

Abbildung 1: Schematische Übersicht der Struktur des STELLA-Projektes



Das **Arbeitspaket 1 - Datenerhebung** befasst sich vor allem mit der Unterteilung der Stellnetzflotte in einheitliche Gruppen für eine gruppen-orientierte Datenerhebung, Analyse und Ansprache sowie mit der Sammlung besserer Aufwandsdaten aus der Stellnetzfischerei durch die Entwicklung einer Smartphone-App.

Das **Arbeitspaket 2 – Modifizierte Stellnetze** entwickelt und testet mit Acrylglaskugeln besetzte Stellnetze, um den Beifang sich primär akustisch orientierender Meeressäuger wie Schweinswale zu reduzieren.

Im **Arbeitspaket 3 – Alternative Fanggeräte** wird das Verhalten von Dorschen an Fischfallen systematisch untersucht und erstmals eine schwedische Ponton-Hebereuse in deutschen Boddengewässern getestet und baulich optimiert.

Im sozialwissenschaftlichen **Arbeitspaket 4 – Fischereiliche Handlungspraxis** werden Fischer interviewt, um den allgemeinen Orientierungsrahmen und die Einstellungen der Fischer gegenüber Beifängen besser zu verstehen.

Die enge Verknüpfung der einzelnen Themenschwerpunkte und das daraus resultierende Gesamtverständnis ermöglichen es, ganzheitliche Konzepte und Lösungen zur Mitigation der unerwünschten Beifänge zu erarbeiten. Dies geschieht im **Arbeitspaket 5 – Synthese**, in dem zukünftiger Forschungsbedarf und Handlungsempfehlungen für das Management abgeleitet werden.

3.4 Besonderheiten

Das STELLA-Projekt ist in der Struktur und Ausgestaltung durch einige Besonderheiten charakterisiert, die rückblickend essentiell für die erfolgreiche Durchführung dieses Vorhabens waren.

Die Entscheidung, einen durchweg systematischen Forschungsansatz zu verfolgen, erforderte eine flexible Herangehensweise bereits in der Antragsphase des Projekts. Dies betraf insbesondere die beiden fangtechnischen Arbeitspakete „Modifizierte Stellnetze“ und „Alternative Fanggeräte“. Zum Zeitpunkt des Projektbeginns gab es eine Reihe möglicher Optionen im fangtechnischen Bereich, die konkret hätten verfolgt werden können. Unter Berücksichtigung der verfügbaren Ressourcen und der zeitlichen Limitationen wurden die Forschungsschwerpunkte nach einer mehrmonatigen intensiven Review- und Findungsphase festgelegt. In dieser Periode wurde der Forschungsstand zusammen mit internationalen Experten (z. B. aus Dänemark und Schweden) und das fangtechnische Verbesserungspotential in allen relevanten Teilbereichen evaluiert (z. B. zum Beifang von Meeressäugern, Beifang von Seevögeln, Erkenntnisstand zu Fischfallen usw.) und – basierend auf den Analysen des Status quo – Entscheidungen für das weitere Vorgehen getroffen. Die identifizierten Forschungsschwerpunkte wurden auf bereits laufende nationale und internationale Forschungsvorhaben abgestimmt und Forschungskooperationen vereinbart, um möglichst große Fortschritte und schnelle Umsetzbarkeit der Ergebnisse zu erzielen. Dies beinhaltete zum Beispiel eine enge Kooperation zwischen OF und DTU-Aqua in Dänemark zur Stellnetzmodifikation, die Arbeiten zu Fischfallen wurden in Zusammenarbeit mit der SLU in Schweden durchgeführt.

Damit verbunden war ein relativ unspezifisch gehaltener Investitionstitel für Fanggeräte, der dem Projekt genau die Freiheitsgrade verschaffte, die für die Verfolgung eines ergebnisoffenen, evidenzbasierten und systematischen Forschungsansatzes erforderlich waren.

Es muss erwähnt werden, dass der voraussichtlich größte Treiber für Veränderungen in der Stellnetzfischerei an der deutschen Ostseeküste, das Anwachsen der Kegelrobbenpopulation in den östlichen Untersuchungsgebieten, während der Konzeptionierung und der Startphase des Projektes nicht absehbar war. Soweit möglich wurden die Folgen insbesondere der umfangreichen technischen Interaktionen zwischen Fischerei und Kegelrobben berücksichtigt (Beschädigung von Fang und Fanggerät), z. B. bei der Weiterentwicklung der Ponton-Hebereuse, die nicht nur den Beifang und das Ertrinken von Seevögeln und Schweinswalen verhindern soll, sondern auch den von Kegelrobben. Die Auswirkungen der Interaktionen gehen aber natürlich weit über das hinaus, was durch Fischereitechnik adressiert werden könnte. Die Systematisierung der Fischergruppen und die Befragungen der Fischer konnten diese neuere Entwicklung nicht vollständig berücksichtigen. In die Bewertung der Vorschläge geht sie aber natürlich ein.

Eine weitere Besonderheit dieses Projektes war die transdisziplinäre Vorgehensweise durch die Kombination von drei naturwissenschaftlichen und einem sozialwissenschaftlichen Arbeitspaket innerhalb des gleichen Institutes. Im STELLA-Projekt förderte insbesondere die enge inhaltliche Verzahnung der Arbeitspakte Datenerhebung und Fischereiliche Handlungspraxis die transdisziplinäre Kommunikation und erhöhte das Verständnis für die verschiedenen Herangehensweisen.

3.5 Zur Struktur dieses Abschlussberichts

Dieser Bericht ist in zwei Teile gegliedert. Im ersten Teil fasst – nach dieser Einleitung – die Synthese die Ergebnisse der Arbeitspakete zusammen und leitet daraus zukünftigen Forschungsbedarf und Handlungsempfehlungen für die Politik ab. Im Anschluss finden sich die Zusammenfassungen der vier Arbeitspakete Datenerhebung, Modifizierte Stellnetze, Alternative Fanggeräte und Fischereiliche Handlungspraxis. Im zweiten Teil sind die Details bzw. Ergebnisse der Arbeitspakte in Form wissenschaftlicher Veröffentlichungen oder Berichte zu finden.

4 Arbeitspaket 5 – Synthese und Empfehlungen an die Politik

Das STELLA-Projekt war darauf angelegt, grundlegende Aspekte systematisch zu adressieren, die für die Entwicklung einer zukunftsfähigen kleinen Küstenfischerei an der deutschen Ostseeküste und hier insbesondere für die Mitigation der Interessenkonflikte zwischen Meeresnaturschutz und Fischerei wichtig sind. Das STELLA-Projekt konnte wesentliche Antworten hierfür liefern und Forschungslücken identifizieren. Aus der gemeinsamen Betrachtung der Ergebnisse der eng verzahnten Arbeitspakete lassen sich nun der zukünftige kurz- und mittelfristige Forschungsbedarf sowie Empfehlungen an die Politik ableiten.

Arbeitspaket 1, die Datenerhebung aus und Klassifizierung der kleinen Küstenfischerei, hat zwei wesentliche Aspekte adressieren können: Es wies erstens nach, dass die deutsche Stellnetzfischerei der Ostsee viel weniger homogen in Bezug auf Anlandeprofile, Fischereitaktiken und Fangstrategien ist als bisher angenommen, und identifizierte eine Reihe zeitlich und räumlich stabiler Gruppen von Fischern mit unterschiedlicher Fischereiaktivität. Die Berücksichtigung der Heterogenität ist wichtig, weil die Gruppen unterschiedlich auf Managementmaßnahmen reagieren. Die in AP 1 identifizierten Gruppen wurden auch für die Auswahl der Interviews in AP 4 genutzt. Sie dienen weiterhin dazu, zukünftige Maßnahmen zur Reduzierung unerwünschter Beifänge spezifischer gestalten zu können, was eine erfolgreiche Umsetzung von Maßnahmen wahrscheinlicher macht. Denn es erlaubt eine realistischere Abschätzung der positiven (Beifangreduzierung) und negativen Effekte (Zielartverluste) solcher Maßnahmen für einzelne Gruppen von Fischern statt für die gesamte deutsche kleine Küstenfischerei. Ferner ermöglicht eine differenziertere Betrachtung der Fischereigruppen, die Erfassung unerwünschter Beifangereignisse spezifisch anzupassen und dadurch die Datenqualität zu erhöhen und den Beprobungsaufwand gleichzeitig zu optimieren.

Zweitens wurden in AP1 die technischen Grundlagen für eine effiziente Datenerhebung geschaffen. Wir konzentrierten uns hierbei zunächst auf die Erfassung des Fischereiaufwandes der kleinen Küstenfischerei. Robuste Daten zum Fischereiaufwand der Stellnetzfischerei fehlen bislang fast vollständig, sie sind aber u.a. für die Hochrechnung von Beifängen und die Ableitung gezielter Schutzmaßnahmen essentiell. Wir setzten hierbei auf die Möglichkeiten der Digitalisierung und entwickelten eine leicht bedienbare und kostengünstige Smartphone-Applikation, die wir „Mofi“ („mobile fisheries log“) nennen. Wir konnten die Einführung und Anwendung der App im Rahmen einer Ausnahmeregelung von der Laichschonzeit für Dorsch testen: Fischer mit Fahrzeugen <12m Länge, die „Mofi“ verwendeten, durften im Februar und März flacher als 20 m Wassertiefe fischen, während die Fischerei zum gerichteten Fang von Dorsch in der westlichen Ostsee ansonsten untersagt war. Die Begleitung ermöglichte uns eine kontinuierliche Weiterentwicklung der App. Die verpflichtende Einführung ohne Alternative gegen unseren ausdrücklichen Rat durch die BLE (Bundesanstalt für Landwirtschaft und Ernährung in Hamburg, verantwortlich für Umsetzung von Fischereikontrolle- und management) erwies sich als kontraproduktiv und hat die Bereitschaft der Fischerei, die für sie entwickelte Software zu nutzen, stark reduziert. Die ablehnende Haltung der Fischerei zur Nutzung der App wurde durch einige technische Probleme, die zu Beginn der Einführung noch nicht beseitigt waren, und das Fehlen einer iOS-Version noch verstärkt. Dabei haben wir gelernt, wie wichtig die Schaffung geeigneter Anreize für die Bereitschaft der Fischerei ist, Aufwandsdaten zu liefern, denn der Anreiz (Ausnahme von der Laichschonzeit) war in diesem Fall stark genug, um trotz der erheblichen Vorbehalte ausreichende Daten zu erheben. Außerdem wurde deutlich, dass selbst bei der sehr einfachen Bedienbarkeit der App eine intensive Nutzerbetreuung bei der Einführung einer solchen Technologie erforderlich ist, und wie essentiell die frühzeitige Beteiligung der Fischerei, Testläufe und die Adressierung von Datenschutzaspekten früh in der Entwicklung sind.

Ungeachtet dieser Probleme in der ersten Implementierungsphase Anfang Februar 2018 konnten wir den Nachweis führen, dass es auf Fahrzeugen aller Größe möglich ist, mit einer Smartphone App wie „Mofi“

hochaufgelöste Aufwandsdaten mit minimaler Belastung für die Fischerei zu erheben. Da lediglich ein Smartphone mit GPS-Empfang erforderlich ist, um die App zu nutzen, könnte dieses Tool unverzüglich und europaweit eingeführt werden. Nach dem Entwurf der neuen EU-Kontrollverordnung ist vorgesehen, eine umfangreiche Dokumentation der Fischereiaktivität und -fänge für die kleine Küstenfischerei verpflichtend vorzuschreiben. Allerdings fehlt weiterhin eine verpflichtende Erhebung von Daten zu unerwünschten Beifängen von Meeressäugern und Seevögeln. Die vorgesehene vierjährige Übergangsfrist für die vollständige Implementierung dieser neuen Kontrollverordnung erscheint uns zumindest aus technischer Sicht nicht erforderlich. Wir nehmen an, dass diese lange Frist eingeräumt wurde in der Absicht, die kleine Fischerei zu schonen – tatsächlich ist diese vermeintliche Schonung aber kontraproduktiv: Nur durch mehr Transparenz, also vollständige Dokumentation der Fischereiaktivität einschließlich Fängen und Beifängen geschützter, gefährdeter oder empfindlicher Arten, kann die Zukunft der Küstenfischerei gesichert werden, denn nur dadurch ist eine nachhaltige Ressourcennutzung auf hohem Niveau (nach MSY-Ansatz) möglich, nur dadurch können pauschale Verbote und großräumige Ausschlüsse vermieden werden, und nur durch Transparenz kann der derzeit schlechte Ruf der Fischerei als nicht auf den Erhalt der Meeresumwelt bedachter Wirtschaftszweig verbessert werden. In jedem Fall ist die deutsche Fischerei und die Fischereikontrolle, die bisher anführten, dass elektronische Monitoringsysteme (EM) auf kleinen Fahrzeugen der deutschen Küstenfischerei nicht einsetzbar seien, nun technisch mit „Mofi" für die Anforderungen der neuen Kontrollverordnung gut vorbereitet.

Abweichungen vom Arbeitsplan: In AP1 war geplant, eine Reihe von Fahrzeugen mit umfangreicheren Elektronischen Monitoringsystemen auszustatten, insbesondere mit Kameras (Englisch: Closed Circuit Television - CCTV) ausgestattete EMs, die eine unabhängige Verifikation der Beifänge von Meeressäugern und Seevögeln ermöglichen. Auch hierfür waren verschiedene Anreizszenarien vorgesehen, die eine langfristige Mitwirkung von Fischern sicherstellen sollten. Leider konnte – bis auf die Ausnahme von der Laichschonzeit – keines der vorgesehenen Szenarien realisiert werden: Die MSC-Zertifizierung der passiven Heringsfischerei im 1. und 2. Quartal in Mecklenburg-Vorpommern wurde vor allem wegen des schlechten Bestandszustandes der Zielart, aber auch wegen möglicher Beifänge von Schweinswalen gestoppt. Zudem war die Fischerei in Schleswig-Holstein nach der zwangsweisen Einführung der Mofi-App durch die BLE so wenig bereit für eine weitere Zusammenarbeit, dass eine generelle Aufnahme der Aufwandserfassung in die Freiwillige Vereinbarung zwischen Fischerei und MELUND nicht durchsetzbar war. Auch die Einrichtung einer Art „Referenzflotte" mit interessierten Fischern, mit dem Anreiz, an technischen Entwicklungen schneller partizipieren zu können und die Kooperation zwischen Fischern und Forschern medial zu begleiten, ist über das Anfangsstadium bislang nicht hinausgekommen. Hier war der Druck innerhalb der Fischerei auf die wenigen Freiwilligen offenbar sehr hoch, nicht aus der ablehnenden Phalanx auszuscheren. Außerdem sorgten die erforderlichen starken Quotenreduzierungen für Dorsch und Hering ab 2019 für derartige Existenznöte in der Küstenfischerei, dass die langfristigen Vorteile durch eine engere Kooperation und die Verbesserung des Rufs in der Priorität weit nach hinten rückten.

Zukünftiger Arbeitsbedarf und Entwicklungen: Die Mofi-App ist so modular entworfen, dass sie nicht nur leicht lokalisiert (verschiedene Sprachversionen sind jetzt schon vorhanden), sondern auch um verschiedene Elemente erweitert werden kann. So ist die App bereits so ergänzt worden, dass sie in naher Zukunft für die fotografische Dokumentation von Fraß- und Netzschäden durch Kegelrobben an Fischereigeräten auf See genutzt werden kann. Diese Dokumentation kann dann für Ausgleichszahlungen des Landes Mecklenburg-Vorpommern verwendet werden, die nicht auf der Basis von Pauschalzahlungen („Gießkannenprinzip"), sondern am tatsächlich entstandenen Schaden bemessen wird. Ein solcher Ansatz schafft Anreize, Daten zu erheben, die anschließend der Allgemeinheit zur Verfügung gestellt werden können. Hier kann die Interaktion zwischen Robben und Fischerei – Wegfraß gefangener Fische und Zerstörung der Fanggeräte einerseits, Schutz des Fangs vor den Robben und Schutz der Robben vor dem Ertrinken in Fanggeräten andererseits – nur adressiert werden, wenn bessere Daten vorliegen. So könnte es möglich sein herauszufinden, warum und wo genau an bestimmten Tagen Netzschäden auftreten, an anderen aber nicht. Dieses Verständnis ist wiederum die Voraussetzung für maßgeschneiderte Lösungen, um Schäden durch Robben zu reduzieren – z.B. für Empfehlungen, wo an einem bestimmten Tag und Ort geringere Schäden zu erwarten sind. Diese Daten können nun mit „Mofi“ erhoben werden. Der Ansatz ist damit ein gutes Beispiel für die Umsetzung des Prinzips „öffentliche Mittel nur gegen bessere Daten“. Die Erweiterung der App ist schon eingebettet in die Entwicklung eines „Konfliktmanagementplans Fischerei-Kegelrobben“ des Landes MV, die aber leider coronabedingt hinter dem Zeitplan liegt.

Die Anwerbung kooperierender Fischer, die nicht nur möglichst flächendeckend ihren Aufwand und die Aktivität dokumentieren, sondern mittelfristig auch bereit sind, zumindest in repräsentativer Zahl Kamerasysteme einzusetzen, hat weiter hohe Priorität. Die Auswahl sollte repräsentativ für die in AP1 identifizierten Fischercluster erfolgen. Im Rahmen eines mit Schleswig-Holstein diskutierten Projektes zum erneuten Test des Porpoise Alert (PAL, siehe unter „AP2 – zukünftige Entwicklungen“ für mehr Details) könnten sich hierfür neue Möglichkeiten ergeben. Wir haben jedoch gelernt, dass diese Art der Kooperation Vertrauen der Akteure benötigt und der Aufbau eines solchen belastbaren Verhältnisses sehr zeit- und betreuungsaufwändig ist (siehe auch AP4). Kurzfristige Erfolge sind daher nicht erwartbar.

<u>Empfehlungen:</u> Wir empfehlen, möglichst bald mit der flächendeckenden Erhebung von Aufwandsdaten zu beginnen – hierfür kann auf Fahrzeugen jeder Größe die im Rahmen dieses Projekts entwickelte Smartphone-Applikation „Mofi“ eingesetzt werden –, und zeitlich versetzt mit der Verifizierung von Beifängen mit Hilfe von elektronischen Monitoringsystemen. Für die Nutzung von elektronischen Monitoringsystemen sollten Anreize geschaffen werden, die spezifisch für die Bedürfnisse der identifizierten Fischereigruppen sind; Quotenzuschläge und Zugangserleichterungen erscheinen dabei als ein stärkerer Anreiz als monetäre Beihilfen (siehe AP4). Insbesondere die Gewährung öffentlicher Fördermittel sollte mit einer Verbesserung der Datenlieferung verbunden werden. Das Umfeld, in dem die Fischerei operiert, wird zunehmend schwieriger: Verringerte Produktivität der Zielartbestände durch schnelle Änderungen der Umweltbedingungen (z.B. Klimawandel, Eutrophierung) und dadurch erforderliche niedrigere Quoten, Rückkehr der Kegelrobben und dadurch geringere Wirtschaftlichkeit der Herings-Stellnetzfischerei, kritische Wahrnehmung der Fischereitätigkeit in der Öffentlichkeit. Für die einzelnen identifizierten Fischereigruppen sollten daher maßgeschneiderte Lösungen entwickelt werden, wie einerseits eine wirtschaftlich tragfähige deutsche Küstenfischerei sichergestellt werden kann und andererseits die Umweltauswirkungen reduziert werden können. Hierfür ist die zeitnahe Entwicklung einer Gesamtstrategie erforderlich, die so viele Betriebe und Häfen wie möglich im Geschäft hält und nicht nur die Seeseite (Fänge und Umweltauswirkungen), sondern auch die Landseite (Infrastrukturen) mitdenkt. Diese Strategieentwicklung muss alle beteiligten Akteure einbeziehen. Der derzeitige Managementansatz führt in der deutschen Ostseeküstenfischerei in Richtung „Mediterranisierung“, also durch den Verlust größerer Fahrzeuge zu einer Dominanz kleinerer Fahrzeuge, viele davon im Nebenerwerb mit geringer Quotenausstattung, deren Aktivitäten schwerer zu kontrollieren sind als die der größeren Fahrzeuge. Ohne ein Gegensteuern der Politik werden entscheidende Strukturen an Land (wie die Erzeugerorganisationen) bereits in den nächsten Jahren zusammenbrechen. Denn diese Strukturen werden fast ausschließlich von der Haupterwerbsfischerei und größeren Fahrzeugen erhalten. Es muss angenommen werden, dass die unerwünschten Beifänge von Meeressäugern und Seevögeln mit dem Fischereiaufwand skalieren und nicht mit der offiziellen Anlandemenge. Die „Mediterranisierung“ könnte daher zu einer Erhöhung dieser Beifänge führen.

Arbeitspaket 2, die Modifikation von Stellnetzen, konzentrierte sich nach einer intensiven Literaturrecherche und Phase des Austauschs mit deutschen und internationalen ExpertInnen vor allem auf die Reduzierung von Schweinswalbeifängen in Stellnetzen. Im Rahmen des STELLA-Projektes wurde die akustische Sichtbarkeit von Stellnetzen erstmals systematisch verbessert. Die Untersuchungen identifizierten kleine Acrylkugeln, die durch

Resonanz ein starkes Echo geben, ohne die Fängigkeit des Netzes maßgeblich zu beeinflussen, als eine geeignete Modifikation. Modellierungen und erste Tests in der Fischerei lieferten vielversprechende Ergebnisse. Wie erwartet waren aber die Beifangraten von Schweinswalen in der für den Versuch zugänglichen Fischerei so gering, dass sie für eine statistisch valide Beurteilung noch nicht ausreichten – dafür müsste entweder die Anzahl der verglichenen Netze oder die Beobachtungsdauer weiter erhöht werden.

Technische Lösungen können vergleichsweise einfach helfen, die Umweltauswirkungen einer Fischerei zu reduzieren, denn sie können in vielen Fällen mit geringen Änderungen des Fischer-Verhaltens und damit zügig implementiert werden. Die systematischen Untersuchungen in den technischen Arbeitspaketen 2 und 3 des STELLA-Projektes zeigten, dass die verschiedenen in der Fischerei eingesetzten Fanggeräte ein hohes Entwicklungspotential aufweisen, obwohl sie teilweise schon seit sehr langer Zeit im Einsatz sind. Ein Grund hierfür dürfte sein, dass die Fanggeräte bislang nicht auf das Ziel „geringere Umweltauswirkungen“, z.B. durch verbesserte Selektivität, optimiert wurden und damit Umweltkosten externalisiert wurden. Die vielversprechenden Ergebnisse, die hier in vergleichsweise kurzer Zeit erzielt werden konnten, lassen hoffen, dass der Einsatz alternativer Fangmethoden in Kombination mit spezifischen, auf die jeweiligen Fischereien und Fanggebiete abgestimmten zusätzlichen Maßnahmen eine Alternative zu großräumigen und dauerhaften Fischereiausschlüssen sein könnte und die Schutzziele trotzdem erreicht werden könnten.

<u>Abweichungen vom Arbeitsplan:</u> Ursprünglich war geplant, in AP2 auch unerwünschte Beifänge von Seevögeln zu adressieren. Es zeigte sich jedoch, dass am Anfang systematischer Entwicklungen zur Beifangmitigation zunächst Wissen über die Ursachen der Beifänge, also dem Verhalten der Seevögel am Fanggerät vorhanden sein muss. Es wurde schnell klar, dass die Mechanismen des Beifangvorgangs bei heimischen Seevögeln weitgehend unbekannt und auch noch von Art zu Art unterschiedlich sind. In Kooperation mit dem Forschungs- und Technologiezentrum Westküste (FTZ) der Universität Kiel wurden entsprechende Untersuchungen begonnen, die jedoch aus technischen Gründen abgebrochen wurden. Ziel dieser Untersuchungen war es, das Verhalten von tauchenden Seevögeln zu untersuchen und somit Rückschlüsse auf die möglichen Mechanismen der Interaktion mit Stellnetzen zu schließen. Dabei waren insbesondere Aspekte wie tageszeitliche Muster in der Tauchaktivität, Tauchtiefenprofile und Tauchdauer von Interesse. Hierfür sollten neuentwickelte Datenlogger eingesetzt werden. Im Laufe der Versuche zeigte sich jedoch, dass ausgerechnet die Datenaufzeichnung der für die o.g. Fragestellung wichtigen Tauchtiefe nicht zuverlässig funktionierte. Aus diesem Grund wurden die entsprechenden Arbeiten in STELLA nicht weitergeführt. Gemeinsam mit DTU Aqua, Dänemark, wurden im Rahmen von STELLA Untersuchungen zur Sichtbarmachung von Stellnetzen durch Licht zur Reduzierung von Seevogelbeifängen durchgeführt; aber auch dies war leider erneut, wie in verschiedenen anderen vorher durchgeführten Versuchen auch, nur ein Beispiel für das erfolglose Testen einer eher zufällig entstandenen Idee, ohne dass klar war, wie die Modifikation genau Beifänge reduzieren soll. Für eine systematische Suche nach Lösungen des Seevogelbeifang-Problems ist eine erhebliche Steigerung des Grundlagenwissens zum Verhalten von Seevögeln bei der Nahrungssuche notwendig. Im STELLA-Projekt war die erforderliche Grundlagenforschung nicht zu leisten. Die Ressourcen wurden daher auf die Vermeidung von Schweinswalbeifängen konzentriert.

<u>Zukünftiger Arbeitsbedarf und Entwicklungen:</u> Weitere Tests mit dem „Perlennetz“ sind erforderlich, sowohl Feldversuche in der kommerziellen Fischerei wie auch Experimente zur genauen Wirkungsweise der akustisch „sichtbareren“ Stellnetze. Die Wiederholung der ergebnislosen Versuche zur Beeinflussung des Verhaltens der Schweinswale in Dänemark ist bereits für 2021 geplant (siehe Beschreibung von Arbeitspaket 2 unten). Für diese Arbeiten konnte eine Zuwendung der US National Oceanographic and Atmospheric Administration (NOAA) für 18 Monate eingeworben werden. Auch die International Whaling Commission hat Interesse an den Arbeiten am „Perlennetz“ bekundet; da es ein rein physikalisches Prinzip nutzt, sollte es für viele kleine Zahnwalarten verwendbar sein – wobei geringfügige Anpassungen an die Ortungsfrequenzen anderer Arten erforderlich sind. Dabei könnte die Effizienz u. U. noch gesteigert werden, wenn das „Perlennetz“ in Verbindung mit akustischen Signalen wie PAL (der art-eigene Warnlaute aussendet) eingesetzt wird. Denn auch

eine gute akustische „Sichtbarkeit“ des Netzes reduziert die Beifänge nur dann, wenn die Schweinswale in Bereichen mit Stellnetzen ihre Echolokation auch nutzen. Durch eine „aktive“ Warnung sich annähernder Schweinswale könnten Schweinswale angeregt werden, die akustische Orientierung zu intensivieren und die Perlennetze dann noch besser erkennen.

Die größte Herausforderung zum weiteren Testen und dann auch zur Einführung in der kommerziellen Fischerei ist aus derzeitiger Sicht allerdings die Entwicklung eines Verfahrens zur mechanisierten Herstellung des „Perlennetzes“. Die bisherige Methode, das rein manuelle Vorbereiten und Einkleben der Perlen, ist ausgesprochen arbeits- und zeitintensiv. Dies beschränkt die Tests sehr und verlängert den Zeitraum erheblich, bis eine statistisch valide Aussage zur Wirksamkeit getroffen werden kann. Wir haben Kontakte mit interessierten Firmen aufgenommen, die für die Entwicklung von geeigneten Verfahren in Frage kämen. Ohne eine Anschubfinanzierung z. B. aus Innovationsfördermitteln erscheint den angefragten Unternehmen das wirtschaftliche Risiko aber noch zu hoch.

Die Reduzierung von Seevogelbeifängen in der kommerziellen Fischerei bleibt ein drängendes Thema. Allerdings fehlen wie oben geschildert grundlegende Kenntnisse zum Verhalten der wichtigsten Arten und bei der Nahrungssuche unter Wasser und damit dem Verhalten, das zu Beifängen führt. Diese Erkenntnisse müssten so bald wie möglich von geeigneten Forschungseinrichtungen erzielt werden, bevor mit der systematischen Entwicklung technischer Lösungen begonnen werden kann. Bis dahin bieten sich lediglich alternative Fanggeräte, die Vogelbeifang verhindern, und die Ableitung möglichst spezifischer zeitlicher und räumlicher Schließungen der Stellnetzfischerei zur Beifangreduzierung an. Die dafür benötigten belastbaren Aufwands- und Beifangdaten sollten deshalb so schnell wie möglich in einem kooperativen Ansatz von Fischerei, Kontrollbehörden und Wissenschaft erhoben werden (siehe AP1).

Empfehlungen: Wir empfehlen, nach hoffentlich erfolgreichem Beleg der Wirksamkeit des „Perlennetzes“, dieses möglichst zügig in der kommerziellen Fischerei einzuführen, in allen Gebieten, in denen kleine Zahnwale beigefangen werden. Um die Einführung zu beschleunigen, erscheint uns bei übersichtlichen Kosten für die Verwendung der neuen Netze hier eine entsprechende Verpflichtung, also eine regionale, gesetzliche Lösung, zielführender als die freiwillige Verwendung nach Schaffung von Anreizen.

Arbeitspaket 3, die Entwicklung von Alternativen zum Stellnetz, untersuchte Fischfallen und Hebereuse auf Anwendbarkeit in der deutschen Küstenfischerei. Diese Geräte haben ein hohes Potential, den unerwünschten Beifang von Seevögeln und Meeressäugern zu vermeiden. Sie haben aber im Vergleich zum Stellnetz erhebliche Nachteile in der Fängigkeit und im erforderlichen Arbeitsaufwand beim Einsatz. Bei den Arbeiten zur Fischfalle lag der Schwerpunkt auf der Erhöhung der Fängigkeit, um sie überhaupt als Alternative zum hocheffizienten Stellnetz attraktiv zu machen. Im Projekt wurde insbesondere der Einfluss verschiedener Modifikationen von Fischfalleneingängen auf die Fängigkeit systematisch untersucht. Durch die systematischen Versuche konnten Fischfalleneingänge identifiziert werden, die sowohl das Hineinschwimmen der Fische in die Fischfalle erleichtern und gleichzeitig das Entkommen aus der Fischfalle verhindern. Die erforderlichen Änderungen zur Verbesserung konventioneller Fischfallen erscheinen vergleichsweise überschaubar, sind aber essentiell für eine Verbesserung ihrer Fängigkeit und damit der Wettbewerbsfähigkeit im Vergleich zu anderen Fanggeräten – insbesondere Stellnetzen.

Bei der Hebereuse standen Aspekte der Hantierbarkeit und die Anpassung an das heimische Meeresgebiet im Vordergrund. Dabei waren umfangreiche Änderungen in der Konstruktion erforderlich. Damit ist der Nachweis gelungen, dass sich auch alternative Fanggeräte systematisch so weiter entwickeln lassen, dass sie in absehbarer Zeit als Alternative für Stellnetze zur Verfügung stehen könnten – zumindest überall dort, wo es sonst keine akzeptablen Lösungen gibt. Als wichtigster Treiber für die Einführung alternativer Fanggeräte wird sich in naher Zukunft jedoch zumindest in den östlichen Gebieten der deutschen Ostseeküste die Rückkehr der

Kegelrobben erweisen. Denn Beschädigungen von Fang und Fischereigerät in der Stellnetzfischerei sowie die Notwendigkeit, das Ertrinken von Kegelrobben in diesen Netzen zu verhindern, werden wahrscheinlich die Unterschiede in der Rentabilität zugunsten alternativer Fanggeräte ändern. Dieser Faktor war zu Beginn des STELLA-Projektes noch nicht absehbar. Das intrinsische Interesse der Fischerei an Fanggeräten, die (i) den wertvollen Fang dem Zugriff der Robben entziehen, die (ii) hinreichend robust sind, um nicht von Kegelrobben beschädigt werden, und die (iii) für Robben keine Gefährdung darstellen, wird sehr schnell steigen. Jede zusätzliche Verbesserung der Fängigkeit und Handhabbarkeit der alternativen Fanggeräte wird diesen Prozess beschleunigen und die Akzeptanz der Geräte noch erhöhen.

<u>Abweichungen vom Arbeitsplan:</u> Wir hatten gehofft, bis zum Projektende eine optimierte Fischfalle entwickelt und erprobt zu haben. Bis zum Stadium eines Prä-Prototypen ist allerdings noch zusätzliche Entwicklungsarbeit erforderlich. Da wesentliche Voraussetzungen zur weiteren Entwicklung erfolgt sind, insbesondere zur Verhaltensbeobachtung an Fallen, sollten die noch ausstehenden Schritte zügig erfolgen können.

<u>Zukünftiger Arbeitsbedarf und Entwicklungen:</u> Die systematische Weiterentwicklung von Fischfalle und Hebereuse wird ohne Unterbrechung, aber mit geringerer Intensität, aus Hausmitteln des Thünen-Instituts für Ostseefischerei fortgeführt, mit dem Ziel, diese Geräte möglichst schnell in den kommerziellen Einsatz zu bringen. Zum Beispiel konnte aus Dänemark inzwischen eine weitere Ponton-Hebereuse akquiriert werden, die nun ebenfalls umgebaut wird und im schleswig-holsteinischen Ostseegebiet eingesetzt werden soll, um sie nach den Boddengewässern auch an der Außenküste zu testen. Die Ergebnisse aus diesen Tests sollten, schon um die Akzeptanz zu erhöhen und Hinweise der Fischerei zeitnah einfließen zu lassen, in enger Kooperation in die Entwicklung des Konfliktmanagementplans Fischerei-Kegelrobben (KFK) des Landes Mecklenburg-Vorpommern oder anderen Gesprächskreisen in Schleswig-Holstein (z.B: lokale Fischerei-Aktionsgruppe, FLAG) eingebettet werden. Weiterer Entwicklungsbedarf bei der Optimierung von Fischfallen umfasst die Aspekte der Köderwahl, Handhabbarkeit, Beifangvermeidung und Sicherung des Fangs vor Robben.

<u>Empfehlungen:</u> Wir empfehlen die kontinuierliche Weiterentwicklung der alternativen Fanggeräte, zunächst vor allem eingebettet in die Entwicklung eines Konfliktmanagementplans Fischerei-Kegelrobben. Die Entwicklung dieses Plans bietet unerwartete Chancen, zeitnah und mit vorbildlicher Akteursbeteiligung diese Fanggeräte als echte Alternative zum Stellnetz zu etablieren. Die Verwendung der Fanggeräte-Alternativen ist unter den sich ändernden Bedingungen so sehr im Interesse der Fischerei, dass die Einführung freiwillig erfolgen und durch geeignete maßgeschneiderte Anreize unterstützt werden sollte. Fangquotenzuschläge und Zugangsrechte für ansonsten gesperrte Gebiete und Zeiten erscheinen hier sinnvoller als monetäre Anreize bzw. Ausgleichzahlungen, denn offenbar ist die reine Ausgleichszahlung für Fangeinbußen bei Verwendung einer Fangmethode mit geringeren Umweltauswirkungen nicht ausreichend attraktiv für die Fischerei (siehe AP4).

Das sozialwissenschaftliche **Arbeitspaket 4 zur fischereilichen Handlungspraxis in Bezug auf die Vermeidung unerwünschter Beifänge** adressierte die soziale Dimension der Stellnetzfischerei und ergänzt dadurch die biologisch-technischen Arbeitspakte zu einem multidisziplinären Projekt. Auf der Basis aufwändiger Interviews konnte mit Hilfe von Methoden der qualitativen Sozialforschung eine Typologie von Fischern aufgrund ihrer Einstellungen zu unerwünschten Beifängen und ihrer fischereilichen Handlungspraxis erfolgen. Die Auswahl der Fischer basierte auf Analysen aus AP1. Es wurden drei Fischertypen und zwei verschiedene Einstellungen zum Thema Beifang indentifiziert. Die drei Typen waren: (i) iterativ – diese meist vergangenheitsorientierten Fischer sind meist spezialisiert und wenig zugänglich für neue Routinen, (ii) evaluativ – diese eher gegenwartsorientierten Fischer wägen ab, ob die Anwendung neuer Handlungsschemata angebracht ist und (iii) projektiv – diese zukunftsorientierten Fischer entwickeln und verwenden bereitwillig neue Handlungsschemata, handeln meist aber aus intrinsischer Motivation, unabhängig von sich veränderten Strukturen. Die Typologie der Fischer ermöglicht es, technische Lösungen (aus AP2 & AP3) und Maßnahmen (aus den Expertenworkshop in AP4) gezielt einzusetzen. So ist die Verwendung von neuem Fanggerät bspw. zugänglicher für projektive und evaluative Typen. Iterative Typen hingegen sehen keine Alternative zum Stellnetz, so dass sie am ehesten über Regularien zu erreichen sind. Als ein weiteres Ergebnis konnten wir zwei unterschiedliche Diskurse um das Thema Beifang identifizieren. Während der Beifang von Seevögeln meist normalisiert wurde, wurde Beifang von marinen Säugern meist nicht normalisiert. Das bedeutet, dass Beifangereignisse von Seevögeln von den Fischern als akzeptabel thematisiert wurden. Beifangereignisse von Schweinswalen hingegen wurden eher als Ereignisse beschrieben, die Fischer kognitiv verarbeiten müssen und für deren Vermeidung sie aktiv nach Lösungen suchen. Die Erkenntnisse aus dem Bereich des Beifangdiskurses legen nahe, dass ein zentrales Element für die Beifangvermeidung der Diskurswandel ist. Insgesamt wurden mehrere politische Maßnahmen recherchiert und im Kontext der Erkenntnisse aus der Typologie, dem Diskurs und einem Expertenworkshop analysiert. Eine Erkenntnis betrifft monetäre Anreize, welche als nicht zielführend eingeschätzt werden: Einerseits wurde im Expertenworkshop bestätigt, dass es aktuell ausreichend finanzielle Unterstützung gibt, andererseits haben die Interviews gezeigt, dass die meisten Fischer ihren fischereilichen Aktivitäten nachgehen wollen wie bisher und z.B. keine Kompensation beantragen wollen, um nicht fischen zu gehen. Die Ergebnisse geben wichtige Hinweise auf zukünftige Strategien zur erfolgreichen und effizienten Einführung von beifangvermeidenden Methoden und Verhalten: (1) Regularien und die Einführung alternative Fanggeräte müssen strukturell an die drei vorherrschenden Fischertypen angepasst sein, um ein hohes regelkonformes Verhalten (Compliance) zu erreichen und (2) Umweltbildung und Co-Management sind zentrale Elemente, um ein Umdenken im Diskurs, also unter anderem in den Einstellungen der Fischer zu erreichen, so dass Beifang als nicht normal oder akzeptabel angesehen wird. Ein Beispiel für einen Co-Management-Prozess ist eine freiwillige Vereinbarung. Solche Vereinbarungen könnten z.B. in den Küstengewässern, in denen nur deutsche Fischer Fangrechte besitzen, realisierbar sein, vorausgesetzt, die Erhebung von Aufwands- und Beifangdaten und ein hoher Grad an Einhaltung der Regeln („compliance“) sind gewährleistet. Wir haben in diesem AP viel gelernt über die Kooperation mit der Fischerei, und wie aufwändig und langwierig der Aufbau eines vertrauensvollen Verhältnisses ist, um gemeinsam und ohne Misstrauen an Lösungen zu arbeiten. Erste Schritte sind erfolgt, allerdings erfordert das Verbessern eines Vertrauensverhältnisses eine aktive und kontinuierliche Kommunikation samt stabiler organisatorischer Strukturen. Solche Strukturen könnten eine Stiftung, NGO oder dergleichen sein, wie sie bereits in Schleswig-Holstein mit dem Ostseeinformationscenter Eckernförde vorhanden ist.

Abweichungen vom Arbeitsplan: Die anfangs geplante quantitative Erfassung von Daten zu unerwünschten Beifängen geschützer Arten durch Interviews, um unabhängige Hinweise auf tatsächliche Beifangzahlen abzuleiten, konnte nicht umgesetzt werden. In der Durchführung der Interviews stellte sich heraus, dass den Fragen ausgewichen oder widersprüchliche Angaben gemacht wurden. Wir haben gelernt, dass Befragungen zur Erhebung von belastbaren Beifangzahlen ungeeignet sind, da das Thema Beifang sehr sensibel ist und die Fischer aufgrund der empfundenen Stigmatisierung der Fischerei nur bedingt auskunftsbereit sind.

Zukünftiger Arbeitsbedarf und Entwicklungen: AP 4 hat mit der Typologie der Fischer die Grundlage für zukünftige, gezielte Maßnahmen geliefert. Um die dominierende Gruppenausprägung zu quantifizieren und zukünftige Managementmaßnahmen auf diese Gruppe zu fokussieren, ist nun die Typologie der gesamten deutschen Stellnetzfischerei notwendig. Ein weiterer Untersuchungsgegenstand wäre die vertiefte Erhebung des Beifangdiskurs (siehe oben: Wahrnehmung von Beifängen geschützter Arten als Problem), um zu erforschen, wie Co-Management-Ansätze diesen beeinflussen und potentiell ändern können. Die sozialwissenschaftlichen Arbeiten werden z. B. im Rahmen des DAM-Projektes „Mobile Grundberührende Fischerei“ zur Evaluierung von Schutzgebieten in der AWZ fortgeführt[1]. Synergien bestehen auch mit dem

---

[1] https://www.thuenen.de/de/of/projekte/fischerei-umwelt-ostsee/was-sind-die-auswirkungen-nach-einsatz-eines-bodenschleppnetzes-mgf-ostsee-fisch/

laufenden BMBF-Projekt „marEEshift“[2], dass ein sozialwissenschaftliches Arbeitspaket hat, sowie mit der Entwicklung des Konfliktmanagementplans Fischerei-Kegelrobben im Land Mecklenburg-Vorpommern.

Empfehlungen: Wir empfehlen, sozialwissenschaftliche Aspekte bei der Konzeptionierung und Durchführung von Maßnahmen zur Reduzierung der Umweltauswirkungen der Fischerei von Anfang an mit einzubeziehen, und für jede Maßnahme eine umfassende Beteiligung aller Akteure vorzusehen. Dies mag zu Beginn aufwändig erscheinen, spart aber bei der Implementierung voraussichtlich so viel Zeit und Energie, dass es sich in der Summe lohnt – ganz abgesehen davon, dass die Akteursbeteiligung inzwischen einfach State-of-the-Art für solche Vorhaben ist. Das Schaffen von sorgfältig auf die spezifische Zielgruppe zugeschnittenen Anreizen hilft zu verdeutlichen, dass die Maßnahmen auch im Interesse der Fischerei liegen. Ziel muss es sein, zu einem echten Co-Management in der Fischerei zu kommen, das Interessen des Naturschutzes berücksichtigt, aber die Fischerei nicht als Gegner im Prozess behandelt. Wir empfehlen die Schaffung von Strukturen in Mecklenburg-Vorpommern zur Änderung des Beifangdiskurses, in Anlehnung an die freiwillige Vereinbarung in Schleswig-Holstein mit einer vermittelnden Organisation (in SH: Ostsee Info-Center) und zusätzlich einer Kontrollmöglichkeit der Effizienz des Ansatzes. Für Fischertypen, die durch freiwillige Maßnahmen nicht zu erreichen sind, erscheinen angepasste Regularien (z. B. Echtzeit-Gebietsschließungen) das zielführendere Bewirtschaftungsinstrument.

Insgesamt war der gewählte streng wissenschaftlich-systematische Ansatz des STELLA-Projektes aus unserer Sicht sehr erfolgreich. Die hier erzielten Ergebnisse können nicht sofort umgesetzt werden, zeigen aber den in Zukunft zu beschreitenden Weg auf. Die uns durch den Mittelgeber gewährten Freiheiten waren ein Garant für die Erreichung zentraler Projektziele. Die Ergebnisse haben die Grundlage für vielfältige weitere Forschung gelegt. Die meisten offenen Forschungsstränge werden unmittelbar fortgeführt, teilweise wegen des hohen Eigeninteresses aus Eigenmitteln des Thünen-OF; für einige sind bereits weitere Drittmittel-Finanzierungen innerhalb eines halben Jahres nach Projektende entstanden. Dies gewährleistet eine intensive weitere Forschung.

Die Ergebnisse sind geeignet, wesentliche Konflikte zwischen Naturschutz und Naturnutzung – hier durch die Fischerei – zu mitigieren. Wir haben positive Ansätze zur Auflösung der Gegnerschaft zwischen Fischerei und Meeresnaturschutz generieren können. Wichtig ist nun die Umsetzungsphase, in der die richtigen Anreize geschaffen und Fischer dadurch ermutigt werden, selbst zur Lösung der Probleme beizutragen, und erfahren, dass sich dies für sie lohnt. Der Zeitpunkt für mehr Kooperation und weniger Konfrontation ist aufgrund der sich schnell ändernden Rahmenbedingungen für die Küstenfischerei günstig (Stichworte Kegelrobben, massiver wirtschaftlicher Druck durch Quotensenkung und Strukturwandel). Dies erfordert jedoch als erstes Ziel eine kohärente Strategie für die Zukunft der deutschen Küstenfischerei, in der Naturschutzaspekte eine essentielle Rolle spielen.

---

[2] https://www.thuenen.de/de/of/projekte/fischerei-umwelt-ostsee/mareeshift-marine-ecological-economic-systems-in-the-western-baltic-sea/

5 Arbeitspaket 1 – Verbesserte Datenerhebung aus der Stellnetzfischerei

Verantwortliche: Steffi Meyer (Betreuung: Uwe Krumme)

An der deutschen Ostseeküste waren im Jahr 2016 951 Fischereifahrzeuge im EU-Flottenregister erfasst, die eine LÜA (Länge über alles) von weniger als 12 m hatten und damit zur kleinen Küstenfischerei zählten (EU, 2018). Das entspricht ca. 75% aller Fischereifahrzeuge, die zu diesem Zeitpunkt an der gesamten deutschen Nordsee- und Ostseeküste registriert waren. Die Mehrheit dieser Fischereifahrzeuge (ca. 96%) hatte im EU-Flottenregister „Stellnetz“ als Hauptfanggerät angegeben. Nur neun Fahrzeuge mit Fanggerät „Stellnetz“ fielen in die Größenklasse 12–15 m. Diese Fahrzeuge sind polyvalent und haben im Betrachtungszeitraum überwiegend mit Schleppnetzen gefischt. Drei weitere Stellnetzfahrzeuge sind über 15 m lang. Sie gehören dänischen Eignern und operieren nicht von deutschen Häfen aus, eine Beprobung war für uns bislang nicht möglich. Es kann also davon ausgegangen werden, dass die deutsche Ostsee-Stellnetzfischerei fast ausschließlich aus Fahrzeugen kleiner 12 m Länge besteht.

Fischereibetriebe der Stellnetzfischerei werden oft als eine einheitliche Gruppe wahrgenommen und im Fischereimanagement häufig auch als solche behandelt. Tatsächlich agiert die Stellnetzfischerei teilweise sehr kleinskalig und in Raum und Zeit unterschiedlich. Die Aktivitätsmuster der einzelnen Fahrzeuge können sich auch innerhalb des gleichen Gebietes deutlich voneinander unterscheiden, z. B. in Bezug auf Zielfischarten, Fangplätze und den Fischereiaufwand (Stergiou et al., 2002; Tzanatos et al., 2006; Andersen et al., 2012).

Diese Heterogenität sollte in Zukunft im Fischereimanagement der Stellnetzfischerei berücksichtigt werden. Insbesondere bei der Erfassung von unerwünschten Beifängen ist ein randomisierter Ansatz (zufällige Stichprobe), der auf die gesamte Stellnetzflotte hochgerechnet wird, angesichts von Anzahl, Verteilung und der potentiellen Vielfalt der Fischereiaktivitäten in Kombination mit der rechtsschiefen Verteilung von Beifangereignissen (sehr viele Fangreisen ohne Beifänge und sehr wenige Reisen, in denen gehäuft Beifänge auftreten; Glemarec et al., 2020) nicht effektiv. Eine Zufallsauswahl an zu beprobenden Fahrzeugen (Stichprobe) aus allen verfügbaren Stellnetzfahrzeugen (Grundgesamtheit) würde zu einer sehr großen Varianz des Schätzwertes führen. Eine gezielte, statistisch valide Auswahl relevanter Fahrzeuge zur effizienten und belastbaren Erfassung unerwünschter Beifänge erfordert eine Unterteilung der Stellnetzflotte anhand ihrer Fischereiaktivität. Die in AP1 durchgeführte Identifizierung fester Gruppen von Stellnetzfahrzeugen ist somit die Grundlage, um die große und heterogene Flotte in sinnvolle, homogenere Gruppen unterteilen zu können (Stratifizierung). Anschließend kann entschieden werden, welche Gruppe an Fahrzeugen auf Grund ihrer räumlich-zeitlichen Aktivitäten von Bedeutung für die Erhebung von Beifangdaten ist und näher untersucht werden sollte. Nachdem man sich für bzw. gegen die Beprobung bestimmter Gruppen entschieden hat, können geschichtete Zufallsstichproben aus den ausgewählten Gruppen für statistisch valide Hochrechnungen gezogen werden.

Im ersten Teil dieses Arbeitspaketes bestand daher die Aufgabe, die Komplexität der deutschen Stellnetzfischerei in der Ostsee aufzuschlüsseln und möglichst homogene Gruppen von Fischereifahrzeugen mit ähnlichen Aktivitätsmustern zu identifizieren.

Die Analyse erfolgte anhand von Anlande-Daten von 1243 Stellnetzfahrzeugen <12 m Länge aus den Jahren 2008-2018. Auf dieser Basis wurden für jedes Jahr monatliche Anlande-Profile charakterisiert, sodass jedem Stellnetzfahrzeug eine jährliche Anlande-Sequenz von zwölf monatlichen Anlande-Profilen zugeordnet wurde. Mittels der jährlichen Anlande-Sequenzen konnten die Fahrzeuge dann in Gruppen unterteilt werden, die sich jeweils durch einen charakteristischen Jahresverlauf monatlicher Anlandungen auszeichneten. Die gruppenspezifischen Muster wiesen eine hohe zeitliche Stabilität auf, sie waren in allen Untersuchungsjahren vorzufinden und traten wiederholt auf.

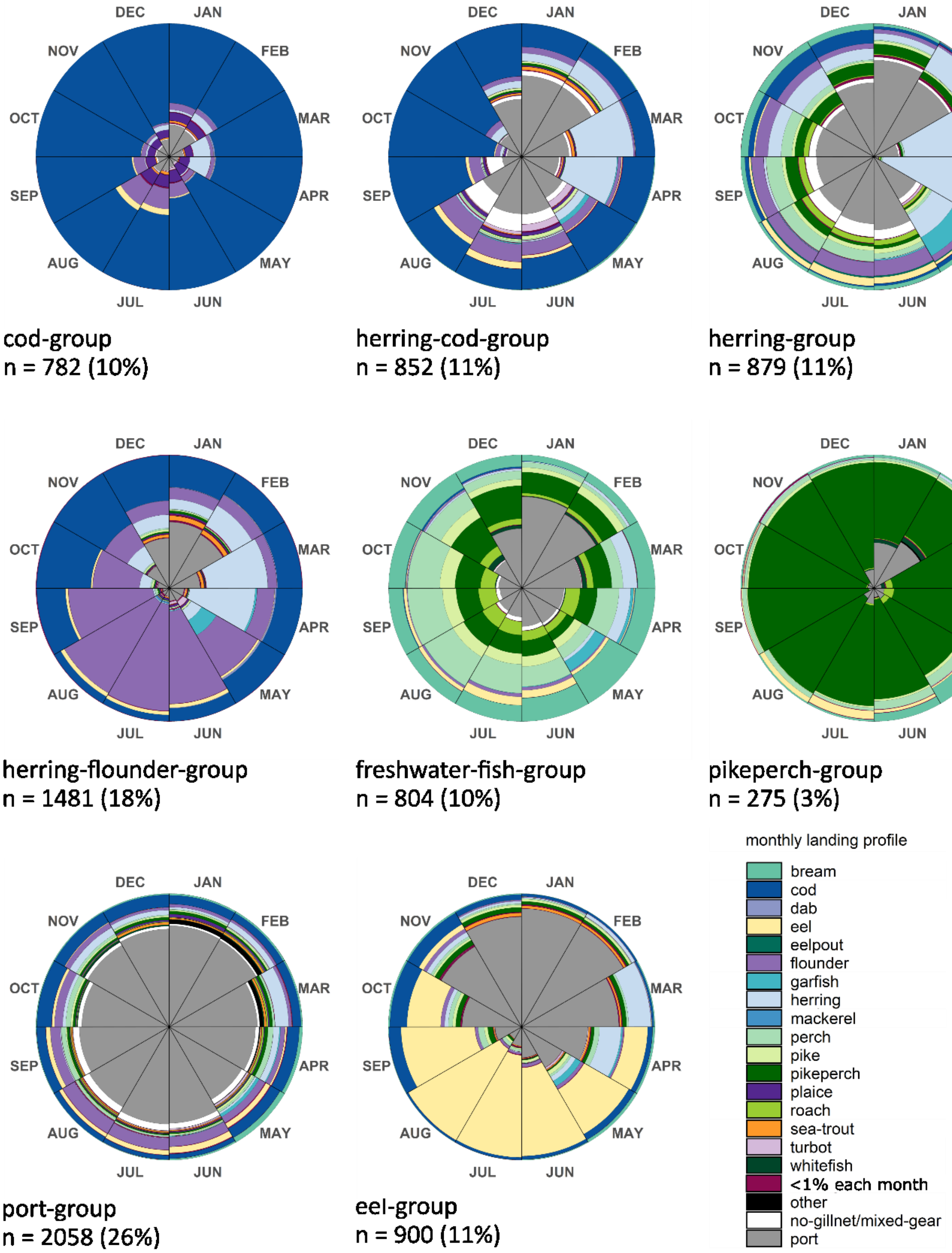
Folgende acht Gruppen mit spezifischen, jährlichen Anlande-Sequenzen wurden identifiziert und jeweils nach einem oder zwei dominanten monatlichen Anlande-Profilen benannt: 1) Dorsch, 2) Hering, 3) Hering-Dorsch, 4) Hering-Flunder, 5) Süßwasserfische, 6) Zander, 7) Hafen (die meisten Monate des Jahres mit Aufenthalt im Hafen und ohne Anlandungen), 8) Aal (Abbildung 2). Die ersten vier Gruppen umfassten über die Jahre die meisten Fangreisen (Fangreisen konnten nur für Fahrzeuge > 8m mit Logbüchern ermittelt werden), gefolgt von der Süßwasserfisch-, der Hafen- und der Zander-Gruppe. Zu den Fangreisen der Aal-Gruppe konnte keine Aussage getroffen werden, weil keines der Fahrzeuge in dieser Gruppe größer 8m war. Die Aal-Gruppe verdeutlicht zudem die Folgen eingeschränkter Datenverfügbarkeit bei der kleinen Küstenfischerei. Die Identifikation eines Stellnetz-Clusters mit der Hauptzielart Aal ist offensichtlich falsch, da Aale nicht mit Stellnetzen gefangen werden. Da Angaben zur Verwendung von Stellnetzen in den Anlandeerklärungen nicht obligatorisch sind, musste auf die Informationen zu den Fanggeräten im EU-Flottenregister zurückgegriffen werden, die diese Fahrzeuge als Stellnetzfahrzeuge definierten. Nur für die Anlandungen der Fahrzeuge mit Logbuch konnte anschließend in der Analyse zwischen Anlandungen aus Stellnetzen- und solchen aus anderen Fanggeräten (wie Aalkörben) unterschieden werden.

Das wiederkehrende Auftreten gruppenspezifischer, saisonaler Muster monatlicher Anlandungen über die Jahre verdeutlicht, dass die monatlichen Anlandungen aufeinander aufbauen und untereinander verknüpft sind und nicht wahllos aufeinander folgen. In Kombination mit der räumlichen Verteilung der Gruppen spiegeln diese die saisonale und regionale Verteilung der Fischereiressourcen wider. Dies verdeutlicht die Abhängigkeit der kleinen Küstenfischerei von der Ressourcenverfügbarkeit, die zusätzlich durch die festgeschriebenen Verteilungsschlüssel der Fangquoten (die sogenannte „relative Stabilität“ in der Quotenverteilung; für die deutschen Ostseefischer betrifft dies v.a. Dorsch, Hering und Scholle) beeinflusst und gefestigt wird.

Die Analysen zeigten, dass die Darßer Schwelle nicht nur eine biologische Grenze für die Verbreitung verschiedener Arten darstellt (Witkowski et al., 2005; Wasmund et al., 2011; Snoeijs-Leijonmalm et al., 2017), die die Gebiete mit höherem Salzgehalt im Westen von den Gebieten mit niedrigerem Salzgehalt im Osten trennt. Sie trennt offensichtlich auch die kleine Küstenfischerei: die Dorsch-Gruppe ist fast ausschließlich westlich der Darßer Schwelle, die Zander- und Süßwasserfisch-Gruppe fast ausschließlich östlich der Darßer Schwelle vertreten.

Die Ergebnisse dieser Gruppierung lieferten die Basis für die gezielte Auswahl relevanter Gruppen und Fischer für Arbeitspaket 4 zur Analyse von Handlungspraxen in Bezug auf Vermeidung unerwünschter Beifänge in der Stellnetzfischerei. Unter Berücksichtigung der Herausforderungen bei der nicht zensusbasierten Erfassung von unerwünschten Beifängen in der Stellnetzfischerei (u.a. die rechtsschiefe Verteilung) liefern die Gruppen die Grundlage, um gezielt, effizient und statistisch valide mögliche unerwünschte Beifangereignisse zu untersuchen und maßgeschneiderte Mitigationsstrategien zu entwickeln.

Abbildung 2: **Die acht identifizierten Fahrzeuggruppen mit unterschiedlichen jährlichen Anlande-Sequenzen aus der deutschen Stellnetzflotte der Ostsee. Relative Anteile der monatlichen Anlande-Profile über den Untersuchungszeitraum und Anzahl der jährlichen Anlande-Sequenzen pro Gruppe (gesamte Stellnetzflotte: n = 8031, Anlande-Sequenzen von insgesamt 1243 Fahrzeugen zwischen 2008 und 2018). Maßstab der Diagramme: Mitte = 0%, Außenkante: 100%. „<1% pro Monat“: monatliche Anlande-Profile mit einem Anteil von weniger als 1% pro Monat. Weitere Details finden sich im Anhang.**



cod-group
n = 782 (10%)

herring-cod-group
n = 852 (11%)

herring-group
n = 879 (11%)

herring-flounder-group
n = 1481 (18%)

freshwater-fish-group
n = 804 (10%)

pikeperch-group
n = 275 (3%)

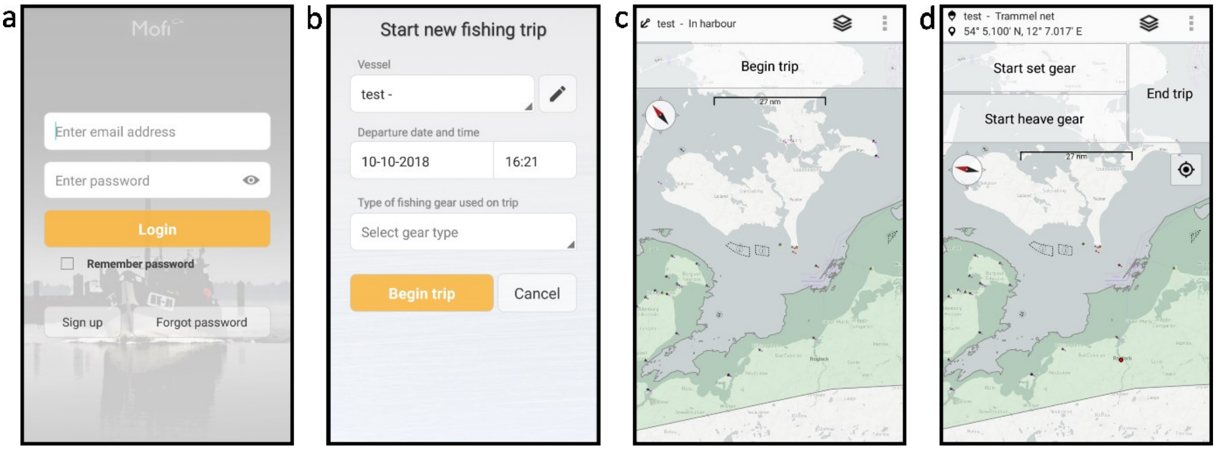
port-group
n = 2058 (26%)

eel-group
n = 900 (11%)

Ein zentrales Defizit bei der Erfassung und Quantifizierung von unerwünschten Beifängen in der Stellnetzfischerei ist die Bestimmung des Fischereiaufwands. In der Regel werden für die Extrapolation von Beifangereignissen die Länge der Netze und deren Stelldauer (Netzlänge pro Tag) benötigt. In den Logbüchern ist die Angabe der Netzlänge und der Fangdauer (Stellzeit) nur ein optionaler Eintrag (EU, 2011). Für Fahrzeuge, die keiner Logbuchpflicht unterliegen (Fahrzeuge < 8m in der Ostsee) und stattdessen nur monatliche Anlandeerklärungen abgeben müssen, fehlen diese Daten komplett. Folglich haben Abschätzungen zum Fischereiaufwand (also der Nenner des Quotienten „Anzahl Beifänge“/“Aufwand“) meist einen Bias, der nur schwer zu bestimmen ist und sich auf die Qualität der Ergebnisse erheblich auswirkt.

Daher wurde im zweiten Abschnitt dieses Arbeitspaketes anhand einer Fallstudie untersucht, wie bessere Aufwandsdaten der Stellnetzfischerei aller Größenklassen erfasst werden können. In Zuge dessen wurde zusammen mit dem kommerziellen Anbieter Anchor Lab (http://www.anchorlab.net/) die Smartphone-Applikation (App) „Mofi“ („mobile fisheries log“) als vielseitiges elektronisches Dokumentations-Tool entwickelt. Mit Mofi kann die Fischerei ihre Fangtätigkeiten mit einem Smartphone (Android und iOS) direkt auf See selbst dokumentieren und klassifizieren, einschließlich der räumlich-zeitlichen Verteilung des Fischereiaufwands (Abbildung 3).

Abbildung 3: **Startbild der Mofi App (links) und verschiedene Fenster in der Anwendung (Anmeldung, Dokumentation einer Reise).**



Vessel: test -

Departure date and time: 10-10-2018 16:21

Type of fishing gear used on trip: Select gear type

test - Trammel net

54° 5.100' N, 12° 7.017' E

Mofi funktioniert unter den Betriebssystemen Android OS 5.0 und höher sowie iOS 9.3 und höher und ist auf die GPS-Funktionalität des Mobilgeräts angewiesen. Ein Zugang zum GSM-Netz ist nur erforderlich während der Registrierung, wenn Änderungen am Benutzerkonto vorgenommen und wenn Daten der Fangreisen zur Datenspeicherung an einen Server übertragen werden.

Schiffsführer registrieren sich, erstellen ein Konto und fügen ihre Fischereifahrzeuge aus einer Liste hinzu, die auf dem EU-Flottenregister basiert. Zu Beginn einer Fangreise wählt der Kapitän das zu verwendende Fahrzeug und Fanggerät aus. Beide Informationen sind obligatorisch, um eine Reise starten zu können. Zusätzlich können noch freiwillig weitere Angaben zum Fanggerät gemacht werden, im Fall der Stellnetze die Maschenöffnung.

Sobald diese Daten eingegeben sind, kann der Fischer die Fangreise starten. Zu diesem Zeitpunkt werden Datum, Uhrzeit und die dazugehörige geografische Position in Intervallen von 5 Minuten aufgezeichnet.

Während der Fangreise gibt der Fischer die Fischereitätigkeit über die App an, z. B. gibt es für Schleppnetze die Option >Fanggerät aussetzen< und >Fanggerät hieven<; und für Stellnetze die Option >Start Aussetzen des Fanggeräts< und >Stopp Aussetzen des Fanggeräts<, wenn das Netz gestellt wird, und >Start Hieven des Fanggeräts< und >Stopp Hieven des Fanggeräts<, wenn das Netz eingeholt wird. Sobald eine Aktion ausgewählt wird, die den Beginn einer Fischereiaktivität beschreibt, z. B. den Start eines Schleppstriches oder den Start des Setzens eines Stellnetzes, verringert sich das Aufzeichnungsintervall auf 1 Minute.

Als Fallstudie diente die Anwendung von Mofi während der Dorsch-Laichschonzeit vom 1. Februar bis zum 31. März 2018. In diesem Zeitraum durfte die Fischerei auf Dorsch in der westlichen Ostsee nur von Fahrzeugen < 12m LÜA in Gebieten flacher als 20 m Wassertiefe betrieben werden (EU, 2017). Laut Anordnung der deutschen Kontrollbehörde war für den Nachweis einer regelkonformen Fischerei durch die deutsche Fischerei Mofi einzusetzen (BLE, 2018). Die App wurde der Fischerei kostenlos zur Verfügung gestellt und diese musste dafür Sorge tragen, dass ein entsprechendes mobiles Endgerät vorhanden war. Für die speziellen Regelungen der Laichschonzeit wurde zusätzlich zu den Standardfunktionen von Mofi die 20 m-Tiefenlinie in deutschen und dänischen Gewässern ergänzt, einschließlich einer Warnung für den Schiffsführer, falls sich das Fahrzeug in der Nähe oder tiefer als 20 m befindet.

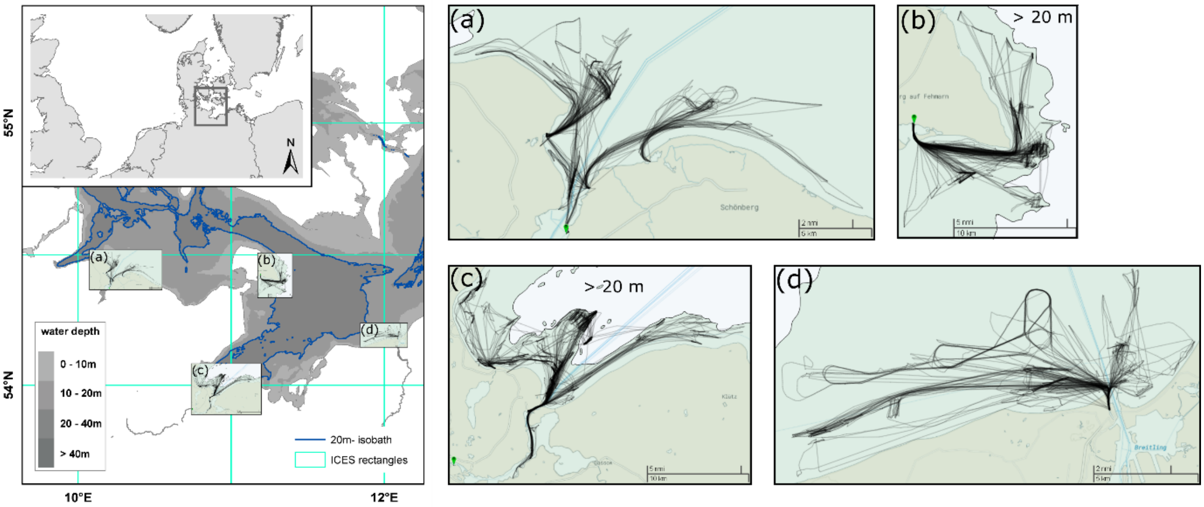
Die Auswertung von insgesamt 1279 Fangreisen von 90 Fischereifahrzeugen zeigte, dass Mofi es der kleinen deutschen Küstenfischerei ermöglichte, ihre Fischereiaktivitäten in hoher zeitlicher und räumlicher Auflösung zu dokumentieren und den Nachweis zu erbringen, dass sie sich an die Vorgaben der Dorsch-Laichschonzeit gehalten hat (Abbildung 4). Die räumlich hoch aufgelösten Mofi-Daten zeigten, dass die Fahrzeuge sehr differenziert operierten und teilweise sehr nah entlang der 20m-Linie fischten. Nur bei drei Fangreisen bestand der Verdacht, dass regelwidrig tiefer als 20 m gefischt worden war.

Die kleinskaligen Aktivitätsmuster der kleinen Küstenfischerei können durch die bestehenden Dokumentationsverpflichtungen, u.a. Logbuch, Anlandeerklärungen und Vessel Monitoring System, nicht erfasst werden. Mobile Apps hingegen haben das Potential, Fischereiaufwandsdaten auch auf den kleinsten Fahrzeugen der kleinen Küstenfischerei zuverlässig und mit vertretbarem Aufwand zu erheben.

Die durch Mofi erhobenen Daten liefern die Basis für die Ermittlung von Stellzeiten und Netzlängen der Stellnetzfischerei. Allerdings wird deren Berechnung durch die Komplexität der Fangtätigkeit (z. B werden Stellnetze nicht immer in geraden Linien gestellt) und die Qualität der definierten Fangaktivität durch die Fischerei erschwert. Dies erfordert weitere Entwicklungen, um in Zukunft große Datenmengen, die mit mobilen Apps erhoben wurden, effizient hinsichtlich des Fischereiaufwands auswerten zu können.

Die Anwendung von Mofi hat gezeigt, dass es möglich ist, mittels mobiler Apps detaillierte Informationen zum Fischereiaufwand der kleinen Küstenfischerei zu erheben. Diese Daten sind essentiell, um Lösungen für die Mitigation unerwünschter Beifänge in der Ostseefischerei zu entwickeln. Gleichzeitig eröffnet die Datenerhebung mittels mobiler App die Chance der Beweislastumkehr (oder besser: Teilen der Beweislast), indem die Fischerei eigenständig belegen kann, wie sie wann und wo operiert. Dadurch übernimmt sie Verantwortung für ihr Handeln und trägt maßgeblich zum Co-Management in der Fischerei bei, welches darauf basiert, dass alle beteiligten Parteien sowohl Macht als auch Verantwortung untereinander aufteilen und gemeinsam tragen (Wilson et al., 2003; Fitzpatrick et al., 2011).

Abbildung 4: **Beispiele für Fangreisen in vier Regionen der deutschen Ostseeküste während der Dorschlaichschonzeit vom 01.02.-31.03.2018. Jede Region zeigt 79 bis 99 Reisen von fünf bis zwölf Fahrzeugen (Reisen sind nicht in Dampfen und Fischen unterteilt). Beachtlich ist die Differenz in der räumlichen Auflösung zwischen der obligatorischen ICES-Rechteck-Angabe (30 x 30 Seemeilen) in Logbüchern und Anlandeerklärungen und den tatsächlichen, mit Mofi erfassten kleinräumigen Nutzungsmustern des Seegebiets durch die kleine Küstenfischerei.**



Mofi wird kontinuierlich weiterentwickelt und an verschiedene Aufgaben angepasst. Am einfachsten ist die Hinterlegung anderer Gebietskulissen als der 20 m-Tiefenlinie, wie die von Schutzgebieten, mitsamt der Information für den Anwender, welche Tätigkeiten in diesem speziellen Gebiet gestattet sind. Auch eine Weiterentwicklung zur möglichen Verwendung im Rahmen von Ausgleichszahlungen für durch Kegelrobben in Gewässern Mecklenburg-Vorpommerns verursachte Schäden ist abgeschlossen: Fischende können die Schäden fotografisch dokumentieren, die Fotos werden automatisch an der richtigen Position an den Reiseverlauf angehängt und können so als Grundlage für staatliche Entschädigungszahlungen dienen. Für die Fischenden ergibt sich so ein weiterer Anreiz für die Dokumentation ihrer Fischereiaktivitäten. Für die nahe Zukunft ist die Erweiterung um eine Logbuchfunktionalität geplant. Die Erfahrungen mit Mofi werden ferner in die Entwicklung einer App zur Dokumentation der Fänge und Aktivitäten der Freizeitfischerei einfließen.

6 Arbeitspaket 2 – Modifizierte Stellnetze: Entwicklung eines akustisch sichtbaren Stellnetzes

Verantwortliche: Isabella Kratzer (Betreuung: Daniel Stepputtis)

In diesem Teilprojekt wurden anfangs zwar auch Möglichkeiten zur Reduktion von Seevogelbeifängen in Stellnetzen erörtert (siehe z. B. die ersten Zwischenberichte) und auch Eiderenten mit Sendern ausgestattet, da aber fundamentale Prozesse des Seevogelbeifangs noch unverstanden sind und absehbar nicht ohne weiteres innerhalb der Projektlaufzeit geklärt werden konnten, wurde dieser Bereich nicht intensiv weiterverfolgt. Im Rahmen der Kooperation mit DTU-Aqua war das OF dennoch an Tests mit Unterwasser-Lichtquellen zur Vermeidung von Seevogelbeifängen in Stellnetzen im Öresund beteiligt. Stattdessen wurde die Beifangreduktion von Schweinswalen durch die Verbesserung der akustischen Sichtbarkeit von Stellnetzen als ein realistisches Ziel identifiziert und systematisch bearbeitet.

Trotz intensiver Forschung sind die Gründe, weshalb sich Schweinswale in Stellnetzen verfangen, nach wie vor nicht eindeutig geklärt. Eine Hypothese postuliert, dass Schweinswale das Stellnetz mittels Echolokation zwar orten können, aber nicht als undurchdringliches Hindernis wahrnehmen, oder nur die Schwimmleine „sehen“ und dann versuchen, nach oben oder nach unten auszuweichen. Wenn sie in den Bereich unterhalb der Schwimmleine auszuweichen versuchen und das Netz nicht als Hindernis erkennen, ist das Risiko hoch, dass sich das Tier verfängt. Dieser Problematik könnte begegnet werden, wenn das Stellnetzblatt akustisch ebenso sichtbar wäre wie die Schwimmleine und der Schweinswal eine „Wand“ erkennen würde. Frühere Versuche, das Stellnetz mittels Änderung der Garndichte akustisch sichtbarer zu machen, haben keine konsistenten Erfolge erzielt oder unerwünschte Nebeneffekte gehabt, wie z. B. eine Reduktion im Fang der Zielarten oder schlechte Handhabbarkeit der Netze (Goodson, 1997; Hembree and Harwood, 1987; Larsen et al., 2007; Trippel et al., 2003).

In diesem STELLA-Arbeitspaket wurde systematisch nach einer Möglichkeit gesucht, um das Stellnetzblatt akustisch sichtbarer zu machen, d.h. sowohl das Echo signifikant zu erhöhen als auch das zugehörige akustische Bild des Stellnetzblattes so zu verändern, dass der Eindruck einer Wand entsteht. Dabei wurde darauf geachtet, dass die Modifikation möglichst keinen Einfluss auf die Fängigkeit haben sollte, da die erhöhte Steifigkeit der Netze vergangener Versuche sowohl für die Beifangreduktion als auch für die geringere Fangmenge der Zielart verantwortlich gemacht wurde (Larsen et al., 2007).

Die Entwicklung eines „Design-Guides“ für ein unverändert fängiges, aber akustisch sichtbares Stellnetz beinhaltete vier Schritte:

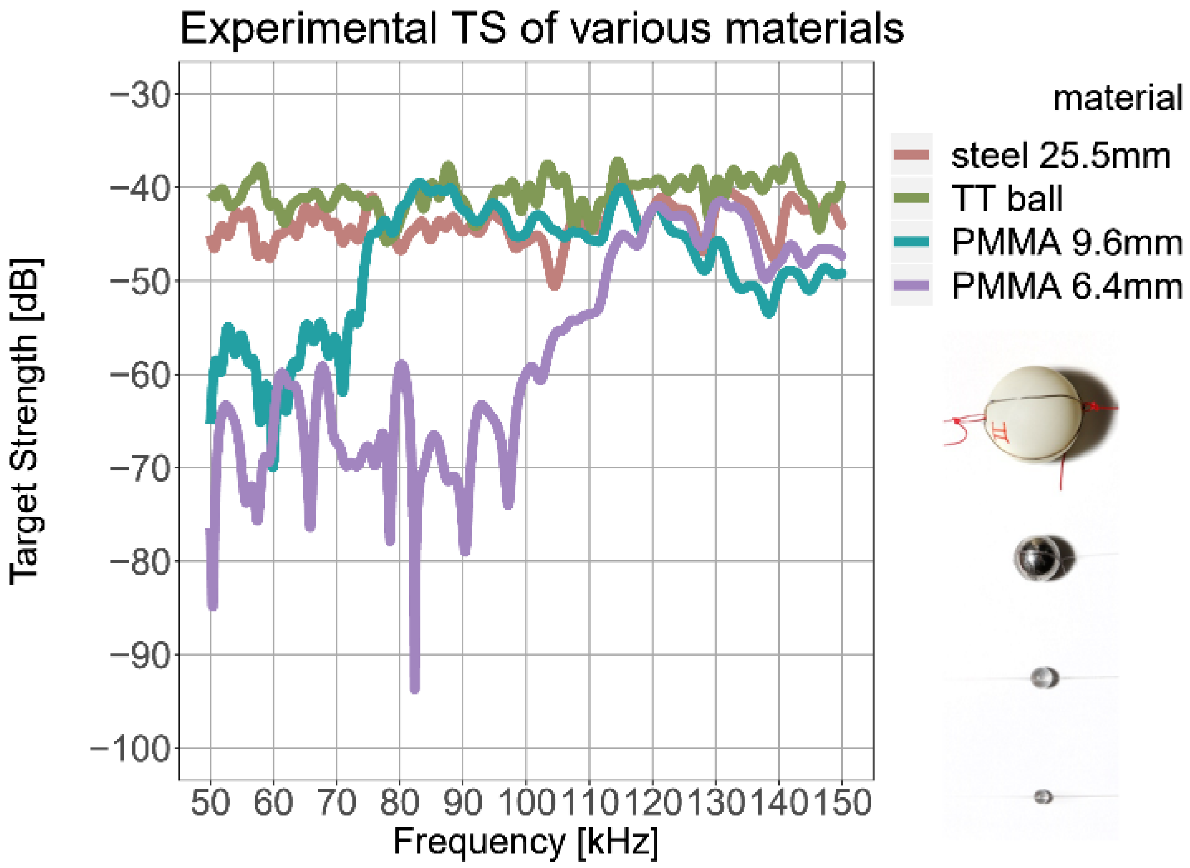
- systematische Simulation der akustischen Eigenschaften verschiedener Körper zur Identifikation einer optimalen Modifikation (siehe Arbeitspaket 2 Veröffentlichung 1)
- experimentelle Überprüfung der akustischen Eigenschaften modifizierter Stellnetze (siehe Arbeitspaket 2 Veröffentlichung 1 und 2)
- Verhaltensexperiment zur Beobachtung von Schweinswalen in der Nähe modifizierter Stellnetze
- Einsatz des modifizierten Netzes („Perlennetz“) in einer kommerziellen Fischerei (siehe Arbeitspaket 2 Veröffentlichung 3)

Um die akustische Sichtbarkeit von Stellnetzen zu erhöhen, wurde der Ansatz gewählt, das Echo des Netzes durch das Einbringen akustisch reflektierender Objekte zu erhöhen, damit es von Schweinswalen leichter erkannt werden kann. Um die bestmögliche Stellnetzmodifikation zu finden, wurde in einer Parameterstudie das akustische Verhalten von Körpern einer großen Bandbreite an geometrischen und mechanischen Eigenschaften simuliert, da es Einfluss auf die Rückstreufähigkeit des Körpers hat. Dabei wurde besonderes

Augenmerk auf kleine Kugeln gelegt, da kugelförmige Körper ihre akustischen Eigenschaften nicht in Abhängigkeit vom Beschallungswinkel ändern. Außerdem wurde das Echo eines Filaments stellvertretend für ein konventionelles Stellnetz simuliert und festgestellt, dass eine Erhöhung der Dichte nicht zu signifikanter Erhöhung des Echos führt. Die Simulation wurde für einen breiten Frequenzbereich durchgeführt, um zukünftig auch Modifikationen für andere Zahnwalarten entwickeln zu können.

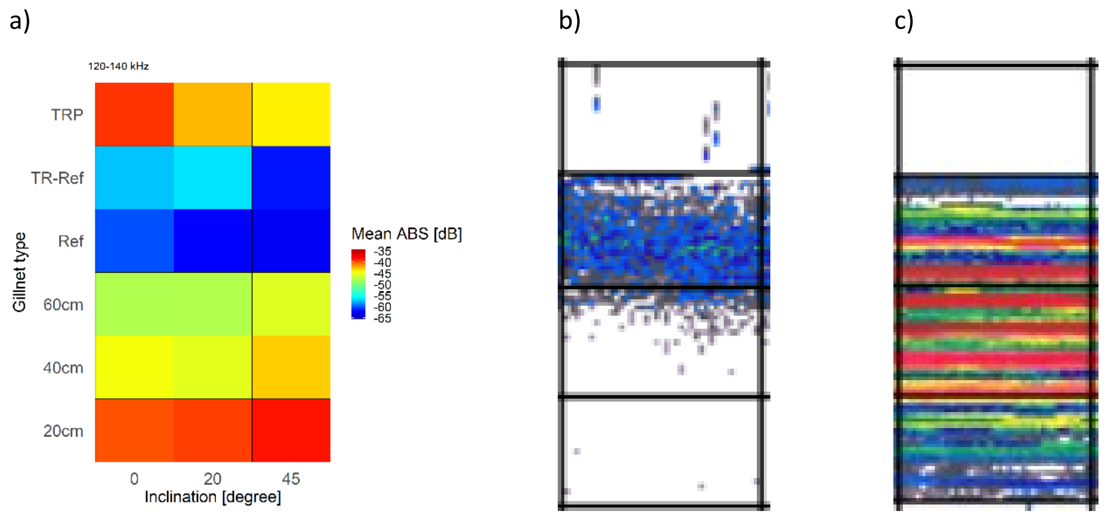
In der Parameterstudie und anschließender experimenteller Verifikation zeigte sich, dass kleine Acrylglaskugeln von etwas weniger als 10 mm Durchmesser bei 130 kHz (der Schweinswal-Ortungsfrequenz) dieselben Echoeigenschaften haben wie ein Tischtennisball, dessen Durchmesser fünfmal größer ist, oder eine Stahlkugel von 25 mm Durchmesser (Abbildung 5). Die Kombination aus Materialeigenschaften und Größe führt in diesem Frequenzbereich zu Resonanz, was ein stärkeres Echo zulässt als die geometrische Form erwarten lässt. Des Weiteren hat Acrylglas in etwa dieselbe Dichte von Seewasser, so dass es unwahrscheinlich ist, dass sich durch das Einbringen der Kugeln die Netzeigenschaften, insbesondere Auf- oder Abtrieb, ändern. Acrylglas ist außerdem transparent, so dass es für Fische unsichtbar ist. Ein negativer Effekt der Netzmodifikation auf die Fängigkeit der Zielart ist daher nicht zu erwarten.

Abbildung 5: **Akustisches Zielmaß („Target strength“) verschiedener Körper (Stahlkugel –steel, Tischtennisballl – TT ball, Acrylglaskugeln – PMMA (Polymethylmethacrylat)) im Frequenzbereich von Zahnwalen (50-150 kHz).**



Der Effekt der Kugeln auf das Echo eines ganzen Stellnetzes wurde in einem weiteren systematischen Versuch getestet. Ein Dorschstellnetz und ein türkisches Steinbuttnetz wurden mit Kugeln in verschiedenen Abständen zueinander beklebt (20 cm, 40 cm, 60 cm für das Dorschnetz, ca. 35 cm für das Steinbuttnetz) und die Reflektivität und das „akustische Bild“ mit dem jeweiligen Referenznetz verglichen. Da in der Vergangenheit festgestellt wurde, dass das Echo von Stellnetzen mit erhöhtem Beschallungswinkel abnimmt (Au and Jones, 1991; Kastelein et al., 2000; Mooney et al., 2004), fanden die Messungen aus drei Winkeln statt. Die Messungen wurden in einem U-Boot-Hangar der Wehrtechnischen Dienststelle 71 in Kiel durchgeführt. Die Netze wurden zeitgleich mit einem Echolot im Frequenzbereich 38 – 170 kHz beschallt und das Echo gemessen. Die Netze mit Kugeln zeigten deutlich höhere Echowerte als die Referenznetze (Abbildung 6) im Frequenzband zwischen 120 – 140 kHz (Frequenzbereich des Schweinswals; Miller and Wahlberg, 2013), und die Kugeln waren im Echogramm deutlich sichtbar (Abbildung 6). Insbesondere ist hervorzuheben, dass das Echo mit zunehmendem Winkel bei Netzen mit Kugeln sogar stärker wird, während es bei den Referenznetzen abnimmt und diese so sogar nahezu „unsichtbar“ werden.

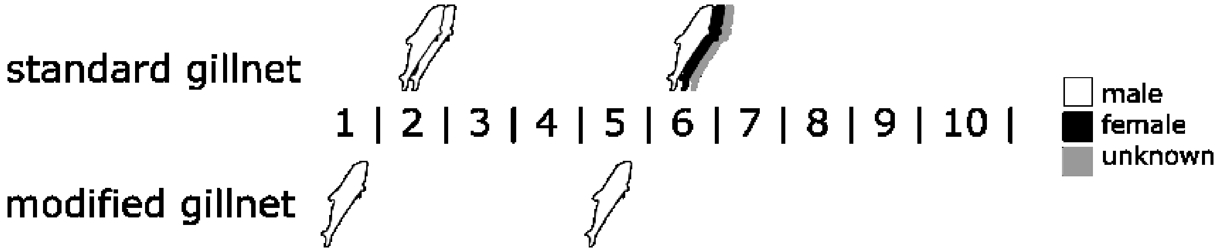
Abbildung 6: a) Echostärke des beschallten Netzbereichs („ABS“) verschiedener Netztypen bei verschiedenen Anstellwinkeln. „TR“: Steinbuttnetz, Ref: Dorsch-Referenznetz, 20, 40, 60 cm: Dorschnetze mit Perlen in entsprechender Entfernung zueinander. Die Echogramme von Referenznetz (b) und Dorschnetz mit 40 cm Kugelabstand (c) zeigen deutlich den Unterschied in der Sichtbarkeit bei 45° Beschallung. Rote Linien in (c) sind die Perlenreihen.



Im Sommer 2018 wurde in Fyns Hoved, Dänemark, ein Verhaltensexperiment durchgeführt, bei dem die Reaktion von Schweinswalen auf Stellnetze mit und ohne Kugeln untersucht werden sollte. Trotz aufwendiger Planung lieferten die dort erhobenen Daten keine weiterführenden Erkenntnisse, u.a. weil die Schweinswale in jenem Sommer so küstennah schwammen, dass ein Einfluss der Netze auf ihr Schwimmverhalten nicht zu bestimmen war (siehe zweiter Zwischenbericht vom 17. April 2019) und aufgrund der Wetterlage (v.a. Wind und Welle) nur relativ wenige valide Beobachtungstage stattfinden konnten.

Im Herbst 2019 wurde das „Perlennetz“ in einer kommerziellen Fischerei getestet. Ein modifiziertes Stellnetz („Perlennetz“) wurde in einer Steinbuttfischerei am Schwarzen Meer (Sinop, Türkei) mit einem konventionellen Netz verglichen. Dieser Untersuchungsort wurde ausgewählt, da dort in der Vergangenheit gehäuft Schweinswalbeifänge auftraten (Gönener and Bilgin, 2009), und weil die eingesetzten Netze vergleichsweise klein sind (geringe Höhe und geringe Länge) und damit mit überschaubarem Aufwand manuell mit Acrylperlen beklebt werden konnten. Ferner ist die Fangsaison vergleichsweise kurz und die Betreuung des Versuchs auch bei weit entferntem Untersuchungsgebiet möglich. Insgesamt wurden 2 km konventionelles gegen 2 km modifiziertes Stellnetz in 10 Hols paarweise getestet. Dabei wurden insgesamt sieben Schweinswale beigefangen, davon fünf im konventionellen und zwei im modifizierten Netz (Abbildung 7). Die geringe Anzahl an Hols lässt noch keine statistisch belastbare Aussage zu, jedoch ist ein vielversprechender Trend zu beobachten, da das modifizierte Netz deutlich weniger Schweinswale fing als das Standardnetz.

Abbildung 7: **Anzahl der Schweinswale nach Geschlecht, die im konventionellen (standard gillnet) und im modifizierten Stellnetz (modified gillnet) im Sommer 2019 bei Sinop (Türkei) beigefangen wurden.**



Der nächste logische Schritt in der Weiterentwicklung des „Perlennetzes“ ist ein koordinierter Versuch in einem größeren Seegebiet, in dem viele Fischer mit „Perlennetzen“ ausgestattet werden und diese eine Saison lang im direkten Fangvergleich zu ihrem Standardnetz erproben. Um einen solchen Einsatz durchführen zu können, muss allerdings dringend an der industriellen Fertigung von „Perlennetzen“ gearbeitet werden, um eine ausreichend große Zahl an „Perlennetzen“ für statistisch valide Untersuchungen im Feld testen zu können. Derzeit müssen die Perlen noch zeitaufwendig per Hand ins Netz geklebt werden. Die Versuche sollten wissenschaftlich begleitet werden und nach Möglichkeit auch den Einsatz von autonomen Hydrophonen (CPODs) beinhalten, so dass zeitgleich zum Effekt auf den Beifang in der kommerziellen Fischerei auch Daten zum Echolokationsverhalten der Tiere aufgezeichnet werden können.

Das „Perlennetz“ wurde im Rahmen einer Masterarbeit auch in der schwedischen Seehasenfischerei getestet (Gustafsson, 2020). Dabei wurde mit Hilfe von akustischen Rekordern (F-Pods) vor allem das Echoortungsverhalten (u.a. Klickrate) und Abundanz (detective positive minutes per hour) zwischen dem Standardnetz und dem Perlennetz verglichen. Die Auswertung ergab Unterschiede zwischen den Netzen. Dabei wurden in der unmittelbaren Nähe von Perlennetzen weniger Schweinswale detektiert, die Häufigkeit von Echoortungsclicks (Buzz) war jedoch teilweise höher. Die im Rahmen dieses Projektes entwickelte Stellnetzmodifikation („Perlennetz“) ist ein sehr vielversprechender Ansatz, der den Beifang von Schweinswalen deutlich verringern könnte und darüber hinaus das Potential hat, auch den Beifang anderer Zahnwalarten zu reduzieren.

7 Arbeitspaket 3 – Alternative Fanggeräte: Systematische Verbesserung von Fischfalle und Hebereuse

Verantwortliche: Jérôme Chladek (Betreuung: Daniel Stepputtis)

Eine der Möglichkeiten, den unerwünschten Beifang in Kiemen- und Verwickelnetzen zu reduzieren, ist der Einsatz alternativer Fanggeräte, die durch ihre Bauart bzw. Fangmethode den die Verwickelung und das Ertrinken geschützter Arten verhindern oder zumindest unwahrscheinlicher machen.

In diesem Arbeitspaket wurden zwei Fanggeräte untersucht, die alternativ zu Stellnetzen eingesetzt werden können und geringere Beifänge von Seevögeln und Meeressäugern erwarten lassen: Fischfallen und Pontonhebereuse. Dazu wurde ein Infrarot-Kamerasystem entwickelt, um das Verhalten von Fischen tags und nachts an Fischfallen und Reusen beobachten zu können.

Als Alternative für Stellnetze mit Zielart Dorsch fanden systematische Untersuchungen mit Fischfallen statt. Als weitere Alternative für Stellnetze (z. B. für die Zielart Hering) wurde eine mit Pressluft vom Boden an die Wasseroberfläche hebbare Großreuse modifiziert und getestet, die sogenannte Ponton-Hebereuse.

Bei fangtechnischen Lösungen wird meist nur der Fang als Indikator für den (Miss-)Erfolg eines Fallen- bzw. Reusentyps diskutiert. Dabei ist der Fang das integrierte Resultat von vier Teilprozessen während der Stellzeit des Fanggeräts. Ohne ein fundiertes Verständnis dieser Teilprozesse an einer Reuse bzw. Fischfalle kann der Mechanismus ihrer Fängigkeit nicht verstanden werden – und in der Folge kann auch kein systematischer Verbesserungsprozess in Gang kommen. Dementsprechend wurde auch hier ein systematischer Forschungsansatz verfolgt, insbesondere bei der Untersuchung bzw. Weiterentwicklung der Fischfalle. Dabei wurde der Fangpprozess in klare, getrennte Einzelschritte unterteilt, um jeden Einzelschritt dann separat und so kontrolliert wie möglich untersuchen zu können.

Fischfallen

Fischfallen sind vergleichsweise kleine und somit leicht transportierbare, mit Netz- oder Gitterwänden versehene schachtelförmige passive Fischfanggeräte, die üblicherweise beködert gestellt werden. Fischfallen haben im Vergleich zu anderen Fanggeräten relativ geringe negative Umweltauswirkungen (z. B. Grabowski et al., 2014; Thomsen et al., 2010) und eine effektive und leicht einstellbare Größenselektion (Ovegård et al., 2011). Vor allem aber weisen sie ein wahrscheinlich deutlich geringeres Beifangrisiko für luftatmende Meerestiere wie Seevögel, Meeresschildkröten und Meeressäuger im Vergleich zu Stellnetzen auf, die eine hohe Verwicklungs- und somit Beifangpotential für diese Taxa aufweisen (z. B. Northridge et al., 2016; Žydelis et al., 2013). Des Weiteren werden Fische in Fischfallen in den meisten Fällen lebend und unverletzt gehievt, was die Fischfiletqualität erhöht und die Überlebensrate von unerwünschtem Beifang (von Kiemenatmern) maximiert (Suuronen et al., 2012). In der Ostsee ist Fallenfischerei auf Dorsch wenig verbreitet, da die Fangeffizienz von Fischfallen (bisher) deutlich unter der Effizienz von Stellnetzen liegt (z. B. Anders et al., 2017).

Fischfallen sind in der Regel über mehrere Tage im Einsatz. Der Fangprozess mit einer Fischfalle lässt sich in 4 Schritte unterteilen:

(1) Anlocken der Dorsche zur Falle (z. B. mit Köder) - *attraction*,

(2) im Nahbereich muss ein angelockter Dorsch den Eingang finden - *encounter*

(3) daraufhin muss der Dorsch den Eingang queren können – *entrance* -, und

(4) schließlich muss der Dorsch am Wiederaustreten aus der Falle gehindert werden - *escape*.

Fischfalleneingänge sind grundsätzlich so konzipiert, dass das Eintreten von Fischen in die Falle möglichst begünstigt und gleichzeitig das Verlassen der Falle möglichst erschwert werden soll (Thomsen et al., 2010). Die geringe Fangeffizienz von Fischfallen liegt offenbar zu einem erheblichen Teil an den Fischfalleneingängen, die einen Flaschenhals in der Fängigkeit darstellen: Nur ein Bruchteil der Dorsche, die sich einer Fischfalle nähern, finden auch in die Falle hinein, und ein noch kleinerer Teil wird anschließend am Hinausschwimmen bis zum Hieven der Falle effektiv gehindert (Hedgärde et al., 2016; Ljungberg et al., 2016; Meintzer et al., 2017).

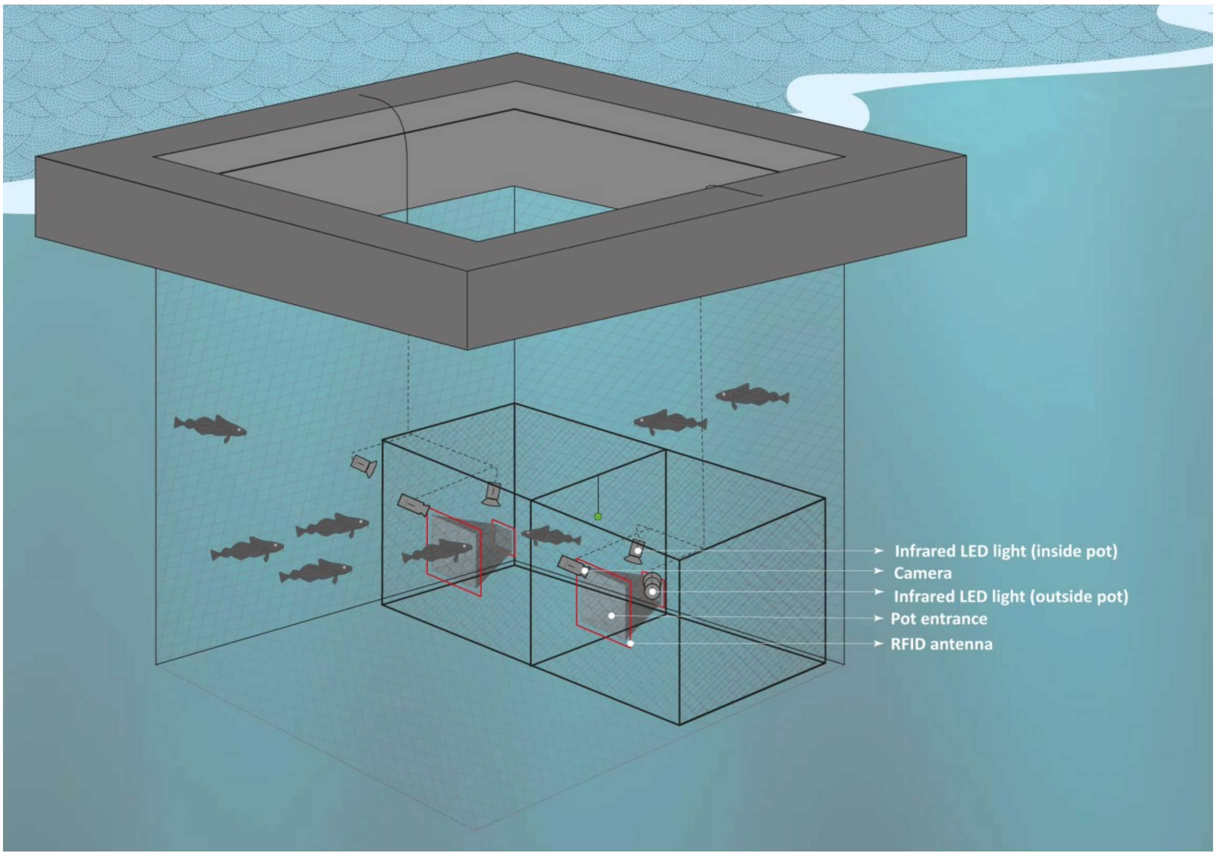
Um die Wirkung unterschiedlicher Fischfalleneingangsparameter zu untersuchen, eignen sich die üblichen Fangvergleiche nicht. Denn dabei wird nur die Anzahl der sich am Ende der Stellzeit in den Fischfallen befindenden Fische erfasst. Sie erlauben somit keine Rückschlüsse darauf, wie Fische mit unterschiedlichen Eingängen interagieren. Des Weiteren bleibt bei klassischen Fangvergleichen unklar, wie viele Fische ihren Eintrittsversuch abgebrochen haben bzw. wie viele Fische hinein- und wieder hinausgeschwommen sind (Furevik and Løkkeborg, 1994; Hedgärde et al., 2016). Somit haben in letzter Zeit vor allem Studien mit Videobeobachtungen von Fischen an Fallen das Verständnis über die Interaktion von Dorschen mit Fischfalleneingängen und somit zum Fischfallenfangprozess verbessert (Anders et al., 2017, 2016; Bacheler et al., 2013; Hedgärde et al., 2016; Ljungberg et al., 2016; Meintzer et al., 2017; Renchen et al., 2012).

Um die Interaktion von Dorschen mit verschiedenen Fischfalleneingängen systematisch zu untersuchen, wurde ein Experimentaufbau entwickelt, bei dem Dorsche unter kontrollierten Bedingungen in Interaktion mit den austauschbaren Eingängen einer Fischfalle beobachtet werden konnten (Abbildung 8).

Bisherige Videobeobachtungen von Dorschen und anderen Fischen an Fischfallen haben gezeigt, dass das Einlassvermögen und das damit verbundene Rückhaltevermögen (die Schritte 3 und 4, s.o.) der Falleneingänge das Nadelöhr sind, durch das die Fängigkeit einer Falle maßgeblich bestimmt wird (Hedgärde et al., 2016; Ljungberg et al., 2016; Meintzer et al., 2017). Um diesen, für die Fängigkeit entscheidenden Fangprozess an den Eingängen von Fallen besser zu verstehen, muss das Verhalten der Zielarten am Fanggerät über den gesamten 24 Stunden-Zyklus unbeeinflusst beobachtet werden können. Dies betrifft nicht nur Fischfallen, sondern grundsätzlich alle Eingänge von Fangkammern.

Der Einsatz von Licht des sichtbaren Spektrums würde bei Nacht jedoch von Dorschen wahrgenommen werden und kann potentiell Verhaltensänderungen bewirken. Da Dorsche Infrarot-Licht nicht wahrnehmen können (Bowmaker, 1990), wurde ein System aus wasserdichten Infrarot-Schweinwerfern und Kameras entwickelt.

Abbildung 8: Schematischer Versuchsaufbau: Dorsche wurden in einem Netzkäfig in Interaktion mit Fischfalleneingängen mit Infrarot-Kameras beobachtet.

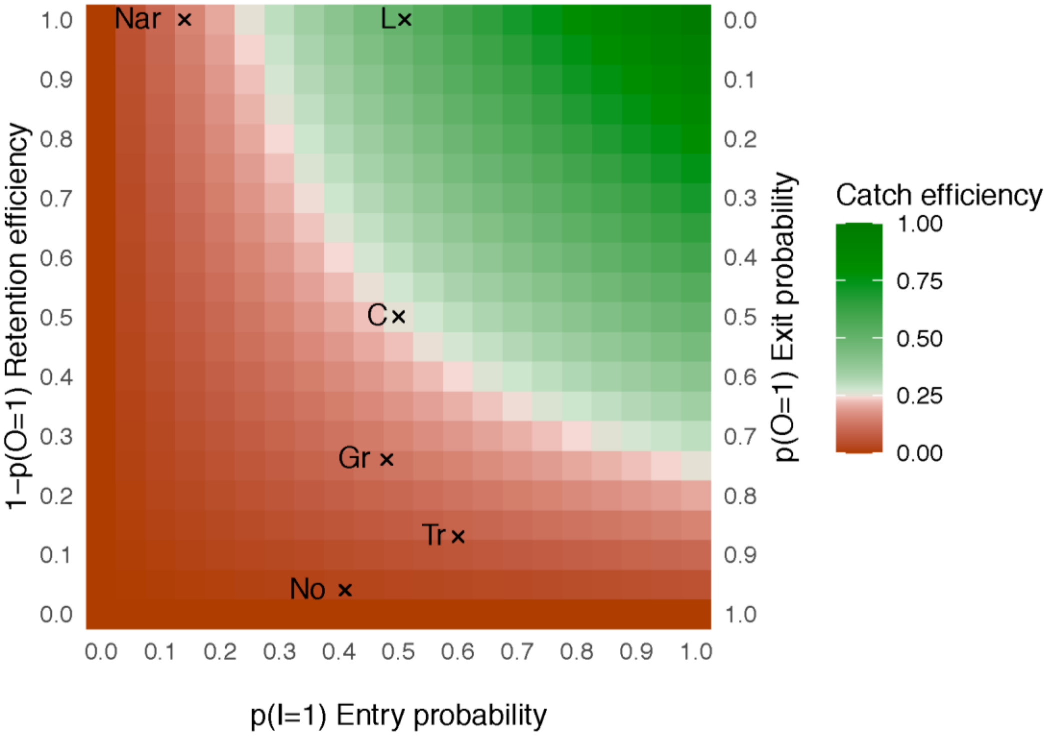


In einem ersten Schritt wurden grundlegende Parameter von Fischfallenkehlen (trichterartige, konusförmige Fischfalleneingänge) auf die Ein- und Austrittsrate von Dorschen untersucht. Die untersuchten grundlegenden Parameter waren: Kehlenfarbe, Kehlenlänge und Kehlenform.

Es wurde zum ersten Mal beobachtet, dass Dorsche bei Nacht ohne für sie sichtbare Beleuchtung kaum durch Fischfalleneingänge finden. Diese Erkenntnis ist wichtig für die Fangstrategie bei Fischfallen, vor allem, wenn olfaktorische Köder (z. B. Heringsstücke) verwendet werden, deren Köderfahne aufgrund von Diffusion innerhalb kurzer Zeit stark abnimmt (Løkkeborg, 1990; Westerberg and Westerberg, 2011). Ergebnisse aus früheren Beobachtungen an Fischfalleneingängen mit für Dorschen sichtbarer Beleuchtung, bei denen die Durchtrittsrate nachts höher war als am Tage, haben sehr wahrscheinlich hauptsächlich den Effekt (die Lockwirkung) der künstlichen Lichtquelle gemessen, und nicht das Verhalten von Dorschen unter natürlichen Bedingungen (Hedgärde et al., 2016; Humborstad et al., 2018). Die Erkenntnisse dieser Studien sind trotzdem wichtig, denn sie bestätigen die im Experiment gemachten Beobachtungen, dass Dorsche bei den meisten Eingangsinteraktionen die Eingänge visuell inspizieren, d.h. die Interaktion der Dorsche mit den Eingängen erfolgt allem Anschein nach primär visuell.

Die Kehlenfarbe verändert den Kontrast und somit die Wahrnehmbarkeit des Kehlennetzmaterials im Vergleich zum Hintergrund. Deswegen näherten sich Dorsche transparenten Kehlen signifikant öfter und durchschwommen sie auch signifikant häufiger als eine weiße Standardkehle. Da sie allerdings auch signifikant häufiger durch sie hinausschwammen, wurde die transparente Kehle insgesamt als schlechter fängig bewertet (Abbildung 9).

Abbildung 9: Fangeffizienz der getesteten Fallenkehlen im Vergleich. Per Definition hat die Standardkehle ("C") eine Fängigkeit von 0.25. „Nar“= schlitzförmige Kehle, „L“= lange Kehle, „Gr“= grüne Kehle, „Tr“= transparente Kehle, „No“= keine Kehle, nur Öffnung in Netzwand.



Die Kehlenlänge beeinflusste die Durchtrittsrate stark. Bei dem Eingang ohne Kehle (Kehlenlänge = 0 cm) gab es signifikant weniger Eintritte sowie mehr Austritte als bei den Eingängen mit Kehle. Dieses Teilexperiment zeigte auf, warum Kehlen so wichtig für die Fischfallen-Fangeffizienz sind: Dorsche außerhalb der Falle finden den Eingang mit Kehle besser als den Eingang ohne Kehle, da Kehlen die Fläche des Eingangs vergrößern (Trichterfunktion). Dorsche haben somit eine größere Chance auf den Eingang zu treffen, wenn sie die Falle ansteuern. Von innen werden Dorsche vor allem nachts durch Kehlen vom Ausgang abgeleitet (Abbildung 10). Durch die Kehle wird die Fläche verkleinert, durch die Dorsche ein freies Blickfeld nach außen haben (Abbildung 11), und dies verringert die Anzahl an Annäherungen an den Ausgang. Ein Verlängern der Kehle von 50 cm (Standardkehle) auf 75 cm verstärkte diesen Effekt noch zusätzlich. Die Kehle kann aber auch nicht beliebig verlängert werden, denn ab einer bestimmten Länge reduziert sich die Fängigkeit wieder: Wenn die Kehle zu nah an der Rückwand endet, werden Dorsche, die an der Rückwand entlangschwimmend einen Ausgang suchen, den Kehlenausgang in ihrem Nahbereich leichter erkennen und somit leichter aus der Falle herausfinden können. Das optimale Verhältnis zwischen Faktoren wie Kehlenlänge, Fallengröße und Fischgröße sollte in künftigen Untersuchungen bestimmt werden.

Abbildung 10: Illustration der Ablenkungswirkung von Fischfallenkehlen bei Nacht: Ein Dorsch schwimmt von innen gegen die Kehlenwand, wird dann zur Fallenrückwand abgelenkt (A, B) und schwimmt an der Rückwand entlang, bis er an die Öffnung ohne Kehle kommt und aus der Falle schwimmt.

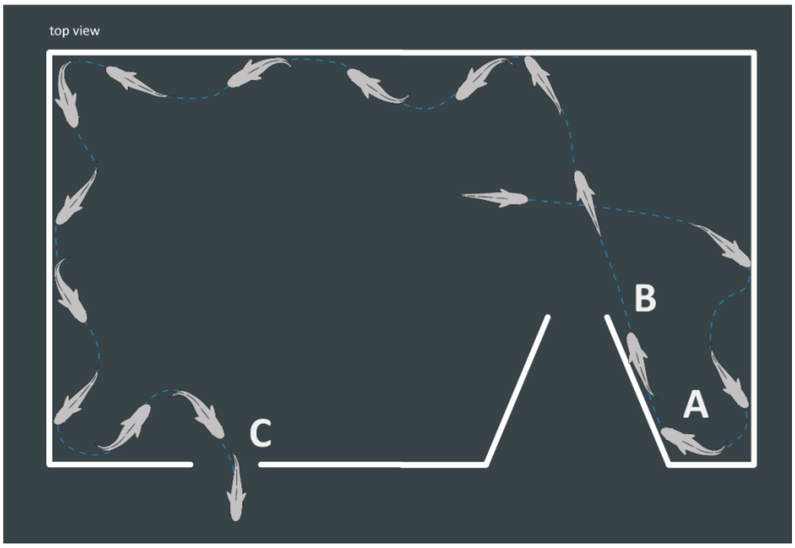
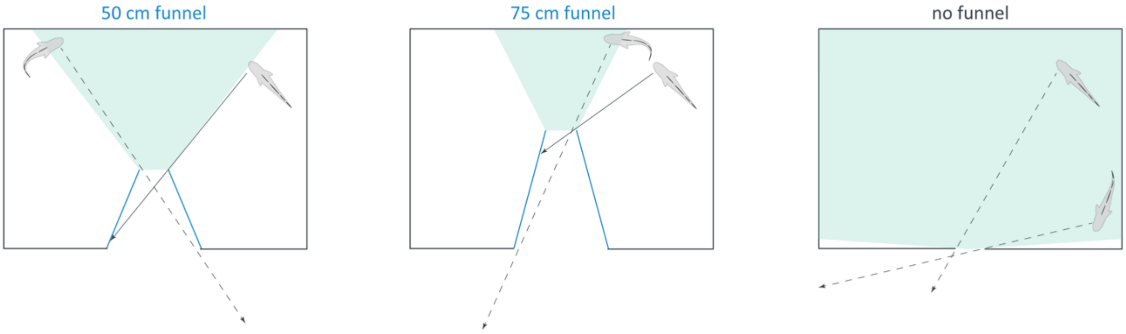


Abbildung 11: Fläche in der Fischfalle, durch die der Ausgang für bereits gefangene Fische frei sichtbar ist (bei gleicher Größe der Öffnung).



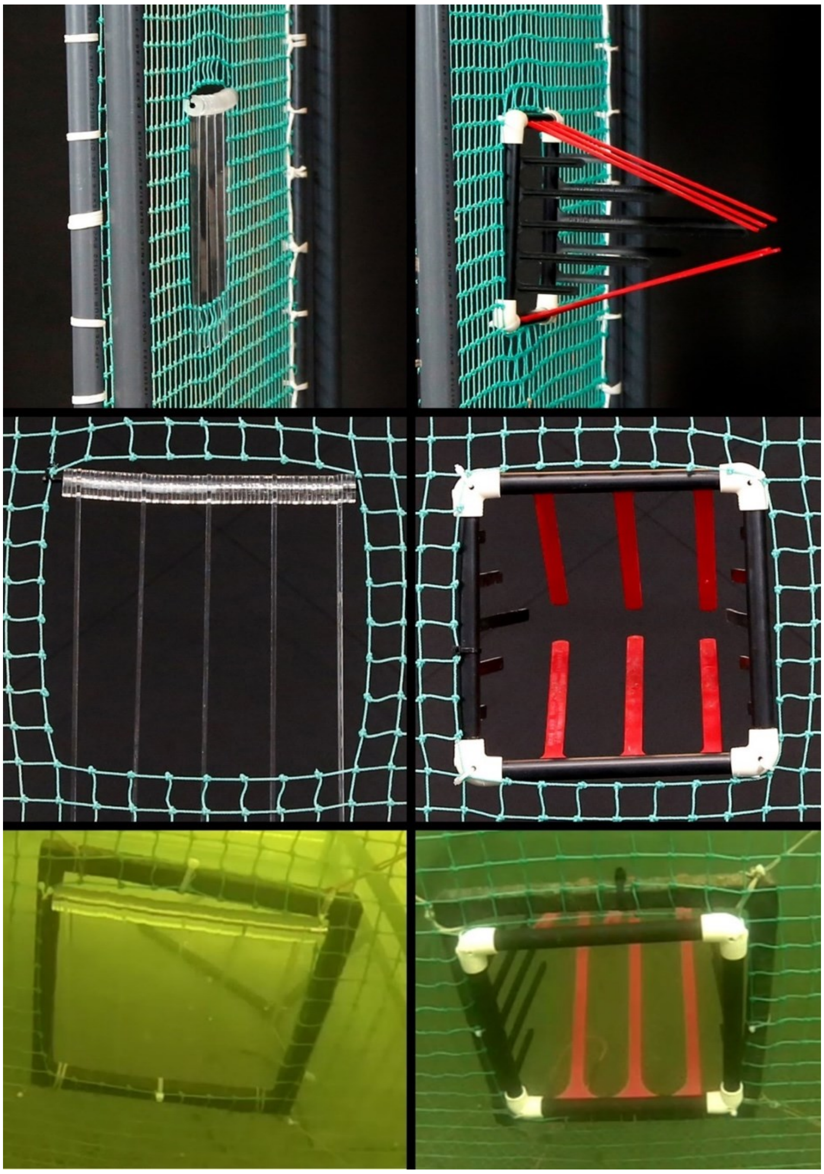
Die schlitzförmige Kehle hatte die schlechteste Fängigkeit aller untersuchter Kehlen (Abbildung 9), da zwar kaum Dorsche durch sie die Falle verließen, jedoch auch kaum Dorsche in die Falle eintraten. Somit beeinflusst auch die Kehlenform die Fischfallen-Fängigkeit stark.

In einem zweiten Schritt wurde untersucht, ob spezielle fingerförmige Fisch-Rückhaltevorrichtungen (“Fish retention devices“ – FRD) die Fangrate erhöhen, da sie die Fische zwar durch die Eingänge einlassen, aber durch einen Schließmechanismus am Wiederverlassen der Fischfalle hindern. Dabei wurde ein konventioneller FRD-Typ mit einem im Projekt neu entwickelten, durchsichtigen FRD-Typ („Acrylic finger“, AF; Abbildung 12) verglichen. Die unter Wasser fast nicht erkennbaren Acrylfinger erhöhten die Fängigkeit der Standardkehle fast auf das Doppelte: Die Eintrittsrate unterschied sich nicht signifikant von der der Standardkehle, während die Austrittsrate signifikant verringert wurde. Es wurden zwar keine Austritte aus der Falle durch die konventionellen FRD („Neptune fingers“, NF) beobachtet. Trotzdem war die Fängigkeit signifikant schlechter als die der Kontrollkehle bzw. den mit AF ausgestatteten Eingängen, da die Dorsche auch kaum durch sie in die Falle hinein schwammen.

Der Versuchsansatz zur Beobachtung von Dorschen in Interaktion mit Fischfallen hat sich als geeignet erwiesen, detaillierte Fragestellungen zu Fischfallen systematisch zu beantworten. In Zukunft könnte damit nicht nur die Wirkung weiterer Fischfalleneingangsparameter auf die Fängigkeit untersucht werden, sie ist auch geeignet, weitere Parameter, z. B. die Köderplatzierung oder die Fallengröße, zu untersuchen.

Die AF-FRD haben großes Potential, die Fängigkeit von Fischfallen zu erhöhen. Es ist anzunehmen, dass die Kombination von den unter Wasser nahezu durchsichtigen AF und einer transparenten Kehle eine weitere Erhöhung der Fängigkeit ermöglichen wird. Allerdings ist noch unklar, wie robust die AF unter realen Fischereibedingungen sind, insbesondere da Kratzer sowie Algenbewuchs die Durchsichtigkeit und Funktionalität der AF wahrscheinlich negativ beeinflussen. Der praktische Test und die anschließende Weiterentwicklung der AF sind für umfangreiche Praxistests in der nahen Zukunft geplant.

Abbildung 12: Acrylfinger (AF; links) und Neptunfinger (NF; rechts), angebracht an Fischfalle (ohne Kehle). Reihe oben und Mitte: an der Luft, untere Reihe: unter Wasser.



Ponton-Hebereuse

Wesentliche Probleme beim Einsatz von Reusen statt Stellnetzen sind nicht nur die höheren Anschaffungskosten, sondern auch der viel höhere Personalaufwand bei der Handhabung des Fischereigerätes. In diesem Projektteil wurde erstmals in deutschen Gewässern eine durch Luftdruck hievbare und damit durch ein oder zwei Personen bedienbare Großreuse getestet. Diese sogenannte Ponton-Hebereuse wurde in Schweden entwickelt, da seit den 1990er Jahren die Kegelrobben durch Netzfraß die Stellnetzfischerei an Teilen der schwedischen Ostseeküste praktisch unmöglich gemacht haben. Die Ponton-Hebereuse schützt die in der Fangkammer befindlichen Fische vor Kegelrobben und erlaubt ein einfaches Hieven (Hemmingsson et al., 2008). Die Dyneema-verstärkte Fangkammer der Ponton-Hebereuse verhindert effektiv den Wegfraß des Fanges durch die Kegelrobbe (Königson et al., 2013). Sie kann mittels Druckluft mit einem kleinen tragbaren Kompressor von nur einem Fischer binnen Minuten gehoben, anschließend entleert und wieder gesetzt werden. Die Hebereuse wurde in Schweden bisher v. a. in der kommerziellen Fischerei an relativ geschützten Standorten auf die Zielfischarten Lachs und Maräne eingesetzt. Dieses Gerät ist durch mehrere Entwicklungszyklen gegangen (s. u. a. Hemmingsson et al., 2008; Lundin et al., 2011) und wird von Wissenschaftlern der Swedish University of Agricultural Sciences (SLU) momentan für den Einsatz in der küstennahen Fischerei auf Dorsch und Hering getestet.

In diesem Projekt wurde die Handhabung und Fängigkeit der schwedischen Pontonreuse in deutschen Gewässern erstmals getestet. Bereits nach den ersten Tests war absehbar, dass das ursprüngliche Design der Reuse in deutschen Gewässern nur eingeschränkt einsetzbar ist. Bei einem Workshop Ende 2018 zu den ersten Praxis-Erfahrungen mit der schwedischen Ponton-Hebereuse wurden eine ganze Reihe notwendiger Verbesserungen der Reuse identifiziert sowie der Neubau einer verbesserten Reusen-Version beschlossen (Abbildung 13). Der Neubau wurde dann 2019 zum ersten Mal getestet, woraufhin weitere Verbesserungen vorgenommen werden konnten. Im Sommer 2020 befindet sich die Pontonreuse in der nächsten Phase des Erprobungsbetriebs. Die Ergebnisse der Erprobung in den Boddengewässern sind vielsprechend, eine Erprobung unter den anspruchsvolleren Bedingungen an der Außenküste steht noch aus.

Abbildung 13: Modifizierte Ponton-Hebereuse im Einsatz im Gebiet Rügen.

8 Arbeitspaket 4 - Fischereiliche Handlungspraxis in Bezug auf die Vermeidung unerwünschter Beifänge

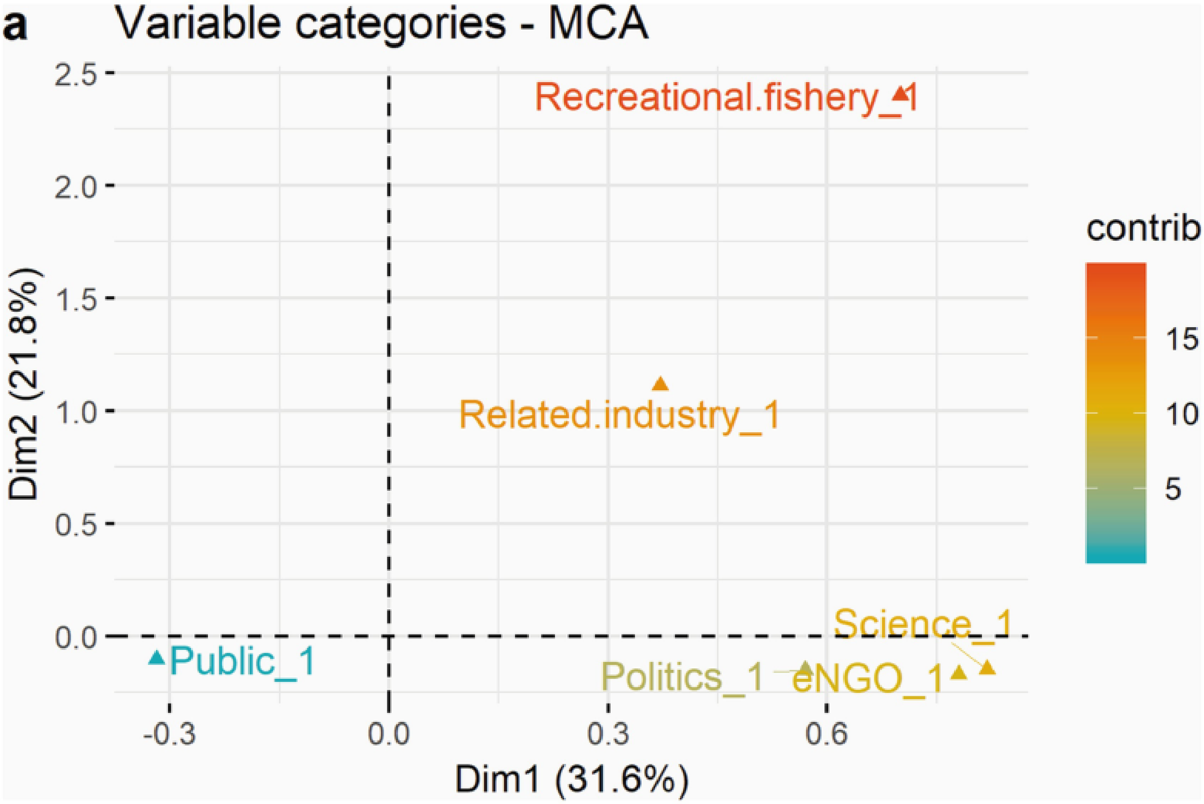
Verantwortliche: Fanny Barz (Betreuung: Sarah B. M. Kraak, Harry V. Strehlow)

Im vierten Arbeitspaket des STELLA-Projektes wurde die Beifangvermeidung aus sozialwissenschaftlicher Perspektive beleuchtet. Um die Anwendung und Umsetzung von beifangvermeidenden Maßnahmen effektiver und nutzbarer zu gestalten, ist es wichtig, die Fischer als Anwender und Zielgruppe vom Fischereimanagement sowie ihre Werte und Handlungen zu verstehen (Christensen und Raakjær 2006). Die relevantesten Akteure in dem vorliegenden Projekt waren die Stellnetzfischer der deutschen Ostsee.

Es fand zum einen eine Literaturstudie von möglichen partizipativen (teilnehmenden) Methoden, wie z.B. Workshops, Runde Tische statt, die bei der Arbeit mit Fischern unterstützend wirken können. Zum anderen wurde empirisch eine qualitative soziologische Betrachtung von Stellnetzfischern durchgeführt; darauf aufbauend fand eine Evaluierung von Instrumenten zur Beifangvermeidung statt. Diese Einschätzung kann die Basis für partizipative Zusammenarbeit und für eine Abschätzung von Managementfolgen bilden.

In einem ersten Schritt lag der Schwerpunkt darauf herauszufinden, wie verschiedene Akteure (Stakeholder) angesprochen werden sollten, um sie in den Forschungsprozess zu integrieren und fischereiliche Handlungsmuster im Kontext Beifang von Seevögeln und Schweinswalen zu untersuchen. Zu diesem Zweck wurde ein wissenschaftlicher Review durchgeführt, der wissenschaftliche Veröffentlichungen von Fallstudien im Bereich der Küstenfischerei analysierte (Schwermer et al. 2020). Insgesamt wurden 286 wissenschaftliche Veröffentlichungen identifiziert, wovon 50 für die nähere Betrachtung relevant waren. Ziel war es herausfinden, wie diese Studien „Partizipation“ definierten, welche Akteure angesprochen wurden, mit welchen Methoden und welche Intention dahinter lag. Die Analyse der involvierten Stakeholder durch eine Mehrfachkorrespondenzanalyse (MCA) zeigte Beziehungen zwischen ihnen auf: Die Gruppen der Stakeholder, die im NGO-Bereich, im politischen Bereich und im wissenschaftlichen Bereich tätig sind, werden oft zusammen angesprochen (Abbildung 14). Das kann bereits bei der Einladung von Stakeholdern zu partizipatorischen Prozessen zu einer verzerrten Wahrnehmung der tatsächlich beteiligten Gruppen führen und ihrer Meinungen führen, Durch die konstante Beteiligung dieser drei Gruppen wird ihre Relevanz und Deutungsmacht gestärkt, was zu einer Marginalisierung anderer Stakeholdergruppen führen kann. Darüber hinaus könnten sie wie eine zusammengehörige Gruppe wirken, die einen Gegenpol zur Fischerei bildet und sogar als „Front“ wahrgenommen wird.

Abbildung 14: Ergebnis der Mehrfachkorrespondenzanalyse (MCA), das den Zusammenhang der verschiedenen Stakeholdergruppen in den untersuchten Studien aufzeigt. Die Stakeholdergruppen Science, eNGO und Politics liegen dichter beieinander als die drei übrigen Stakeholdergruppen.



Diese Erkenntnisse mussten wir bei der Durchführung als auch bei der Auswertung der Interviews beachten. Mit Hinblick auf die erwarteten Spannungen, potentiellen Gegenhorizonte und schwierigen Themen in den geplanten Interviews mit Fischern konnte der Leitfaden für das weitere Vorgehen entsprechend angepasst werden. So wurden sensible Themen, die bspw. direkt dem Bereich Naturschutz (Beifangverhalten) oder Verwaltung/Politik (Fischereikontrolle) zugeordnet werden konnten, erst im zweiten Teil des Leitfadens gestellt. Die Wahrnehmung der Wissenschaft-Naturschutz-Politik-Gruppe als Antagonist der Fischerei wurde in den später geführten Interviews von den Fischern bestätigt.

Im Management werden die Fischer als homogene Gruppe betrachtet, obwohl sich verschiedene Studien bereits mit Typologien, also verschiedenen Typen von Fischern, und auch den daraus erwachsenen Konsequenzen für Managementinstrumente beschäftigt haben (Abernethy 2010; Sønvisen 2014; Boonstra und Hentati-Sundberg 2016; Creative Research 2009). Um ein grundsätzliches Verständnis für die Fischer als Stakeholder der Stellnetzfischerei und ihren fischereilichen Handlungspraxen zu entwickeln (gerade in Bezug auf unerwünschten Beifang), wurden problemzentrierte und leitfadengestützte Interviews durchgeführt (Witzel 2000). Die Auswahl der Interviewpartner basierte auf einer Analyse aus AP 1. Nach der Identifizierung von unterschiedlichen Gruppen von Fahrzeugen und Fischern wurden relevante Gruppen mit einem erhöhten Risiko für unerwünschte Beifangereignisse ausgewählt. Dabei wurden verschiedene Kriterien verfolgt: die Gruppen wurden entsprechend der Anzahl ihrer Fischereiausfahrten geordnet, welche als Richtwert für den Fischereiaufwand gewertet wurde (Tregenza et al. 1997). Der Fokus wurde dann auf die ersten drei Gruppen mit den meisten Fischereiaktivitäten im Jahr 2016 gelegt, unter der Annahme, dass eine höhere Fischereiaktivität potentiell zu einem höheren Risiko für unerwünschten Beifang führen kann. Die ausgewählten Gruppen waren die Dorsch-Gruppe (mit Hauptanlandeart Dorsch), die Hering-Dorsch-Gruppe und die Hering-Flunder-Gruppe. Innerhalb der ausgewählten Gruppen wurden Häfen identifiziert, die in der Nähe von Meeresschutzgebieten verortet sind. Anschließend wurden Fischer, die in diesen Häfen anlanden, entsprechend ihrer Anlandungen (Zielarten, Fangmenge) geordnet, kontaktiert und interviewt. Des Weiteren wurden Interviewpartner durch Empfehlungen von anderen Fischern identifiziert. Es wurden 22 auswertbare Interviews durchgeführt, die zwischen 50 und 180 Minuten lang waren. Die Interviews und Namen der Interviewpartner wurden anonymisiert. Die Tonaufnahmen wurden anschließend fast vollständig wortgetreu transkribiert, um sie mit Hilfe der dokumentarischen Methode auszuwerten (Nohl 2012). Während der Analyse wurde untersucht, was die Fischer in den Interviews gesagt haben, aber vor allem, wie etwas gesagt wurde. Diese rekonstruktive Methode liefert den Zugang zu den sogenannten Orientierungsrahmen der Fischer, nach denen sich ihre Handlungsweisen richten.

Als erstes Ergebnis wurden drei Fischertypen identifiziert, die wir im Folgenden nach ihrer „Agency“ einteilen, einem soziologischen Konzept, dass Handlungsmacht ausdrückt und damit das Handeln der Fischer in komplexen Kontexten beschreiben kann: (i) iterativ, (ii) evaluativ, (iii) projektiv. Fischer, die schwerpunktmäßig **iterativ** handeln, zeichnen sich u.a. dadurch aus, dass ihre Handlungen und Erzählungen stark an der Vergangenheit orientiert sind. Sie rufen dabei bereits erlernte und etablierte Handlungsschemata ihrer fischereilichen Handlungspraxis ab und wenden diese an. Dies macht sie weniger zugänglich für neue Routine, wie sie z. B. mit der Verwendung eines neuen Fanggeräts einhergehen würden. Diese Fischer sind meist sehr spezialisiert, besitzen nur ein Fahrzeug und möchten in Zukunft gerne ihre aktuellen Handlungen weiter ausführen. Sie bewerten dabei nicht neu, ob die angewendeten Handlungsschemata zu der aktuellen Situation der Stellnetzfischerei passen.

Beispiel für die Aussage eines Fischers, der dem iterativen Typ zuzuordnen ist:

> „Nur Stellnetzfischerei, seit zweiundachtzig. Beste Fischerei die es gibt. Ja ist so, ne? Ruhiges Leben, jeden Tag zu Hause, das in Ordnung, ne?“ (Herr Lärche, Absatz 8)

Fischer, die vorherrschend dem **evaluativen** Fischertypus zuzurechnen sind, sind hingegen eher gegenwartsorientiert. Dazu gehört, dass sie Situationen ständig neu bewerten und sich greifbare Ziele setzen, nach denen sie ihre Handlungen ausrichten. Sie handeln opportun, um die aktuelle Situation zu verbessern und wägen ab, ob die Anwendung etablierter oder erneuerter Handlungsschemata angebracht ist. Ein evaluativer Fischer kann dazu übergehen die Fischerei zu verlassen, wenn in seinen Augen keine baldige Besserung in Sicht ist. Er könnte aus demselben Grund aber auch zu illegalen Aktivitäten innerhalb der Fischerei übergehen.

Beispiel für die Aussage eines Fischers, der dem evaluativen Typ zuzuordnen ist:

> „Was meinen Sie denn [was ich machen kann] mit fünf Tonnen Dorsch [Quote]? Da muss ich ja nicht mal einen Hauptschulabschluss haben, dass ich begreife, dass das nicht mehr funktioniert, ne? […] Dass du ja irgendwo immer nur mit Beschiss… ne? […] Regulär - geht das nicht mehr.“ (Herr Buche, Absatz 162)

Handlungen von **projektiven** Fischern zeichnen sich durch eine eher langfristige Ausrichtung aus. Ihre Handlungen, Erzählungen sowie Ziele orientieren sich an der Zukunft. Sie verfolgen meist diverse Zielarten und haben Erfahrungen mit verschiedenen Fangtechniken. Es fällt ihnen leichter, neue Handlungsschemata zu verwenden, meist aus intrinsischer Motivation, unabhängig von sich verändernden Strukturen, wie es z. B. beim evaluativen Fischer der Fall ist.

Beispiel für die Aussage eines Fischers, der dem projektiven Typ zuzuordnen ist:

> „Man muss schon irgendwie eine Idee haben, wie es weitergeht, ne? Ich kann nicht darauf warten, dass irgendetwas… […] Irgendwas muss passieren. Irgendwie. Am besten [wäre es] einen Fischladen auf[zu]machen. Hier ist gar kein Fischladen mehr.“ (Herr Kiefer, Absatz 213)

Diese Typologie wurde induktiv erarbeitet, das heißt, es gab keine vorbestimmten Kategorien oder Muster, die gesucht wurden, sondern die Kategorien haben sich erst aus dem Analyseprozess und dem Text heraus entwickelt. In der Literatur lassen sich ähnliche Typen in der Fischereiforschung, aber auch in anderen Zusammenhängen finden. Creative Research (2009) identifizierte im britischen Küstenfischereibereich Führungspersönlichkeiten (Leader), Leutnants (Lieutenants) und Anhänger (Follower), die beschrieben werden wie projektive, evaluative und iterative Typen. Auch im Bereich der Agrarforschung sind diese Typen grundlegend anzutreffen (Barnes et al. 2011). Dies legt nahe, dass es sich hierbei um universelle Handlungstypen handelt, die sich auch bei den deutschen Stellnetzfischern der Ostsee finden.

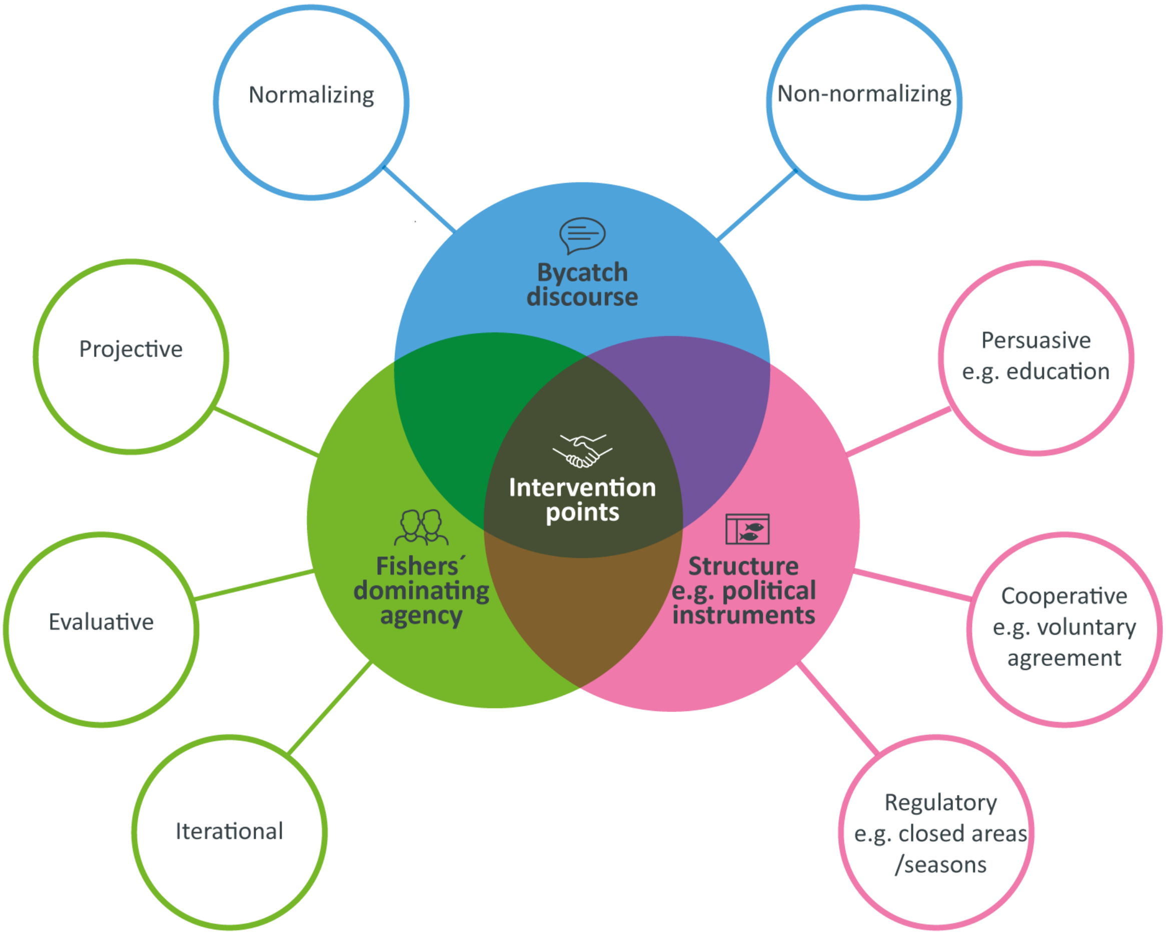
Als ein weiteres Ergebnis konnten wir zwei unterschiedliche Diskurse um das Thema Beifang identifizieren. Während der Beifang von Seevögeln meist normalisiert wurde, wurde Beifang von marinen Säugern meist nicht normalisiert. Normalisierung bedeutet, dass Beifangereignisse von Seevögeln von den Fischern als Teil ihrer Arbeitsroutine thematisiert wurden, was jedoch keinen Rückschluss auf die Häufigkeit eines Beifangereignisses zuließ. Fischer thematisierten Beifang von Seevögeln außerdem als etwas, deren Vermeidung außerhalb ihrer Handlungsmacht liegt. Beifangereignisse von Schweinswalen hingegen wurden eher als Ereignisse beschrieben, welche die Arbeitsroutinen der Fischer unterbrechen und können somit im soziologischen Sinne als das Gegenteil einer Routine, namentlich als eine Krise bezeichnet werden. Trotz der beschriebenen wahrgenommenen Handlungsohnmacht der Fischer gegenüber Beifangereignissen haben sie Strategien entwickelt, die darauf abzielen, Beifang zu vermeiden. Die Fischer gaben an, dass sie bereits diverse beifangvermeidende Maßnahmen angewendet haben und weiter anwenden. Vor allem in Bezug auf die Vermeidung von Seevogelbeifang meiden Fischer gezielt bekannte Risikogebiete, Zeiten und Wassertiefen und führen visuelle Kontrollen auf das Vorhandensein von Seevögeln im Gebiet durch, um diese Gebiete ggfs. zu meiden. Zur Vermeidung von Schweinswalbeifang verwenden sie PALs (Porpoise Alert, eine Art Pinger, die derzeit nur in der schleswig-holsteinischen Fischerei eingesetzt wird) und verringern ihre Stellzeiten, sowie Netzlängen. Die letzten beiden Maßnahmen werden vor allem im Rahmen der Freiwilligen Vereinbarung in Schleswig Holstein (Landesfischereiverband Schleswig-Holstein et al. 2015) durchgeführt. Die langfristige Wirksamkeit der PAL wird derzeit im Projekt PAL-CE untersucht.

Um weitere Ideen für beifangvermeidende Maßnahmen, vor allem auf struktureller Ebene, zu generieren, wurde ein Expertenworkshop abgehalten, an dem 19 Experten teilnahmen. Die diskutierten Maßnahmen wurden in Bezug zu den bisherigen Erkenntnissen gesetzt und bewertet. Generell erachteten die Experten belastbare Beifangdaten als unverzichtbar für ein effizientes Management.

Aus verschiedenen Gründen, die im Folgenden näher erläutert werden, werden monetäre Ansätze (z. B. Entschädigungen bei Meidung von Risikogebieten) als nicht zielführend eingeschätzt. Selbst projektive Fischer, die zukunftsorientierte Strategen sind, richten ihre Planung nicht nach der Maximierung der möglichen finanziellen Unterstützung aus. Evaluative Fischer nutzen am ehesten die Chance, wenn sich finanzielle Unterstützung anbietet, während iterative Fischer meist nicht die bürokratischen Belastungen auf sich nehmen können oder wollen, um finanzielle Unterstützung zu beantragen. Es gibt zahlreiche Hinweise aus anderen Studien, dass monetäre Anreize keine Patentlösung sind und sehr wahrscheinlich intrinsische Motivationen verdrängen (Bowles 2008). Während des oben genannten Workshops waren sich die Expertinnen und Experten weiterhin einig, dass es aktuell (Stand März 2018) generell umfangreiche finanzielle Unterstützung für die Fischerei gibt, die erstmal keines Ausbaus bedürfen.

Die konzeptionellen Ansatzpunkte zur Vermeidung von unerwünschten Beifängen werden wie folgt zusammengefasst (Abbildung 15): auf der Ebene der Fischer und ihrer Agency, auf struktureller Ebene und auf Ebene des Beifangdiskurses. Um maßgeblich zur Beifangvermeidung beizutragen, müssen diese Punkte sinnvoll miteinander verknüpft werden, wie in mehreren Beispielen bereits diskutiert wurde.

Abbildung 15: Konzeptionelle Darstellung der Interventionspunkte zur Vermeidung von unerwünschtem Beifang



Basierend auf den Teilergebnissen aus AP4 gibt es drei wesentliche Ansatzpunkte, um unerwünschte Beifänge in der Fischerei zu vermeiden. Dabei können je nach organisatorischer Kapazität und Kräfteverhältnissen auch nur einzelne Maßnahmen umgesetzt werden. Nur die Berücksichtigung aller Interventionspunkte führt jedoch zu einem hohen Maß an regelkonformen Verhalten (Compliance).

(1) Die Typologie der Fischer ermöglicht es, technische Lösungen und Regularien gezielt einzusetzen. Die Verwendung von neuem Fanggerät ist zugänglicher für projektive und evaluative Typen. Iterative Typen hingegen sehen keine Alternative zum Stellnetz, so dass sie am ehesten über Regularien zu erreichen sind.

(2) Strukturelle beifangvermeidene Maßnahmen können Regularien (wie Echtzeit-Schließungen), freiwillige Vereinbarungen oder Einstellungsänderungen durch Aus- und Weiterbildungsprogramme sein. Diese Maßnahmen können je nach Fischertyp unterschiedlich erfolgreich sein.

(3) Ein Diskurswandel mit dem Ziel, unerwünschten Beifang als nicht normal anzusehen, und dadurch erzeugte Verhaltensveränderungen in der fischereilichen Handlungspraxis hin zur aktiven Vermeidung von Beifang, ist mittelfristig durch die Ausweitung von Bildungsinhalten möglich.

Bei ausreichender Datenbasis könnten Risikogebiete und -zeiten für Beifang identifiziert und mit Echtzeit-Bewirtschaftungsinstrumenten geschlossen und verwaltet werden. Weiterhin sollte die Meldung von Beifängen bundeslandübergreifend verpflichtend sein. Dies könnte in Zukunft auch über eine Foto-Meldung via einer Mobiltelefonapplikation stattfinden (z. B. Mofi). Um in ansonsten geschlossenen Gebieten weiterhin fischen zu dürfen, kann eine aktive Fischereilizenz für dieses Gebiet an verschiedene Bedingungen geknüpft werden, z. B. die Verwendung von Mofi, das Mitführen von Kameras an Bord oder die Nutzung von beifangvermeidendem Fanggerät.

Die Erkenntnisse aus dem Bereich des Beifangdiskurses legen nahe, dass ein zentrales Element für die Beifangvermeidung der Diskurswandel ist. Die Ausweitung von Bildungsinhalten zum Thema Beifang ist daher wichtig, um ein Umdenken im Diskurs zu erreichen. Mit dem Ziel, unerwünschten Beifang als nicht normal anzusehen, könnten Bildungsangebote im Rahmen der Aus- und Weiterbildung von Fischwirten angeboten werden. Da die Zahlen der neu auszubildenden Fischwirte insbesondere für die Ostsee eher gering sind, sollte der Fokus vor allem auf Weiterbildungsprogrammen liegen, um Fischer mit viel und wenig Berufserfahrung gleichermaßen zu erreichen. Des Weiteren sollten Co-Management Prozesse weiterverfolgt werden. Ein solcher Ansatz wurde in Schleswig-Holstein mit der freiwilligen Vereinbarung (einschließlich einer vermittelnden Organisation) etabliert. Bei der zukünftigen Entwicklung eines Co-Managements sollten Strukturen geschaffen werden, die die Überprüfung der Effizienz der Maßnahmen ermöglichen, z.B. durch die Erhebung von Fischereiaufwands- und Beifangdaten. –

Mit entsprechenden Maßnahmen (z.B. Umweltbildungsmaßnahmen und Schaffung eines Co-Managements, Echtzeit-Bewirtschaftungsinstrumente) können alle Fischertypen, wenn auch aus unterschiedlichen Gründen, angesprochen und erreicht werden. Aus- und Weiterbildungsprogramme erreichen alle Fischertypen, da es sich um verpflichtende Lehrprogramme handelt, wenn die Fischerei weiter ausgeübt werden soll. In Bezug auf die freiwillige Vereinbarung können projektive Fischer mit Langzeitstrategien arbeiten, evaluative Fischer bewerten sie als Chance, guten Willen zu zeigen, während iterative Fischer meist partizipieren, wenn die Genossenschaften die Teilnahme zur Vorgabe machen.

9 Bislang aus STELLA erschienene Veröffentlichungen

Barz, F. 2021. `Boats don´t fish, people do´: a sociological contribution towards holistic fisheries bycatch management. Dissertation, University of Rostock, Germany, 230 p. Veröffentlicht als Thünen-Report 95 (2022), 244 p, DOI:10.3220/REP1652092494000

Barz, F., Eckardt, J., Meyer, S., Kraak, S. B. M., Strehlow, H. V. 2020. `Boats don't fish, people do'- how fishers' agency can inform fisheries-management on bycatch mitigation of marine mammals and sea birds. Marine Policy 122: 104268, doi:10.1016/j.marpol.2020.104268

Chladek, J.C. 2022. Fishing gear technology to mitigate harbour porpoise and seabird bycatch in the Baltic Sea: Gillnet modifications and alternative fishing gear fish pot. Dissertation, University of Hamburg, Hamburg. 153 pp. (submitted)

Chladek, J.C., Stepputtis, D., Hermann, A., Kratzer, I.M.F., Ljungberg, P., Rodriguez-Tress, P., Santos, J., Svendsen, J.C. 2021. Using an innovative net-pen-based observation method to assess and compare fish pot-entrance catch efficiency for Atlantic cod (*Gadus morhua*). Fisheries Research 236: 105851, doi:10.1016/j.fishres.2020.105851

Chladek, J.C., Stepputtis, D., Hermann, A., Kratzer, I.M.F., Ljungberg, P., Rodriguez-Tress, P., Santos, J., Svendsen, J.C. 2020. Development and testing of fish-retention devices for pots: transparent triggers significantly increase catch efficiency for Atlantic cod (*Gadus morhua*). ICES Journal of Marine Science 78 (1): 199-219, doi:10.1093/icesjms/fsaa214

Hermann, A., Chladek, J.C., Stepputtis, D. 2020. iFO (infrared Fish Observation) - An open source low-cost infrared underwater video system. HardwareX 8:e00149, https://doi.org/10.1016/j.ohx.2020.e00149

Kratzer, I.M.F. 2021. Gillnet modifications to reduce bycatch of harbor porpoises. Dissertation. Technical University of Denmark, Kopenhagen. National Institute of Aquatic Resources. 172 pp, https://orbit.dtu.dk/en/publications/gillnet-modifications-to-reduce-bycatch-of-harbor-porpoises

Kratzer, I.M.F., Schäfer, I., Stoltenberg, A., Chladek, J.C., Kindt-Larsen, L., Larsen, F., Stepputtis, D. 2020. Determination of optimal acoustic passive reflectors to reduce bycatch of Odontocetes in gillnets. Frontiers in Marine Science 7: Article 539, doi:10.3389/fmars.2020.00539

Kratzer, I.M.F., Brooks, M.E., Bilgin, S., Özdemir, S., Kindt-Larsen, L., Larsen, F., Stepputtis, D. 2021. Using acoustically visible gillnets to reduce bycatch of a small cetacean: first pilot trials in a commercial fishery. Fisheries Research 243: 106088, doi:10.1016/j.fishres.2021.106088

Kratzer, I. M. F., Stepputtis, D., Santos, J., Lütkefedder, F., Stoltenberg, A., Hartkens, L., Schaber, M., Kindt-Larsen, L., & Larsen, F. 2022. Angle-dependent acoustic reflectivity of gillnets and their modifications to reduce bycatch of odontocetes using sonar imaging. Fisheries Research, 250: 106278, doi:10.1016/j.fishres.2022.106278

Meyer, S., Krumme, U. 2021. Disentangling complexity of fishing fleets: using sequence analysis to classify distinguishable groups of vessels based on commercial landings. Fisheries Management and Ecology 28: 268–282, doi:10.1111/fme.12472

Meyer, S., Krumme, U., Stepputtis, D., Zimmermann, C. 2022. Use of a smartphone application for self-reporting in small-scale fisheries: Lessons learned during a fishing closure in the western Baltic Sea. Ocean and Coastal Management 224: 106186, doi:10.1016/j.ocecoaman.2022.106186

Schwermer, H., Barz, F., Zablotski, Y. 2020. A Literature Review on Stakeholder Participation in Coastal and Marine Fisheries. In: Simon Jungblut, Viola Liebich und Maya Bode-Dalby (Hg.): YOUMARES 9 - The Oceans: Our Research, Our Future, Bd. 19. Cham: Springer International Publishing, S. 21–43, https://link.springer.com/chapter/10.1007/978-3-030-20389-4_2

Anhang

Arbeitspaket 1 – Veröffentlichung 1 “Disentangling complexity of fishing fleets: using sequence analysis to classify distinguishable groups of vessels based on commercial landings.”

Meyer, S., Krumme, U. 2021. Disentangling complexity of fishing fleets: using sequence analysis to classify distinguishable groups of vessels based on commercial landings. Fisheries Management and Ecology 28: 268–282, doi:10.1111/fme.12472

Abstract

Capturing the diversity of fishing fleets and identifying distinct subgroups is essential for effectively directing research and management efforts. In this study, the German Baltic gillnet fleet was split into distinguishable groups of vessels by applying a stepwise approach. Monthly landing profiles were classified using clustering techniques and arranged as annual landing sequences, as the basis to form groups of vessels with distinct annual landing sequences using sequence analysis. Commercial landings from 1243 vessels across 11 years (2008–2018) resulted in 8031 annual landing sequences, which were clustered into eight groups, each with a characteristic, annually recurring, seasonal landing pattern (cod group, cod-herring group, herring-flounder group, herring group, freshwater fish group, pikeperch group, eel group and port group). The results highlight the heterogeneity of the fleet and a strong adaptation to regional and seasonal resource availability. Studying sequences of landings instead of isolated events in time provides insight into the interlinkage and succession of landings and can aid at classifying fishing fleets and better targeting groups of vessels of interest.

Vollständige Veröffentlichung (Open Access)

https://onlinelibrary.wiley.com/doi/10.1111/fme.12472

Arbeitspaket 1 – Veröffentlichung 2 " Use of a smartphone application for self-reporting in small-scale fisheries: Lessons learned during a fishing closure in the western Baltic Sea."

Meyer, S., Krumme, U., Stepputtis, D., Zimmermann, C. 2022. Use of a smartphone application for self-reporting in small-scale fisheries: Lessons learned during a fishing closure in the western Baltic Sea. Ocean and Coastal Management 224: 106186, doi:10.1016/j.ocecoaman.2022.106186

Vollständige Veröffentlichung (Pre-print Proof)

Abstract

There is a lack of data on the experience of the use of mobile devices in commercial small-scale fisheries but which are important to evaluate the suitability of these approaches for fisheries monitoring. In February and March 2018, the German Baltic small-scale fishery used a smartphone application for self-reporting of fishing activities to demonstrate compliance with the terms of a fishing closure of cod, which prohibited to fish deeper than 20 m. A total of 1618 trips and 7972 gear activities from 107 vessels were identified and categorized. Data review showed that not all data could be used directly due to operating or technical errors (e.g. mismatch in time and space of self-reported and actual gear activities and missing records on geographical positions). By editing during data evaluation, the proportion of useable trips and gear activities increased from 67 to 78% and from 29 to 69%, respectively. These data provided new insights into the activities of small-scale fishing vessels (< 12 m), especially of the data-poor segment of vessels smaller than 8 m (e.g. for gillnets: mean net length of 664 m ± 538 SD, mean soak time of 30 h ± 12.9 SD, mean trip duration of 2.9 h ± 1.6 SD). Due to the high spatio-temporal resolution, the fishers could demonstrate compliance with the closure, with 99% of all recorded gear activities performed in areas shallower than 20 m. Based on the fast and short operation at sea observed, recording intervals of max. 1 min are advisable for small-scale vessels. Potential suggested improvements involve training of fishers, an independent GPS sensor, a remote control and tailored tools for data analysis to properly address future developments of smartphone applications for the use in data collection in small-scale fisheries.

Keywords

electronic reporting, mobile phone, artisanal fisheries, self-reporting, digital fisheries monitoring

1. Introduction

The monitoring of fishing activities covers a variety of approaches, depending on the objectives. Methods involve for instance paper logbooks and electronic logbooks for documenting inter alia catches or landings (EU, 2011). Further, at-sea observers can be used to assess discard (Heery and Cope, 2014) or electronic monitoring systems (combining GPS (Global Positioning System) data with camera footage and sensors that automatically detect gear activity) are deployed to document unwanted bycatch in fisheries (Kindt-Larsen et al., 2012). Strategies for monitoring the spatial distribution and effort of fishing activities include ship-based (Sonntag et al., 2012) and aerial surveys (Zellmer et al., 2018) as well as interviews (Demestre et al., 2015), VMS (Vessel Monitoring System) and AIS (Automatic Identification System) (Russo et al., 2016).

In addition to these monitoring approaches, applications for mobile devices such as tablets and smartphones have gained increasing attention in recent years (Bradley et al., 2019; Gutowsky et al., 2013). These devices combine different practical features including a GPS sensor, storage for data recording and uploading, photo and video recording, data transfer using wireless networks and the option to access the data in near real-time and to reduce transcription and recording errors (Bradley et al., 2019; Lorenzen et al., 2016; Venturelli et al., 2016). A variety of applications are already used among recreational fishers (Bradley et al., 2019) and are perceived to have great potential in supporting current standard reporting methods in marine recreational fisheries management (Skov et al., 2021). In commercial fisheries, applications for mobile devices were used in real-time management to reduce unwanted bycatch of overfished fish species in a trawl fishery (Kauer et al., 2018) or to support fishers in self-management, e.g. to avoid overfishing of a sea cucumber species (Saville et al., 2015).

In 2018, the German Baltic small-scale fishery (herein defined as vessels smaller than 12 m (EU, 2021a) but without excluding towed fishing gear) was obliged to use a smartphone application during a fishing closure of cod. Western Baltic cod was formerly the major demersal target species in the western Baltic Sea, but the directed fishery was closed in 2022 (EU, 2021b). Different spawning time-related area closures have been implemented over the years for this stock (e.g. EC, 2005, 2001; Eero et al., 2019; EU, 2021b, 2016) with the aim to ensure undisturbed spawning, increase recruitment and thus support stock recovery (Eero et al. 2019). In 2018, the closure lasted for two months (01.02.-31.03.2018) in ICES (International Council for the Exploration of the Sea) SDs (subdivisions) 22-24 (EU, 2017). During this period, a cod fishery was not allowed. However, vessels smaller than 12 m were permitted to target cod in areas shallower than 20 m (EU, 2017) as western Baltic cod mostly spawn in areas deeper than 20 m (Bleil and Oeberst, 2002) where water is more saline and ensures the egg buoyancy needed for successful spawning (Nissling and Westin, 1997). This exemption was linked to the condition that the fishing activities could be monitored at any time using a monitoring system approved by the respective national control authority (EU, 2017).

The standard monitoring methods for German Baltic small-scale vessels are paper logbooks for vessels with a length between 8 m and 12 m (EC, 2009; EU, 2016, 2011) and landing declarations, also in paper format, for vessels smaller than 8 m (BLE, 2005). Since vessels exempt from the closure in 2018 were all smaller than 12 m, VMS was not mandatory (EC, 2009). Spatial resolution of fishing activities was on the level of ICES statistical rectangles, both for logbooks (EU, 2011) and for landing declarations (the latter slightly more detailed for vessels registered in the federal state of Mecklenburg-Western Pomerania (LALLF, 2021)). Temporal resolution was either on the level of single daily trips for vessels using paper logbooks (Castro Ribeiro et al., 2016; EU, 2011) or on a primarily monthly level for vessels using landing declarations (BLE, 2005).

In advance of the regulation on the fishing closure in 2018, the Thünen Institute of Baltic Sea Fisheries (a German federal research institute) commissioned Anchor Lab K/S (http://www.anchorlab.net/) to develop a smartphone application as a digital option to record fishing effort with a high spatio-temporal resolution for vessels of all sizes. This application (called Mobile fisheries log, in brief Mofi), was proposed by the Thünen Institute to then be used voluntarily by the German fishery to electronically self-report fishing activities during the closure, in addition to the standard reporting by means of paper logbooks and landing declarations. The traditional spatial and temporal resolutions for documenting fishing activities were considered too low and not suitable for demonstrating compliance with the terms of the closure. In the end, the national control authority made the use of Mofi mandatory during the two-month closure (BLE, 2018) to ensure constant monitoring of fishing activities during this period (EU, 2017). This decision was announced few days before the start of the closure and making the use of Mofi mandatory was opposed to the original suggestion to use the smartphone application as a voluntary reporting tool. A pre-test of Mofi under commercial conditions did not take place and the German small-scale fishery was left with little to no time to test or adapt to the first-time use of a smartphone application for fisheries monitoring.

Later in 2018, the proposal for amending the EU control regulation was released, which suggests mobile phone technologies as potential tools for monitoring small-scale vessels (COM, 2018). Specific amendments to the control regulation propose the tracking and digital reporting of catches of all vessels, irrespective of vessel size

(COM, 2018). In the light of these developments, the results and experience gained from the first large-scale, two-month application of a smartphone application in a commercial Baltic small-scale fishery might offer useful insights into the viability of such an approach.

In this study, we evaluated the data collected with the smartphone application Mofi during the two-month closure and identified strengths and weaknesses of this method. We examined i) to what degree the self-reported data were useable, ii) if the smartphone application enabled the fishery to demonstrate compliance with the terms of the closure, iii) what type of information could be obtained about the activities of the small-scale fishery from the anonymised self-reported data, and iv) whether the data were supplied on a spatio-temporal resolution appropriately reflecting the activities of small-scale vessels. The analyses iii) and iv) were done separately for the two standard reporting procedures (landing declaration: < 8 m vessel length, paper logbook: 8 – 12 m vessel length) and different business types (part-time, full-time) and fishing gears (gillnets and trawls).

2. Materials and methods

2.1. Coverage

After the 2018 fishing closure, the German control authority granted the authors access to the anonymised Mofi records as well as to anonymised data on logbook and landing records, technical features (vessel length overall, gross tonnage, power), business types (part-time, full-time) and ownership.

We analysed, how many vessels and respective owners registered on Mofi and recorded data during the closure. For the vessels that participated, the shares for the different reporting procedures (landing declaration, logbook) and business types (part-time, full-time) were determined.

We examined, how many German vessels with a length of less than 12 m reported any landings and cod landings originating from ICES SDs 22-24 (Fig. 1). We estimated, how many of the vessels that reported cod landings also had Mofi records and the amount of cod landings they covered, independent of the reporting procedure.

2.2. Functionality of the smartphone application Mofi

The application Mofi was designed as a versatile electronic reporting tool. Data on activities would be self-reported by the fishery and provide directly digitalized data on a high spatio-temporal resolution.

During the closure, the download of Mofi as well the recording of data was free of charge for the fishery. Fishers had to ensure that they had a smartphone on which Mofi worked, and they had to cover the costs for data transfer.

Mofi runs on smartphones with GPS functionality under Android OS 5.0 and higher, and on iOS 9.3 and higher. At the time of the fishing closure in 2018, an iOS version was not yet available and the versions for Android used during the closure were 1.0.25, 1.0.26 and 1.0.27. Connection to a mobile or wireless network was required during registration, while making changes to the user account and when data of completed trips were transmitted to a server for data storage. After an account was created, fishing vessels could be added from a list based on the fleet register of the European Union (more than one vessel can be registered per account).

At the beginning of a trip, the fisher had to choose the vessel and fishing gear to be used (Fig. S1). At the time of the closure only one gear could be chosen during a trip, which is different from logbooks in which fishers enter a new line if they use a different gear or the same gear but with a different mesh size (EU, 2011). Mofi logged two types of data during a trip: i) sensor data and ii) self-reported data. Sensor data were logged continuously at a fixed interval once a trip was started and without any further action required by the fisher, similar to VMS data (ICES, 2019a; Lowman et al., 2013). The sensor data comprised date, time, geographical position, speed and GPS accuracy. For about the first half of the closure the recording interval for the sensor data was set to 5 min and later increased to 1 min.

The self-reported data comprised the time stamps actively set by the fishers using the application to mark activities. By pushing the button for starting and ending a trip or a gear activity, time stamps were set, recording date, time and geographical position as well as the type of the respective action at that specific moment. For example, in case of gillnet activities there was the option to push the buttons >Start set gear< and >Stop set gear< if a gillnet was set (Fig. S2). The activity related time stamps were recorded independently of the continuously logged sensor data. Sensor data were always recorded in 1 min intervals once a gear activity was started and until it was ended.

While data was recorded with Mofi, the fishers could view the current track on a map on the interface of the application, including the gear activities marked by time stamps and the areas shallower than 20 m (Figs. S1-S2), which were based on the 20 m isobath adapted from official national nautical charts from Germany (provided by the Federal Maritime and Hydrographic Agency) and Denmark (provided by the Danish Geodata Agency).

2.3. Categorization and editing of trips and gear activities

To assess the quality of the originally recorded sensor and self-reported data, detect potential recording errors and define which data were useable for subsequent analyses, all trips and gear activities of the original data were checked manually using the commercial analyser software BlackBox Analyzer (Anchor Lab A/S, Version 4.6.5.0). During this process trips and gear activities were identified and assigned to different categories and time stamps were edited to correct for mistakes that occurred during self-reporting. In the remainder, these data are referred to as the categorized sensor and self-reported data covering unedited and edited trips and gear activities. No editing was performed to the sensor data at any point.

The BlackBox Analyzer displayed the sensor data together with the self-reported data and enabled us to identify errors in self-reporting, categorize the trips and gear activities and edit time stamps. The sensor data were shown as geographical tracks on a map linked to a time line with corresponding speed profile (Fig. 2). Speed was also reflected in the colour coding of the tracks in the map. The time stamps of the self-reported data representing start and end of trips and gear activities were labelled in the time line. The analyser had the option to adjust, delete and add time stamps and with it, trips and gear activities and thereby editing the self-reported data. The combination of geographical pattern and speed pattern shown in the map, the speed profile of the time line and the possibility to view previous and subsequent trips and gear activities simultaneously, allowed to identify, evaluate and categorize trips and gear activities, edit time stamps, and match related gillnet activities, i.e. setting activity and hauling activity of the same net. This type of data review required training to gain experience in and familiarize with the different patterns observed for different vessels and to be able to evaluate the set or missing time stamps.

Sensor and self-reported data were exported from the BlackBox Analyzer as CSV files before and after data review to obtain the original and the categorized data sets. Based on the assigned categories, trips and gear activities of the categorized data were defined as i) useable without editing, ii) useable after editing and iii) not useable for further analyses in R 4.1.0 (R Core Team, 2021). For an overview of the different categories, we assessed their distribution across vessels and over time.

To evaluate the effect of editing the time stamps, we compared data from gillnet activities before and after editing. First, the net lengths of all set and hauled gillnets were calculated from the original as well as from the categorized gillnet activities. The time stamps provided the start and end positions, and the sensor data provided the positions in between needed for the net length calculation using the R package geosphere (Hijmans, 2019). Next, only net lengths of complete gillnets pairs with useable gillnet activities were considered. A complete gillnet pair consisted of a net length for when a net was set and for when the exact same net was hauled again. Then we calculated the percentage difference between the net length for setting and the net length for hauling if both activities were not edited. The same was done for complete pairs of which either the net length of setting or the net length of hauling was edited. The latter was done once before editing (original data) and once after editing (categorized data). We then checked if editing caused a decrease in percentage difference and whether this percentage difference was similar to the one observed for pairs where no editing was considered necessary to neither the setting nor the hauling activity.

2.4. Activity data

Trip duration was calculated from all useable trips according to the time stamps that defined start and end of a trip. From the useable trips a subset was taken only containing trips with useable gear activities to assess the number of gear activities per trip. In case of gillnets, only set nets were considered.

The geographical positions of landing sites were extracted using the BlackBox Analyzer. For each useable gear activity the average linear distance to the respective landing site was estimated (R package geosphere (Hijmans, 2019)).

Trip duration, number of gear activities per trip (several gillnets can be set or hauled and trawls performed per trip) and distance to landing site were calculated for different fishing gears, reporting procedures and business types. The latter two were only possible for gillnet activities as trawl activities were only found among logbook and full-time vessels.

For the gear activities per fishing gear, we calculated the average duration needed (time needed for setting and hauling gillnets, time trawled), the average geographical distance covered (net length of setting and hauling gillnets, distance trawled) and the average speed (speed of setting and hauling gillnets, trawling speed, steaming speed of gillnet and trawl trips) recorded.

2.5. Spatial relation of gear activities to the 20 m isobath

For the useable gear activities, the depths were extracted using the geographical coordinates from the sensor data, ESRI ArcMap (version 10.6) and interpolations from GEBCO (GEBCO Compilation Group, 2019). We then calculated the mean depth for gillnet and trawl activities based on the mean depths of the individual gear activities.

To assess the amount of gear activities recorded completely shallower than 20 m, partially deeper than 20 m and completely deeper than 20 m, we used the same shapefile that was used for the demarcation of areas shallower than 20 m in the map displayed in Mofi (R package rgdal (Bivand et al., 2021) and R package sf (Pebesma and Bivand, 2021)). For the gear activities recorded partially deeper than 20 m, the average maximum distance to the 20 m isobath (taking the point of each gear activity furthest away) was calculated. For the gear activities recorded completely shallower than 20 m, the average minimum distance to the 20 m isobath (taking the point of each gear activity that was closest) was calculated as well as the average distance to the 20 m isobath for 25%, 50% and 75% of the gear activities performed completely shallower than 20 m.

3. Results

3.1. Coverage

During the two-month fishing closure in 2018, a total of 110 fishing vessels registered on Mofi. Three of the 110 vessels were registered but never logged in and recorded any data. This left data from 107 vessels and 105 vessels owners to be evaluated. 102 vessels from 100 owners had trip and gear activity data and five vessels from five owners had trip data only (Table 1). The majority of vessels were operated in full-time (62% of the 107 vessels) and the share of vessels using landing declarations was higher than of vessels using logbooks (57% of the 107 vessels) (Table 1).

In February and March of 2018, 351 German vessels with a length of less than 12 m reported landings from ICES SDs 22-24. 107 of these 351 vessels reported cod landings and 85 of the 107 vessels (79%) had Mofi records. The total of reported cod landings from these 107 vessels during the fishing closure were 50 166 kg. 47 780 kg of these cod landings (95%) were from vessels that also had Mofi records. About 2.4 t of cod landings were from the 22 vessels that did not use Mofi during the closure.

3.2. Categorization and editing of trips and gear activities

The original Mofi data covered 1637 trips and 6542 gear activities (Fig. S3) and sensor data showed a GPS accuracy of 7.2 m ± 75.5 SD (median = 4.0 m). During data evaluation eleven categories were defined for the trips and twelve for the gear activities (Tables 2-3). After identification, categorization and editing, the categorized data (Fig. S3) covered a total of 1618 trips (99%) and 7972 (122%) gear activities. The change in number was due to the categories SPLIT and SEVERAL for trips and due to the categories MISSED and SEVERAL for gear activities (Tables 2-3). 67% of the 1618 trips and 29% of the 7972 gear activities were assigned to categories that were considered useable without the need for editing (Tables 2-3). Including also the categories that involved editing of time stamps, the useable trips increased to 78% and the useable gear activities to 69%. Trip categories were not evenly distributed across the vessels and certain categories were more typical for some vessels than for others (Fig. 3). In contrast, gear activity categories were more evenly distributed across the vessels (Fig. 4). Regarding the distribution of trip and gear activity categories over time, a decrease of the TRIAL-category was observed (Figs. S16-S17). Other than that, no clear trends were identified.

The majority of trips (57%) and gear activities (65%) were from logbook vessels and about three-quarter of the trips (73%) and gear activities (77%) were from full-time vessels (Table 4). 76, 16, 2, and 6% of the vessels had records in SD22, SD24, in both subdivisions or could not be assigned as the trips were of the category NODATA or UNK, respectively.

Different data subsets were used for subsequent analyses (Fig. S3) because trips and gear activities covered categories that did not always refer to actual or unambiguously identified trips or gear activities that were considered useable (Tables 2-3).

The percentage difference in net length between complete gillnet pairs decreased from 23% ± 25 SD to 7% ± 6 SD by editing either the setting or the hauling activity because time stamps were considered to not have been set at the correct position. No evidence for a significant difference was found between this decreased percentage difference (7% ± 6 SD) and the percentage difference (6% ± 5 SD) observed for complete gillnet pairs of which neither the setting nor the hauling activity was edited (non-normally distributed data, no equal variance, Wilcoxon signed rank sum test: p-value = 0.149, medianWithoutEditing = 5.24%, medianWithEditing = 5.33%).

3.3. Activity data

Mean duration of trips with gillnet activities was 4.1 h ± 2.3 SD (1176 trips from 92 vessels, Table S1). Trips with gillnet activities from logbook vessels (4.9 h ± 2.4 SD, 731 trips from 40 vessels) and full-time vessels (4.6 h ± 2.3 SD, 905 trips from 58 vessel) lasted longer than those from landing declaration vessels (2.9 h ± 1.6 SD, 445 trips from 52 vessels) and part-time vessels (2.5 h ± 1.3 SD, 271 trips from 34 vessels). Trawl trips lasted about 11.6 h ± 5.9 SD (59 trips from seven vessels, Table S2) and trips without any identified gear activity were short and took on average 0.9 h ± 0.9 SD (23 trips from 14 vessels). About 20% of the trips lasted less than 2 h, 54% less than 4 h and 77% less than 6 h (Fig. 5).

The pattern of trip duration corresponded to the pattern observed for the linear distance of gear activities to a landing site: gillnets from logbook vessels (11.8 km ± 8.7 SD, 3701 gillnets from 37 vessels, Table S3) and from full-time vessels (10.6 km ± 8.4 SD, 4463 gillnets from 55 vessels) were set further away from a landing site than gillnets from landing declaration vessels (4.2 km ± 3.5 SD, 1696 gillnets from 52 vessels) and from part-time vessels (4.0 km ± 4.5 SD, 934 gillnets from 34 vessels). The mean linear distance of gillnets across reporting procedure and business type was 9.4 km ± 8.2 SD (5397 gillnets from 89 vessels, Table S4). Trips with trawl activities did not only last the longest but the gear activities were also furthest away from a landing site (23.7 km ± 12.5 SD, 73 trawls from seven vessel, Table S4).

Landing declaration vessels set less gillnets (2.8 ± 1.9 SD, median = 2, 788 gillnets from 46 vessels) than logbook vessels (3.5 ± 2.5 SD, median = 3, 1588 gillnets from 37 vessels), and part-time vessels (2.7 ± 1.8 SD, median = 2, 165 gillnets from 31 vessels) less gillnets than full-time vessels (3.4 ± 2.4 SD, median = 3, 1936 gillnets from 52 vessels, Table S5). Across all analysed gillnets, 3.3 ± 2.3 SD (median = 3) gillnets were set per trip (2376 gillnets from 83 vessels) and on average 1.6 ± 0.8 SD trawls were performed during a trip (55 trawls from seven vessels, Table S6).

The mean speed during setting and hauling was 2.9 kn ± 1.1 SD and 1.1 kn ± 0.4 SD (2521 setting and hauling activities each from 84 vessels), respectively (Table S7). Setting and hauling a gillnet lasted on average 10.4 min ± 7.6 SD and 29.9 min ± 27.3 SD, respectively (Table S8). Trawling activities had a mean speed of 3.1 kn ± 0.2 SD, lasted 3.4 h ± 1.9 SD and covered a mean distance of 19.2 km ± 11.1 SD (73 trawls from seven vessels, Table S9).

Steaming speed was 5.5 kn ± 1.9 SD for gillnet trips (1087 trips from 84 vessels) and 4.5 kn ± 3.2 SD for trawl trips (46 trips from seven vessels) after excluding outliers using more than two standard deviations from the mean as the threshold (Table S10). For the estimation of the steaming speed of trawl trips we noticed a large difference in the steaming speed between the mean (4.5 kn) and the median (6.1 kn) and that the mean was smaller than that of the gillnet trips (mean = 5.5 kn). Viewing the respective trawl trips in the BlackBox Analyzer showed that this was due to the fact that the gear activity was ended directly after the actual trawling was finished. As a result, gear and catch handling following trawling was marked as part of the steaming phase. Gear and catch handling after the actual trawling can take a considerable amount of time and thus covered many sensor data corresponding to a period when the vessel moves at low speed. However, attributing these data points to the trawling activity would then bias the speed of the actual gear activity. We decided to exclude data from the steaming phase that were below the first quantile (0.7 kn), and re-estimated the steaming speed of the trawl trips, which resulted in 6.0 kn ± 2.3 SD (median = 7.1 kn). This observation was not noticed for the steaming speed of gillnet trips as gear and catch handling is usually already included in the hauling activity.

For the analysis of net length, the means between single pairs of set and hauled nets were used (showed significant linear relationship and no evidence for a significant difference in net length, see Figs. S18-S19). The mean net length was 853 m ± 690 SD (across the mean net lengths of 2521 pairs of set and hauled gillnets from 84 vessels, Table S11), irrespective of reporting procedure and business type and showed a peak at around 500 m (Fig. 6). The mean net length of landing declaration vessels and of logbook vessels was 664 m ± 538 SD (median = 527 m, 792 gillnet pairs from 48 vessels) and 940 m ± 734 SD (median = 765 m, 1729 gillnet pairs from 36 vessels), respectively. The mean net length of part-time vessels and of full-time vessels was 557 m ± 464 SD (median = 475 m, 439 gillnet pairs from 32 vessels) and 916 m ± 713 SD (median = 715 m, 2082 gillnet pairs from 52 vessels), respectively. Soak time across all pairs of set and hauled gillnets was 31.0 h ± 15.7 SD (median = 24 h, 2521 pairs of set and hauled gillnets from 84 vessels, Table S12) and peaked at around 24 h and 48 h (Fig. 6), irrespective of reporting procedure and business type. Soak time of landing declaration vessels and logbook vessels was 30.0 h ± 12.9 SD (median = 23.7 h, 792 gillnet pairs from 48 vessels) and 31.3 h ± 16.8 SD (median = 24.2 h, 1729 gillnet pairs from 36 vessels), respectively. The soak time of part-time vessels and full-time vessels was 27.7 h ± 11.6 SD (median = 23.6 h, 439 gillnet pairs from 32 vessels) and 31.6 h ± 16.3 SD (median = 24.2 h, 2082 gillnet pairs from 52 vessels), respectively.

3.4. Spatial relation of gear activities to the 20 m isobath

Gillnets were set at a mean depth of 11.2 m ± 5.5 SD (5413 gillnets from 89 vessels) and trawls were operated at a mean depth of 18.10 m ± 1.8 SD (73 trawls from seven vessels). 99% of all 7972 identified and categorized gear activities were performed completely in areas shallower than 20 m. Similarly, 99% of the 5486 useable gear activities were performed completely in areas shallower than 20 m. There was one single gillnet that was set and hauled completely deeper than 20 m (representing two gear activities, i.e. 0.04% of the 5486 gear activities). In the other cases, only parts of the gear activities were recorded deeper than 20 m.

The mean maximum distance to the 20 m isobath of useable gear activities partially deeper than 20 m was 36 m ± 45 SD. For the gear activities performed completely in areas shallower than 20 m, the mean minimum distance to the 20 m isobath was 3290 m ± 3799 SD, with 25, 50 and 75% of the gear activities closer than 606, 2032 and 3852 m to the 20 m isobath, respectively. The gillnets were set with a high level of spatial precision in relation to the 20 m isobath and with a clear cut-off in gear activities between areas shallower and deeper than 20 m (Fig. 7).

4. Discussion

The two-month use of the smartphone application Mofi produced a unique set of self-reported data from small-scale fishers in European temperate-zone waters. Not all data could be used for subsequent analysis, though it was possible to increase the proportion of useable gear activities and trips from 29 to 69% and from 67 to 78%, respectively, by editing during the data review. This offered a comprehensive data set for the analysis of activities and showed that 99% of the gear activities were performed shallower than 20 m proving high compliance for the vessels whose activities were monitored with Mofi. Nothing can be said about individual trips or activities that might not have been recorded or the 22 vessels that covered 2.4 t of cod landings during the closure and did not use Mofi.

A combination of sensor and self-reported data allowed for detailed analyses of general trip information (trip duration, location of landing sites and fishing grounds and the linear distance between them, the number of gear activities per trip and the steaming speed), fishing effort (length and soak time of gillnets, trawled distance, trawling duration) and gear handling (speed during setting and hauling of gillnets and during trawling) on the level of single gear activities and trips. This was possible for all vessels independent of their size, including the data-poor segment of vessels smaller than 8 m.

The gillnet fishers conducted fast and precise operations at sea that require a high recording interval to ensure that the spatio-temporal resolution of their activities is appropriately reflected in the collected data. As already noted by Mendo et al. (2019b) for vessels smaller than 9.5 m and supported by our study, recording intervals of max. 1 min provide a reasonable spatio-temporal resolution for small-scale fisheries.

Circumstances for the introduction of Mofi were challenging given that the obligatory use was communicated only shortly before the start of the closure. Fishers were untrained in the use of Mofi and for many it was likely the first time that they had to use such an electronic reporting tool at sea. Several commercial small-scale fishers even desisted from fishing for cod during the closure because they did not want to use Mofi (pers. communication with fishers).

4.1. Activity data

The coverage of vessels smaller than 8 m allowed for first-time insights into the activities of part-time vessels as they were mainly found within this segment. Part-time vessels were less active (covered roughly one-fourth of the trips and gear activities, set fewer and shorter gillnets, trips were shorter and gear activities were closer to a landing site) than full-time vessels. The lesser activity of the part-time vessels might reflect lesser allocated quota. In Germany, part-time vessels that are not organized in a producer organization are part of a rationed quota pool of which each vessel gets the same predefined amount of cod quota per month (in 2018: 100 kg cod per month (BLE, 2017)). This quota is then not related to historical landings, landings of previous years or the fishing capacity (SeeFischG, 1984; STECF, 2020) of the respective non-organized part-time vessel, in contrast to the quota for organized part-time vessels and full-time vessels. Such highly resolved activity data at hand offer the possibility to then assess whether the degree of activity is also reflected and corresponds to the landings declared by the different business types and reporting procedures or whether disparities are observed. Though the vessels smaller than 8 m including part-time as well as full-time vessels were less active than logbook vessels, they still showed a high activity (43% of the trips, 35% of the gear activities), which supports the need for an improved monitoring of this segment.

The mean soak time of 31 h for gillnets was within the range of what has been reported from other demersal gillnet fisheries in the same (western Baltic Sea) or in nearby (Skagerrak) regions of 8, 12 and 41 h in Danish gillnet fisheries (Glemarec et al., 2020; Kindt-Larsen et al., 2016) and of 22 h in a Swedish gillnet fishery (Glemarec et al., 2021). Also, the median net length for logbook vessels (765 m) was similar to what was observed for three Danish gillnetters (731 m) (Glemarec et al., 2020), which however had a higher median number of nets per trip (n = 5) compared to the German gillnetters (n = 3 for logbook vessels). Whether the trip characteristics and gear activities recorded with Mofi during the closure reflect standard gillnet operations typical for targeting demersal fish during the first quarter in the western Baltic Sea can only be assessed if data is also collected under similar conditions but without the provisions set by a closure.

4.2. Spatio-temporal resolution

During our study, we observed a mean duration of setting a gillnet of 10.4 min ± 7.6 SD. In case of a 5 min recording interval for the sensor data, as used at the beginning of our study, the short setting activities would on average only be covered by two data points if not marked by time stamps (which then increased the recording interval to 1 min). This makes it more likely to miss short activities, and our results suggest recording intervals of max. 1 min for the monitoring of small-scale fisheries, which is in line with the findings of previous studies. For example, other electronic monitoring tools worked with intervals as short as 10 s for the recording of GPS positions (Glemarec et al., 2020), and Mendo et al. (2019b) showed that results on area fished were consistent when the recording interval of GNSS (Global Navigation Satellite System) data in a Scottish small-scale pots and trap fishery was < 1 min and < 2 min for vessels with a length of < 9.5 m and 9.5 – 12 m, respectively.

The short trip duration observed also supports the need for a high temporal resolution in monitoring. About 50% of the trips were shorter than 4 h, and if standard VMS monitoring would be used with typical recording intervals of about 1 h (range: 15 min to 2 h; ICES, 2019b), the data coverage would be very low making it more likely to miss activities. It was already shown that even for vessels larger than 12 m the use of VMS at a recording interval of 2 h (common also for the monitoring of German vessels > 12 m (von Dorrien et al., 2013)), causes trips and fishing sets (defined as shooting, closing and hauling a purse seine and transferring the fish on board) not to be identified (Katara and Silva, 2017).

Due to the high spatial resolution, the fishers could prove compliance with the terms of the closure, which would not have been possible at the spatial resolution of ICES statistical rectangles (approx. 30 x 30 nm (ICES, 1977)). Very specific fishing patterns were observed and showed that fishers operated with a very high spatial precision setting gillnets parallel right next to the 20 m isobath and still staying shallower than 20 m. ICES statistical rectangles are often considered too coarse to be effective for marine spatial planning and more spatially explicit information could support a better integration of fisheries into the process of planning the use of marine space (Janßen et al., 2018).

Spatial data on fishing activities are an essential element in fisheries management and could become even more valuable if supplied with high spatio-temporal resolution. Damasio et al. (2020) demonstrated with spatial fisheries data obtained from semi-structured interviews that the geographical extent of fishing areas from Brazilian small-scale fisheries had changed over a time span of 20 years and moved further offshore into deeper waters. There were indications that depletion of the target species might have been the reason for shifting fishing grounds. By applying regular and highly resolved spatial monitoring with reporting tools such as smartphone applications there might be the potential to detect gradual and small changes in time earlier and adapt fisheries management accordingly to circumvent potential negative socioeconomic and ecological consequences.

Also, the design and the assessment of the efficiency and the impact of marine protected areas rely on spatial information. Stelzenmüller et al. (2008) assessed the distribution of fishing effort density from small-scale fisheries in relation to no-take zones in France, Malta and Spain and identified a concentration of effort density around the borders of some of these zones. The coverage of total possible fishing effort ranged from 7 to 100%. Except for Malta where the fishers were obliged to report their catch positions, members of the research team accompanied the fishers on-board of the vessels to record geographical positions of the deployed gear. Such data collections might be facilitated if trained fishers used smartphone applications for data recording, leading to less staff required on-board of the vessels and potentially increasing data coverage to support evaluation of the effectiveness of marine protected areas. This self-reporting approach would also be much more cost-effective.

In a Polish study participatory mapping was carried out to localise fishing grounds used by the small-scale fishery with the aim to highlight areas, which are essential for them and to foster their participation and inclusion in the management of marine space (Psuty et al., 2020). Provided that this is supported by the fishery, the use of a smartphone application for the recording of fishing activities could potentially strengthen their grounds and stress the importance of specific coastal areas reserved for small-scale fisheries.

Spatial information also plays an important role with respect to incidental bycatch. Mustika et al. (2021) showed that fishing area was either the first or second most important factor influencing the amount of marine megafauna bycatch at the northern part of the island Sulawesi, Indonesia. Data on available fishing effort was on the level of number of trips per week and the coastal zones analysed covered several kilometres. Being able to record fishing activities on a high spatio-temporal resolution could help to focus on the areas in which bycatch occurs more frequently and thus develop a specific bycatch mitigation approach.

These studies present examples that show that the use of a smartphone application might be beneficial for fishers and small-scale fisheries management because they can complement data collection and document inter alia fishing grounds, distance to landing site or fishing effort parameters such as net length of gillnets at high spatio-temporal resolution. However, it should be assessed case by case if this electronic reporting approach is the most feasible and suitable for a given situation and the prevailing conditions.

4.3. Challenges and improvements

The majority of trips and gear activities that required editing were related to errors in operating the smartphone application and setting time stamps while at sea. In the following we discuss potential improvements on how these challenges could be overcome.

Training: The lack of training prior to the introduction of Mofi was inter alia reflected by the TRIAL-category and its decrease over time. Each fisher has an individual on-board workflow, sometimes established over years, and it needs time and practice to implement and incorporate new routines. Training to practice the handling of a specific electronic reporting tool could help to decrease operating errors (e.g. Paul et al., 2016). Given the distribution of gear activity categories among the vessels, a general training might be advisable. In the few cases, where a vessel is dominated by a specific category (e.g. SPLIT or SEVERAL for trips) individual support and training might be more appropriate.

Time stamps: Fishers reported that at times it was challenging to simultaneously operate a smartphone application and fishing gear while at sea, especially if only one person was on board and work required the use of gloves (pers. communication with fishers). This can cause delays, either in setting time stamps or in operating the gear. A possible solution to facilitate the handling and reduce the time delay could be a waterproof remote control deployed onboard that connects via Bluetooth to the mobile device and allows to remotely operate the application. Direct handling of the mobile device would then not be required anymore. This might also help to avoid the MULTIPLE-category, which could have been caused by water droplets on the sensitive touch screen disrupting the functionality of the application.

GPS: Missing GPS data or extreme GPS outliers could be related to the challenge of designing a smartphone application across a variety of hardware (different smartphone companies and GPS sensors) and software (different operating systems covering different versions), in combination with the dependency on the user to regularly update any necessary software and thus ensure optimal operability. Also, the recording of GPS data can be hampered if the GPS sensor is shielded by metal. One possible solution could be an external, standardized and dedicated GPS sensor to ensure a more reliable GPS recording. Other electronic reporting tools having their own dedicated GPS sensor could ensure a failure-free GPS recording (Kindt-Larsen et al., 2012). Improvements like an independent GPS sensor or a remote control, including the associated additional costs, challenge the idea of using a mobile device as a universal stand-alone tool for reliable data collection.

Other: Trips without any sensor data (NODATA-category) were mostly very short and there was potentially not enough time for the smartphone application to retrieve data from the GPS sensor or for the GPS sensor to receive a geographical position. In the rare cases where the exact same trip and gear activities were recorded twice (DUPLICATE-category), it is likely that a user logged in into the same account on two different devices at the same time on the same vessel. This can be solved by not allowing for a simultaneous login into the same account.

Data processing: Data evaluation, including the manual identification, categorization, editing of trips and gear activities, and matching of set and hauled gillnets was labour-intensive, required training and experience and was done with our best available knowledge assuming standard trips. In general, the data evaluation and editing seemed acceptable, which was inter alia reflected by the decrease in percentage difference in net length before and after editing and that no evidence for a significant difference was found between the net lengths of corresponding set and hauled gillnets covering edited as well as unedited gear activities. Such detailed and for a large part manual data processing might be justifiable to assess the first-time application of an electronic reporting tool but for routine use more automated, objective and effective evaluation algorithms are essential in order to ensure that data processing and analysis are efficient (Needle et al., 2015). For the development of analytic routines, it could be advantageous that Mofi can provide a combination of self-reported and independently collected data (the sensor data). For the latter, routines already exist, e.g. for VMS data (Hintzen et al., 2012; Watson and Haynie, 2016) or for the analysis of GNSS data (Mendo et al., 2019a) and non-VMS related GPS data (Behivoke et al., 2021).

5. Conclusion

The first large-scale use of the smartphone application Mofi showed potential of this approach to collect highly resolved spatio-temporal activity data, specifically from a temperate-zone European small-scale fishery. In the proposal for amending the EU control regulation, mobile phone technologies are suggested as easy and cost-effective tools to monitor especially small-scale fishing vessels (COM, 2018). However, a variety of aspects must be considered such as quality, accuracy, consistency, standardization, access, ownership and privacy of the recorded data as well as costs involved, handling of the devices and effective routines to analyse the collected data (ICES, 2019a; Skov et al., 2021). The experience gained during the application of Mofi suggests to invest into the training of fishers on how to use a new electronic reporting tool, thereby avoid reporting errors later on and ease the evaluation of the collected data. In some aspects the use of a mobile device as a stand-alone method is challenged and it might be worth investigating if an independent dedicated GPS sensor and a remote control can improve data recording. If the identified deficiencies are tackled, smartphone applications are likely able to complement standard reporting procedures and provide a tool for sharing the burden of proof in fisheries management (Fitzpatrick et al., 2011) and aiding results-based management (Nielsen et al., 2018).

Acknowledgements

We greatly acknowledge the participation of the fishers that used the smartphone application Mofi during the two-month fishing closure in 2018. We are very grateful for the constructive cooperation with Anchor Lab K/S, their dedication and constant support. We thank the German Federal Office for Agriculture and Food for providing the anonymised data and for support whenever questions regarding the data arose. Nakula Plantener kindly helped creating the map of Fig. 1 and extracting the depth data. This work was funded by the German Federal Agency for Nature Conservation (Bundesamt für Naturschutz, project no. 3516821300, Entwicklung von alternativen Managementansätzen und Fangtechniken zur Minimierung der Konflikte zwischen Stellnetzfischerei und Naturschutzzielen in der deutschen AWZ der Ostsee - STELLA).

References

Behivoke, F., Etienne, M.-P., Guitton, J., Randriatsara, R.M., Ranaivoson, E., Léopold, M., 2021. Estimating fishing effort in small-scale fisheries using GPS tracking data and random forests. Ecological Indicators 123, 107321. https://doi.org/10.1016/j.ecolind.2020.107321

Bivand, R., Keitt, T., Rowlingson, B., 2021. rgdal: Bindings for the “Geospatial” Data Abstraction Library. R-project.

BLE, 2018. Bekanntmachung zur Fischerei auf Dorsch im Jahr 2018 unter der Ausnahmemöglichkeit innerhalb der Schonzeiten nach der Verordnung (EU) 2017/1970, Bundesanzeiger. Federal Office for Agriculture and Food. 522 – 04.10 – 41.6 – Bek. 2/18/52.

BLE, 2017. Erste Bekanntmachung über den Fischfang durch Fischereibetriebe mit Fischereifahrzeugen unter Führung der Bundesflagge im Jahr 2018, Bundesanzeiger. Federal Office for Agriculture and Food. 522 - 04.10 - 41.6 - Bek. 29/17/52.

BLE, 2005. Erste Bekanntmachung über den Fischfang durch deutsche Fischereibetriebe im Jahre 2006, Bundesanzeiger. Federal Office for Agriculture and Food. 522 – 114d – 45.5 – Bek. 25/05, Gruppe 52.

Bleil, M., Oeberst, R., 2002. Spawning areas of the cod stock in the western Baltic Sea and minimum length at maturity. Arch. Fish. Mar. Res. 16.

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 Fish 20, 564–583. https://doi.org/10.1111/faf.12361

Castro Ribeiro, C., Holmes, S., Scott, F., Berkenhagen, J., Demaneche, S., Prista, N., Reis, D., Reilly, T., Andriukaitiene, J., Aquilina, M., Calvo Santos, A., Charilaou, C., Dalskov, J., Davidiuk, I., Diamant, A., Egekvist, J., Elliot, M., Ioannou, M., Jakovleva, I., Kuzebski, E., Ozernaja, O., Pinnelo, D., Thasitis, I., Vitarnen, J., 2016. Report on the 2nd workshop on transversal variables Nicosia, Cyprus, 22-26 February 2016: a DCF ad-hoc workshop. Publications Office, Luxembourg.

COM, 2018. 368 Final. Proposal for a Regulation of the European Parliament and of the Council amending Council Regulation (EC) No 1224/2009, and amending Council Regulations (EC) No 768/2005, (EC) No 1967/2006, (EC) No 1005/2008, and Regulation (EU) No 2016/1139 of the European Parliament and of the Council as regards fisheries control. Brussels.

Damasio, L.M.A., Peninno, M.G., Lopes, P.F.M., 2020. Small changes, big impacts: Geographic expansion in small-scale fisheries. Fisheries Research 226, 105533. https://doi.org/10.1016/j.fishres.2020.105533

Demestre, M., Muntadas, A., de Juan, S., Mitilineou, C., Sartor, P., Mas, J., Kavadas, S., Martín, J., 2015. The need for fine-scale assessment of trawl fishing effort to inform on an ecosystem approach to fisheries: Exploring three data sources in Mediterranean trawling grounds. Marine Policy 62, 134–143. https://doi.org/10.1016/j.marpol.2015.09.012

EC, 2009. Council Regulation (EC) No 1224/2009 of 20 November 2009 establishing a Community control system for ensuring compliance with the rules of the common fisheries policy, amending Regulations (EC) No 847/96, (EC) No 2371/2002, (EC) No 811/2004, (EC) No 768/2005, (EC) No 2115/2005, (EC) No 2166/2005, (EC) No 388/2006, (EC) No 509/2007, (EC) No 676/2007, (EC) No 1098/2007, (EC) No 1300/2008, (EC) No 1342/2008 and repealing Regulations (EEC) No 2847/93, (EC) No 1627/94 and (EC) No 1966/2006. Official Journal of the European Union.

EC, 2005. Council Regulation (EC) No 27/2005 of 22 December 2004 fixing for 2005 the fishing opportunities and associated conditions for certain fish stocks and groups of fish stocks, applicable in Community waters and, for Community vessels, in waters where catch limitations are required. Official Journal of the European Union.

EC, 2001. Council Regulation (EC) No 2555/2001 of 18 December 2001 fixing for 2002 the fishing opportunities and associated conditions for certain fish stocks and groups of fish stocks, applicable in Community waters and, for Community vessels, in waters where limitations in catch are required. Official Journal of the European Union.

Eero, M., Hinrichsen, H.-H., Hjelm, J., Huwer, B., Hüssy, K., Köster, F.W., Margonski, P., Plikshs, M., Storr-Paulsen, M., Zimmermann, C., 2019. Designing spawning closures can be complicated: Experience from cod in the Baltic Sea. Ocean & Coastal Management 169, 129–136. https://doi.org/10.1016/j.ocecoaman.2018.12.018

EU, 2021a. Regulation (EU) 2021/1139 of the European Parliament and of the Council of 7 July 2021 establishing the European Maritime, Fisheries and Aquaculture Fund and amending Regulation (EU) 2017/1004. Official Journal of the European Union.

EU, 2021b. Council Regulation (EU) 2021/1888 of 27 October 2021 fixing for 2022 the fishing opportunities for certain fish stocks and groups of fish stocks applicable in the Baltic Sea and amending Regulation (EU) 2021/92 as regards certain fishing opportunities in other waters. Official Journal of the European Union.

EU, 2017. Council Regulation (EU) 2017/1970 of 27 October 2017 fixing for 2018 the fishing opportunities for certain fish stocks and groups of fish stocks applicable in the Baltic Sea and amending Regulation (EU) 2017/127. Official Journal of the European Union.

EU, 2016. Regulation (EU) 2016/1139 of the European Parliament and of the Council of 6 July 2016 establishing a multiannual plan for the stocks of cod, herring and sprat in the Baltic Sea and the fisheries exploiting those stocks, amending Council Regulation (EC) No 2187/2005 and repealing Council Regulation (EC) No 1098/2007. Official Journal of the European Union.

EU, 2011. Commission Implementing Regulation (EU) No 404/2011 of 8 April 2011 laying down detailed rules for the implementation of Council Regulation (EC) No 1224/2009 establishing a Community control system for ensuring compliance with the rules of the Common Fisheries Policy. Official Journal of the European Union.

Fitzpatrick, M., Graham, N., Rihan, D.J., Reid, D.G., 2011. The burden of proof in co-management and results-based management: the elephant on the deck! ICES Journal of Marine Science 68, 1656–1662. https://doi.org/10.1093/icesjms/fsr098

GEBCO Compilation Group, 2019. GEBCO 2019 Grid. doi:10.5285/836f016a-33be-6ddc-e053-6c86abc0788e.

Glemarec, G., Kindt-Larsen, L., Lundgaard, L.S., Larsen, F., 2020. Assessing seabird bycatch in gillnet fisheries using electronic monitoring. Biological Conservation 243, 108461. https://doi.org/10.1016/j.biocon.2020.108461

Glemarec, G., Königson, S., Kindt-Larsen, L., 2021. Bycatch in Baltic Sea commercial fisheries: High-risk areas and evaluation of measures to reduce bycatch. HELCOM.

Gutowsky, L.F.G., Gobin, J., Burnett, N.J., Chapman, J.M., Stoot, L.J., Bliss, S., 2013. Smartphones and Digital Tablets: Emerging Tools for Fisheries Professionals. Fisheries 38, 455–461. https://doi.org/10.1080/03632415.2013.838133

Heery, E., Cope, J.M., 2014. Co-occurrence of bycatch and target species in the groundfish demersal trawl fishery of the U.S. west coast; with special consideration of rebuilding stocks. FB 112, 36–48. https://doi.org/10.7755/FB.112.1.3

Hijmans, R.J., 2019. geosphere: Spherical Trigonometry. R-project.

Hintzen, N.T., Bastardie, F., Beare, D., Piet, G.J., Ulrich, C., Deporte, N., Egekvist, J., Degel, H., 2012. VMStools: Open-source software for the processing, analysis and visualisation of fisheries logbook and VMS data. Fisheries Research 115–116, 31–43. https://doi.org/10.1016/j.fishres.2011.11.007

ICES, 2019a. Working Group on Technology Integration for Fishery-Dependent Data (WGTIFD). ICES Scientific Reports 1, 34. https://doi.org/10.17895/ices.pub.5543

ICES, 2019b. Working Group on Spatial Fisheries Data (WGSFD). ICES Scientific Reports 1, 150. https://doi.org/10.17895/ICES.PUB.5648

ICES, 1977. ICES statistical rectangle coding system. ICES Document CM 1977/Gen:3.

Janßen, H., Bastardie, F., Eero, M., Hamon, K.G., Hinrichsen, H.-H., Marchal, P., Nielsen, J.R., Le Pape, O., Schulze, T., Simons, S., Teal, L.R., Tidd, A., 2018. Integration of fisheries into marine spatial planning: Quo vadis? Estuarine, Coastal and Shelf Science 201, 105–113. https://doi.org/10.1016/j.ecss.2017.01.003

Katara, I., Silva, A., 2017. Mismatch between VMS data temporal resolution and fishing activity time scales. Fisheries Research 188, 1–5. https://doi.org/10.1016/j.fishres.2016.11.023

Kauer, K., Bellquist, L., Gleason, M., Rubinstein, A., Sullivan, J., Oberhoff, D., Damrosch, L., Norvell, M., Bell, M., 2018. Reducing bycatch through a risk pool: A case study of the U.S. West Coast groundfish fishery. Marine Policy 96, 90–99. https://doi.org/10.1016/j.marpol.2018.08.008

Kindt-Larsen, L., Berg, C., Tougaard, J., Sørensen, T., Geitner, K., Northridge, S., Sveegaard, S., Larsen, F., 2016. Identification of high-risk areas for harbour porpoise Phocoena phocoena bycatch using remote electronic monitoring and satellite telemetry data. Marine Ecology Progress Series 555, 261–271. https://doi.org/10.3354/meps11806

Kindt-Larsen, L., Dalskov, J., Stage, B., Larsen, F., 2012. Observing incidental harbour porpoise Phocoena phocoena bycatch by remote electronic monitoring. Endangered Species Research 19, 75–83. https://doi.org/10.3354/esr00455

LALLF, 2021. Formulare und Merkblätter in der Fischereiverwaltung [WWW Document]. URL https://www.lallf.de/fischerei/formulare-und-merkblaetter/ (accessed 28.09.21).

Lorenzen, K., Cowx, I.G., Entsua-Mensah, R.E.M., Lester, N.P., Koehn, J.D., Randall, R.G., So, N., Bonar, S.A., Bunnell, D.B., Venturelli, P., Bower, S.D., Cooke, S.J., 2016. Stock assessment in inland fisheries: a foundation for sustainable use and conservation. Rev Fish Biol Fisheries 26, 405–440. https://doi.org/10.1007/s11160-016-9435-0

Lowman, D.M., Fisher, R., Holliday, M.C., McTee, S.A., Stebbins, S., 2013. Fisheries Monitoring Roadmap. A guide to evaluate, design and implement an effective fishery monitoring program that incorporates electronic monitoring and electronic reporting tools.

Mendo, T., Smout, S., Photopoulou, T., James, M., 2019a. Identifying fishing grounds from vessel tracks: model-based inference for small scale fisheries. R. Soc. open sci. 6, 191161. https://doi.org/10.1098/rsos.191161

Mendo, T., Smout, S., Russo, T., D'Andrea, L., James, M., 2019b. Effect of temporal and spatial resolution on identification of fishing activities in small-scale fisheries using pots and traps. ICES Journal of Marine Science 76, 1601–1609. https://doi.org/10.1093/icesjms/fsz073

Mustika, P.L.K., Wonneberger, E., Erzini, K., Pasisingi, N., 2021. Marine megafauna bycatch in artisanal fisheries in Gorontalo, northern Sulawesi (Indonesia): An assessment based on fisher interviews. Ocean & Coastal Management 208, 105606. https://doi.org/10.1016/j.ocecoaman.2021.105606

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, 1214–1229. https://doi.org/10.1093/icesjms/fsu225

Nielsen, K.N., Aschan, M.M., Agnarsson, S., Ballesteros, M., Baudron, A., Borges, M. de F., Campos, A., Chapela, R., Daníelsdóttir, A.K., Erzini, K., Gregersen, Ó., Holm, P., Lucchetti, A., Margeirsson, S., Mendes, H.V., Olsen, P., Rangel, M., Sala, A., Santiago, J.L., Sigurðardóttir, S., Silva, C., Sykes, D., Viðarsson, J.R., Virgili, M., Wise, L., Fernandes, P.G., 2018. A framework for results-based management in fisheries. Fish Fish 19, 363–376. https://doi.org/10.1111/faf.12257

Nissling, A., Westin, L., 1997. Salinity requirements for successful spawning of Baltic and Belt Sea cod and the potential for cod stock interactions in the Baltic Sea. Mar. Ecol. Prog. Ser. 152, 261–271. https://doi.org/10.3354/meps152261

Paul, S.A.L., Wilson, A.M.W., Cachimo, R., Riddell, M.A., 2016. Piloting participatory smartphone mapping of intertidal fishing grounds and resources in northern Mozambique: Opportunities and future directions. Ocean & Coastal Management 134, 79–92. https://doi.org/10.1016/j.ocecoaman.2016.09.018

Pebesma, E., Bivand, R., 2021. sf: Simple Features for R. R-project.

Psuty, I., Kulikowski, T., Szymanek, L., 2020. Integrating small-scale fisheries into Polish maritime spatial planning. Marine Policy 120, 104116. https://doi.org/10.1016/j.marpol.2020.104116

R Core Team, 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Russo, T., D'Andrea, L., Parisi, A., Martinelli, M., Belardinelli, A., Boccoli, F., Cignini, I., Tordoni, M., Cataudella, S., 2016. Assessing the fishing footprint using data integrated from different tracking devices: Issues and opportunities. Ecological Indicators 69, 818–827. https://doi.org/10.1016/j.ecolind.2016.04.043

Saville, R., Hatanaka, K., Sano, M., Wada, M., 2015. Application of information and communication technology and data sharing management scheme for the coastal fishery using real-time fishery information. Ocean & Coastal Management 106, 77–86. https://doi.org/10.1016/j.ocecoaman.2015.01.019

SeeFischG, 1984. Gesetz zur Regelung der Seefischerei und zur Durchführung des Fischereirechts der Europäischen Union (Seefischereigesetz - SeeFischG).

Skov, C., Hyder, K., Gundelund, C., Ahvonen, A., Baudrier, J., Borch, T., deCarvalho, S., Erzini, K., Ferter, K., Grati, F., van derHammen, T., Hinriksson, J., Houtman, R., Kagervall, A., Kapiris, K., Karlsson, M., Lejk, A.M., Lyle, J.M., Martinez-Escauriaza, R., Moilanen, P., Mugerza, E., Olesen, H.J., Papadopoulos, A., Pita, P., Pontes, J., Radford, Z., Radtke, K., Rangel, M., Sagué, O., Sande, H.A., Strehlow, H.V., Tutiņš, R., Veiga, P., Verleye, T., Vølstad, J.H., Watson, J.W., Weltersbach, M.S., Ustups, D., Venturelli, P.A., 2021. Expert opinion on using angler Smartphone apps to inform marine fisheries management: status, prospects, and needs. ICES Journal of Marine Science fsaa243. https://doi.org/10.1093/icesjms/fsaa243

Sonntag, N., Schwemmer, H., Fock, H.O., Bellebaum, J., Garthe, S., 2012. Seabirds, set-nets, and conservation management: assessment of conflict potential and vulnerability of birds to bycatch in gillnets. ICES Journal of Marine Science 69, 578–589. https://doi.org/10.1093/icesjms/fss030

STECF, 2020. Scientific, Technical and Economic Committee for Fisheries (STECF) – Social dimension of the CFP (STECF-20-14). Publications Office of the European Union, Luxembourg.

Stelzenmüller, V., Maynou, F., Bernard, G., Cadiou, G., Camilleri, M., Crec'hriou, R., Criquet, G., Dimech, M., Esparza, O., Higgins, R., Lenfant, P., Pérez-Ruzafa, Á., 2008. Spatial assessment of fishing effort around European marine reserves: Implications for successful fisheries management. Marine Pollution Bulletin 56, 2018–2026. https://doi.org/10.1016/j.marpolbul.2008.08.006

Venturelli, P.A., Hyder, K., Skov, C., 2016. Angler apps as a source of recreational fisheries data: opportunities, challenges and proposed standards. Fish Fish 18, 578–595. https://doi.org/10.1111/faf.12189

von Dorrien, C., Krumme, U., Grieger, C., Miethe, T., Stötera, S., 2013. Analyse fischereilicher Daten in den schleswig-holsteinischen Küstengewässern der Ostsee. Thünen Institute of Baltic Sea Fisheries.

Watson, J.T., Haynie, A.C., 2016. Using Vessel Monitoring System Data to Identify and Characterize Trips Made by Fishing Vessels in the United States North Pacific. PLOS ONE 11, e0165173. https://doi.org/10.1371/journal.pone.0165173

Zellmer, A.J., Burdick, H., Medel, I., Pondella, D.J., Ford, T., 2018. Aerial surveys and distribution models enable monitoring of fishing in Marine Protected Areas. Ocean & Coastal Management 165, 298–306. https://doi.org/10.1016/j.ocecoaman.2018.08.027

Figures

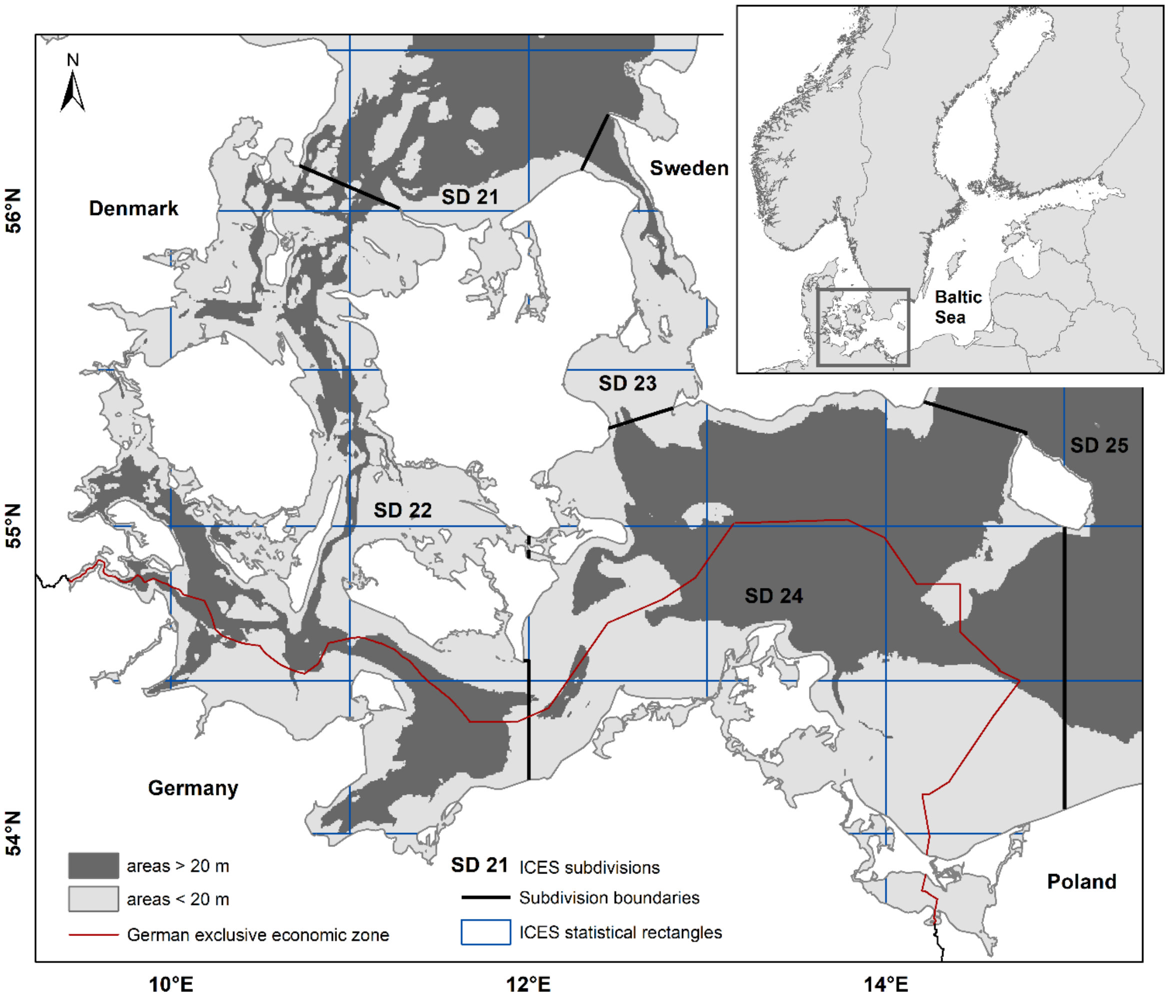


Fig. 1. **Western Baltic Sea showing the area of the fishing closure of cod (ICES subdivisions 22-24) in February and March of 2018, covering the German Baltic Sea coast and the German exclusive economic zone. During the closure, cod fishery was allowed for German vessels smaller than 12 m in areas shallower than 20 m as long as they monitored their activities with the smartphone application Mofi.**

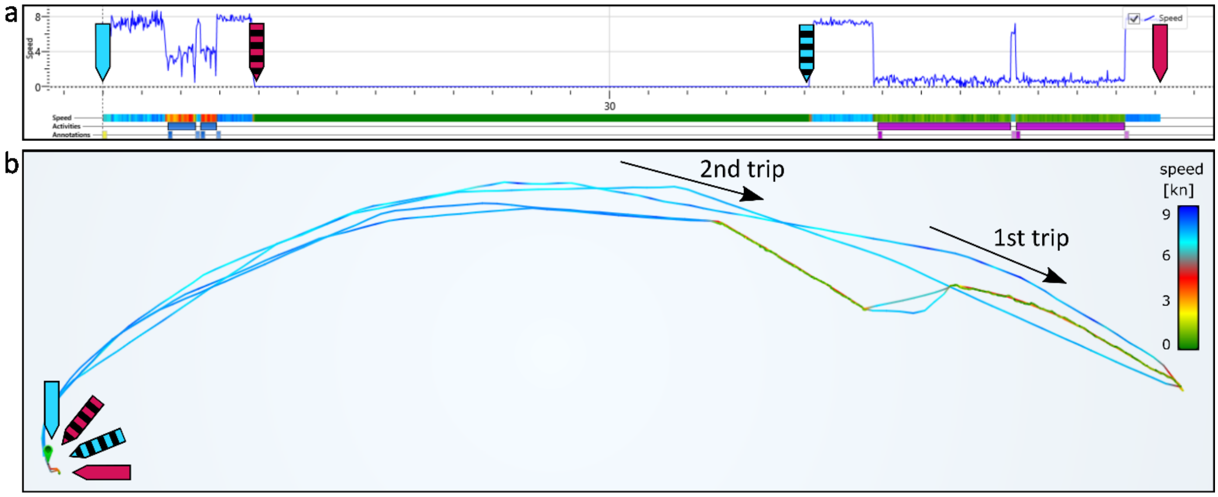


Fig. 2. **Example of trips and related gear activities as displayed in the BlackBox Analyzer to illustrate the editing process. Two trips marked as one by the time stamps set by the fisher were separated to represent two single trips. Panel (a): Time line with speed profile of two separate trips from the same vessel (data exported from the BlackBox Analyzer). Blue graph: recorded speed of the vessel. First data series below blue speed graph: colour-coded speed profile, see speed legend in (b). Second data series below blue speed graph: blue bars mark unedited or edited setting activities of gillnets; purple bars mark unedited or edited hauling activities of gillnets. Third data series below blue speed graph: blue rectangles mark time stamps set by the fisher to indicate start and end of setting activities of gillnets; purple rectangles mark time stamps set by the fisher to indicate start and end of hauling activities of gillnets. Blue and red solid arrows: positions of the original time stamps set by the fisher to define start and end of a trip, respectively. Blue and red striped arrows: positions of time stamps that were re-positioned or newly added during editing to define start and end of a trip, respectively. Panel (b): Screenshot of the mapped geographical tracks of the trips and gear activities shown in (a). Black arrows indicate the direction of the vessel during each trip. Speed along the tracks is colour-coded according to the recorded speed as given in the legend in (b) and arrows imply the same as described for (a). The two original time stamps covered two different trips letting them appear as one trip and affecting the total number of trips and the trip duration. During this one trip, the vessel arrived at and left again from a location typical for the respective vessel to start and end trips (taking into consideration other trips done with same vessel) and showed a prolonged time period with zero speed (a) and no movement (b). This indicated that these were actually two different trips. They were then separated during editing by setting new time stamps and assigned to the respective category. To maintain confidentiality of the anonymised self-reported data from the fishers, coastline, bathymetry, coordinates, scale and orientation are not shown in the map.**

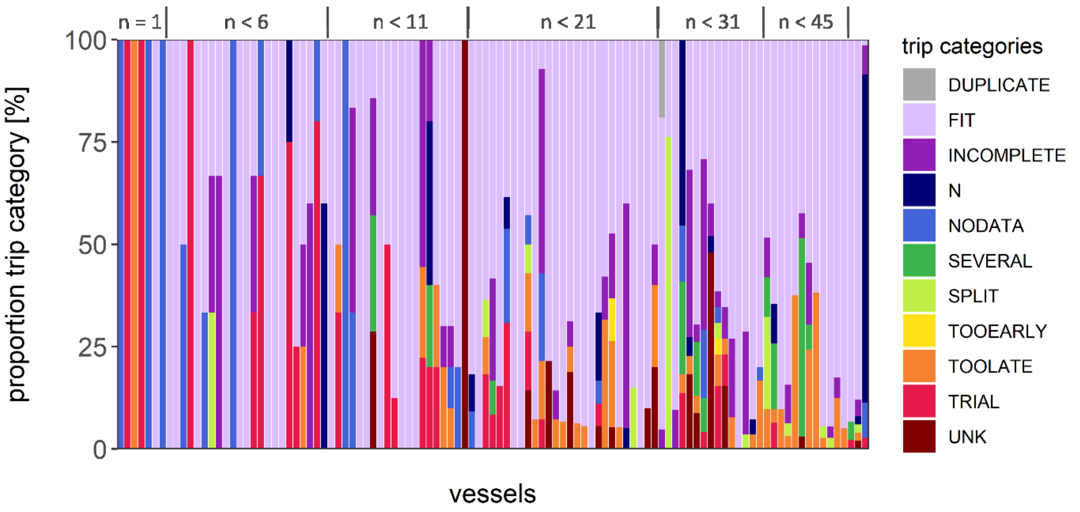


Fig. 3. **Proportion of trip categories per vessel (n = 107); each complete bar (100%) represents a single vessel. Vessels from left to right in ascending order with increasing number of trips per vessel. Number of trips per vessel are given as ranges above the bars. The category INCOMPLETE can overlap with other categories (< 1% overlap of the 1618 trips). In case of overlap, the INCOMPLETE-category was plotted.**

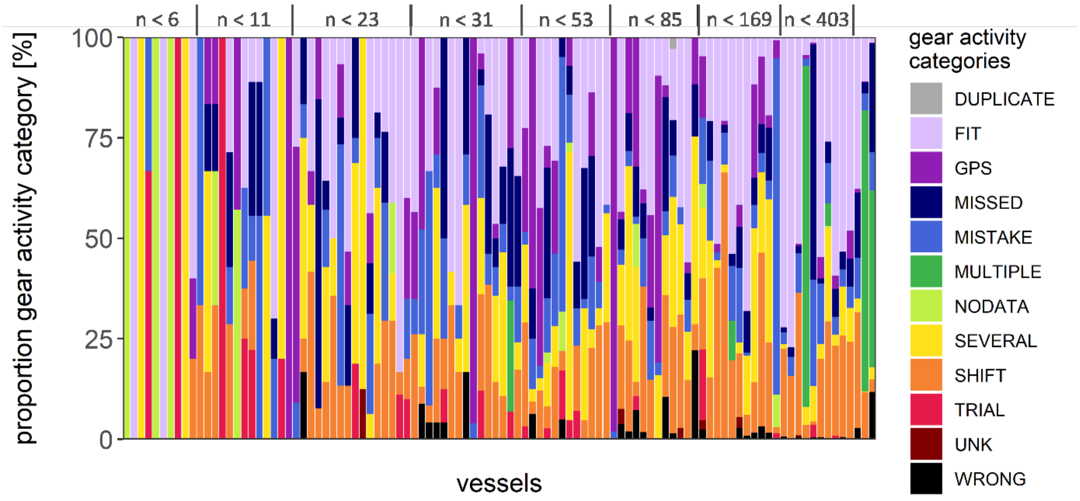


Fig. 4. **Proportion of gear activity categories per vessel (n = 102); each complete bar (100%) represents a single vessel. Vessels from left to right in ascending order with increasing number of gear activities per vessel. Number of gear activities per vessel are given as ranges above the bars. The categories GPS and WRONG can overlap with other categories (GPS: 1.5% overlap of the 7972 gear activities; WRONG: 2% overlap of the 7972 gear activities). In case of overlap, first the WRONG-category and then GPS-category was plotted.**

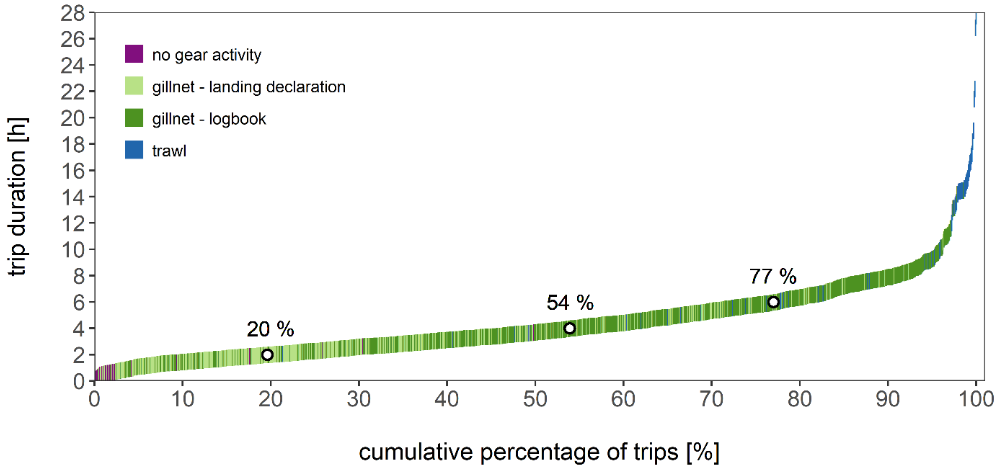


Fig. 5. **Cumulative percentage of trips (1258 trips from 95 vessels) from left to right with increasing trip duration, coded as trips without any gear activity, with gillnet activities from landing declaration vessels, with gillnet activities from logbook vessels and with trawl activities. White circles indicate the cumulative percentage of trips at a trip duration of 2, 4 and 6 h.**

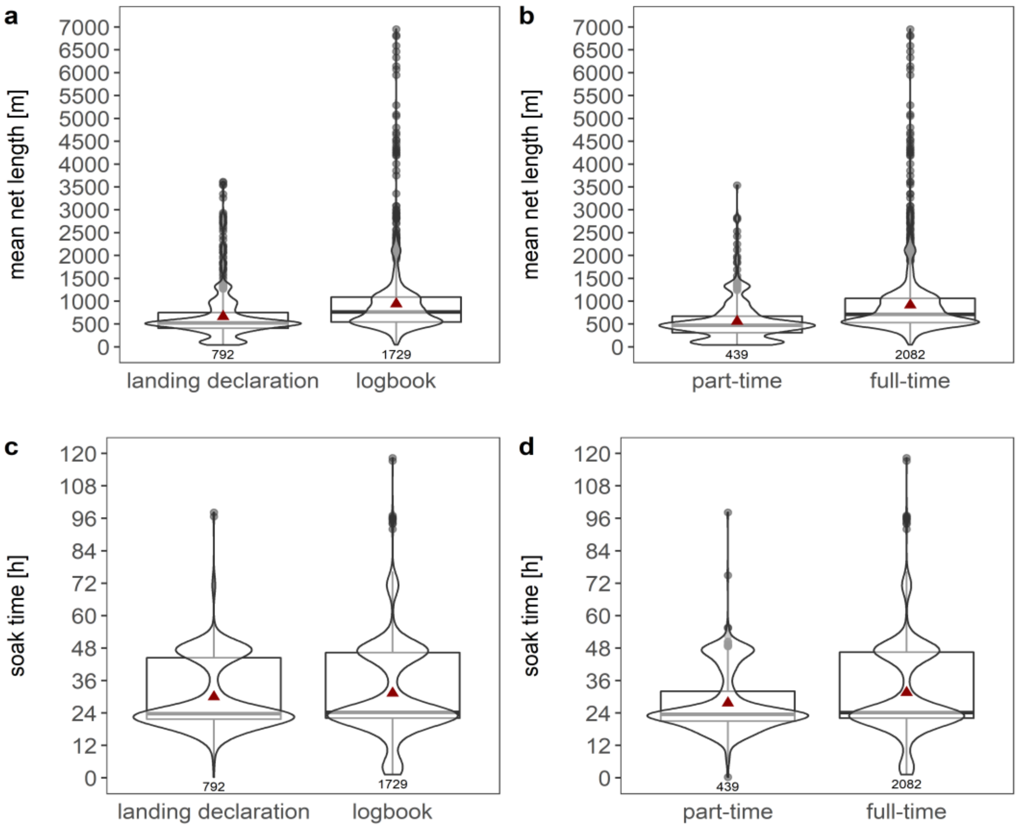


Fig. 6. **Mean net length, panels (a) & (b), and soak time, panels (c) & (d), of 2521 pairs of set and hauled gillnets from 84 vessels. (a) & (c) grouped by reporting procedure (landing declaration, logbook) and (b) & (d) grouped by business type (part-time, full-time) (Tables S11-S12). Each graph shows a combination of a boxplot overlaid with a probability density plot of the underlying data distribution. Boxplots: whiskers extend by a maximum of 1.5 times the interquartile range. Red triangle: mean. Density plots: based on kernel probability density function using normal distribution and the Silverman estimation to define the bandwidths.**

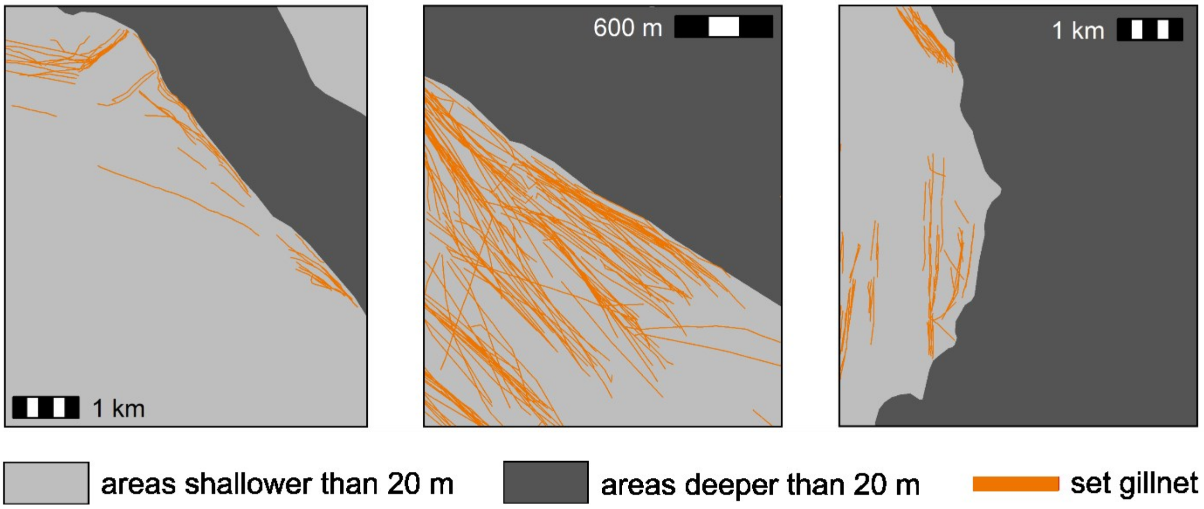


Fig. 7. **Illustrative details of set gillnets from three different areas. Gear activities of at least four vessels across the two-month closure of cod fishery in 2018 are shown per panel. To maintain confidentiality of the anonymised self-reported data from the fishers, coordinates and orientation are not given.**

Tables

Table 1: **Distribution and length range of vessels with Mofi records across reporting procedure and business type. 107 vessels from 105 owners had data on trips and 102 vessels (covering 100 owners) of these 107 vessels had both data on trips and on gear activities. Totals in bold.**

		vessels with trip data			vessels with trip and gear activity data		
		landing declaration (< 8 m)	logbook (8 – 12 m)	total	landing declaration (< 8 m)	logbook (8 – 12 m)	total
number of vessels	part-time	37	4	41 (38%)	35	3	38 (37%)
	full-time	24	42	66 (62%)	22	42	64 (63%)
	total	**61** (57%)	**46** (43%)	107	**57** (56%)	**45** (44%)	102
vessel length range [m]		4.00 – 7.99	8.20 – 11.99		4.20 – 7.99	8.20 – 11.99	
number of vessel owners				105			100

Table 2: Eleven categories were defined to classify the 1618 identified trips viewed with the BlackBox Analyzer. Categories are specified and listed in descending order according to the relative proportion. Italic categories: most likely involving technical causes. Categorized trips usable for trip duration analysis: (a) yes, without editing, (b) yes, after editing, (c) no, not usable. The total exceeds 100% as the INCOMPLETE-category can overlap with other categories. Examples of some major trip categories are explained in Figs. S4-S8. Proportions were rounded to zero decimals if they were > 1.

Trip category	Specifications and details on editing	Proportion (%)
FIT (a)	good correspondence between set time stamps defining start and end of trip and start and end location typical for the respective vessel; no further editing missing GPS records during trip possible	67
TOOLATE (b)	time stamp defining the end of a trip was set with delay (> 30 min after vessel arrived back at landing site) editing of time stamp leading to shortening of trip	7
INCOMPLETE (c)	trip (sensor data) recording started too late (time stamp set too late) or ended too early (time stamp set too early), with start and/or end further away from a start and/or end location typical for the respective vessel no previous or subsequent sensor data available as in case of TOOLATE and TOOEARLY to adjust time stamps can overlap with other categories	7
N (c)	usually few geographical positions recorded, mostly on land or in vicinity of a landing site indicating that no trip was done often with successful trips shortly before and after, making the TRIAL-category unlikely	5
SEVERAL (b)	trip was not ended and covered several independent trips was split into the different single trips increased number of trips	3
TRIAL (c)	trip defined by time stamps did not refer to a trip related to potential activities at sea mostly recorded on land assumed to have been a trial by the fisher to test the smartphone application	3
UNK (c)	not possible to tell whether it was an actual trip often related to missing GPS data	3
NODATA (c)	sensor data missing completely data on time stamps still available	3
SPLIT (b)	trip was suspended and resumed by starting a new trip splitting it into two or more sections sections were fused during editing to form one single trip decreased number of trips	2
DUPLICATE (c)	trip recorded more than once (same date, time, speed pattern and geographical pattern)	0.25
TOOEARLY (b)	time stamp defining the start of a trip was set too early (> 30 min before vessel left landing site) editing of time stamp leading to shortening of trip	0.19

Table 3: **Twelve categories were defined to classify the 7972 identified gear activities viewed with the BlackBox Analyzer. Categories are specified and listed in descending order according to the relative proportion. Italic categories: most likely involving technical causes. Categorized gear activities usable for further analysis: (a) yes, without editing, (b) yes, after editing, (c) no, not usable. The total exceeds 100% as the GPS-category and the WRONG-category can overlap with other categories. Examples of some major gear activity categories are explained in Figs. S9-S15. Proportions were rounded to zero decimals if they were > 1.**

Gear activity category	Specifications and details on editing	Proportion (%)
FIT (a)	good correspondence between set time stamps defining start and end of activity and start and end position of gear activity indicated by speed pattern, geographical pattern and if given in relation to previous and/or subsequent gear activities; no further editing	29
SHIFT (b)	time stamp of gear activity set too early or too late in relation to speed pattern and geographical pattern and if given in relation to previous and/or subsequent gear activities editing of time stamp and with it editing of gear activity	18
MULTIPLE (c)	very large number of subsequent time stamps in quick succession resulting in very short gear activities within a short time period	14
SEVERAL (b)	gear activity defined by time stamps covers several different gear activities editing by adding time stamps to represent the single gear activities increased number of gear activities	12
MISSED (b)	no gear activity marked by time stamps although speed pattern and geographical pattern suggest a gear activity often indicated by a previous or subsequent corresponding gear activity that was missing a partner activity (e.g. setting/hauling of gillnet) adding time stamps to define missed gear activity increased number of gear activities	11
MISTAKE (c)	time stamps did not define an actual gear activity in relation to speed pattern and geographical pattern and if given in relation to previous and/or subsequent gear activities	10
GPS (c)	missing GPS positions or GPS outliers within the recorded track of a gear activity, which can substantially affect its unambiguous identification and estimation of geographical distance covered, e.g. net length in case of gillnets can overlap with other categories	6
WRONG (b)	wrong type of gear activity stamp assigned, e.g. hauling instead of setting inferred from speed pattern, geographical pattern and previous or subsequent partner activity if available (e.g. setting/hauling of gillnet) assignment of correct activity type can overlap with other categories	2
TRIAL (c)	part of a TRIAL trip time stamp did not define an actual gear activity in relation to the speed pattern and geographical pattern assumed to have been a trial primarily done on land by the fisher to test the smartphone application	0.92
NODATA (c)	part of NODATA trip sensor data missing completely data on time stamps still available	0.60
UNK (c)	not possible to infer from speed pattern, geographical pattern or partner activity if it was an actual gear activity	0.15
DUPLICATE (c)	gear activities recorded more than once (same date, time, speed pattern and geographical pattern)	0.03

Table 4: Distribution of identified and categorized trips (n = 1618) and gear activities (n = 7972) from the categorized data across reporting procedure and business type. Totals in bold.

		landing declaration (< 8 m)	logbook (8 – 12 m)	total
number of trips	part-time	411	23	434 (27%)
	full-time	281	903	1184 (73%)
	total	692 (43%)	926 (57%)	1618
number of gear activities	part-time	1692	120	1812 (23%)
	full-time	1090	5070	6160 (77%)
	total	2782 (35%)	5190 (65%)	7972

Arbeitspaket 2 – Veröffentlichung 1 “Determination of optimal acoustic passive reflectors to reduce bycatch of Odonto¬cetes in gillnets.”

Kratzer, I.M.F., Schäfer, I., Stoltenberg, A., Chladek, J.C., Kindt-Larsen, L., Larsen, F., Stepputtis, D. 2020. Determination of optimal acoustic passive reflectors to reduce bycatch of Odontocetes in gillnets. Frontiers in Marine Science 7: Article 539, doi:10.3389/fmars.2020.00539

Abstract

The need to minimize bycatch of toothed whales (odontocetes) in gillnets has long been recognized, because they are often top predators and thus essential to ecosystem resilience. It is likely that a key to achieving this goal is the improvement of gillnet acoustic visibility, because these species use underwater sonar for orientation. Previous work on increasing gillnet detectability for echolocating animals by making the nets more recognizable has been based on trial and error, without understanding the fundamental acoustic properties of the tested modifications. Consequently, these studies have produced mixed and sometimes contradictory results. We systematically identified small, passive reflective objects that can improve the visibility of gillnets at a broad range of frequencies, i.e., for many odontocetes. We simulated the acoustic reflectivity of a wide range of materials in different shapes, sizes, and environmental conditions, with a focus on polymer materials. We verified the simulation results experimentally and calculated detection distances of the selected modifications. For example, if 8 mm acrylic glass spheres are attached to the net at intervals smaller than 0.5 m, the spheres have the same target strength (TS) at 130 kHz as the most recognizable part of a gillnet, the floatline. Modifications of the netting material itself, e.g., using barium sulfate additives, do not substantially increase the acoustic reflectivity of the net.

Vollständige Veröffentlichung (Open Access)

https://www.frontiersin.org/articles/10.3389/fmars.2020.00539/full

Arbeitspaket 2 – Veröffentlichung 2 “Angle-dependent acoustic reflectivity of gillnets and their modifications to reduce bycatch of odontocetes using sonar imaging.”

Kratzer, I. M. F., Stepputtis, D., Santos, J., Lütkefedder, F., Stoltenberg, A., Hartkens, L., Schaber, M., Kindt-Larsen, L., & Larsen, F. 2022. Angle-dependent acoustic reflectivity of gillnets and their modifications to reduce bycatch of odontocetes using sonar imaging. Fisheries Research, 250: 106278, doi:10.1016/j.fishres.2022.106278

Vollständige Veröffentlichung (Pre-print Proof)

ABSTRACT

Incidental capture in gillnets is the most pressing threat for small cetaceans worldwide. One reason why small, echolocating cetaceans entangle in gillnets may be their inability to acoustically detect gillnets and classify them as obstacles. To increase the overall acoustic reflectivity as well as alter the perceived image to simulate an impenetrable barrier, small reflective objects – 8 mm wide acrylic glass spheres – were attached to standard gillnets. This study investigates the acoustic reflectivity of standard gillnets and modified gillnets with different numbers of spheres/m², at several angles of ensonification across a large frequency range. The acoustic reflectivity of standard gillnets is very low and decreases with angle of ensonification. Gillnets equipped with the spheres have substantially higher acoustic backscattering strength, and exhibit a positive relation between backscattering strength and inclination, i.e. gillnets ensonified from an angle have an even larger echo than when ensonified perpendicularly. Gillnets with sphere-sphere distance of 20 cm perform best, while the acoustic backscatter of gillnets with 40 cm and 60 cm sphere-distances is similar. The acoustic image (echogram) of the gillnet with spheres demonstrates a distinct highly visible acoustic pattern, potentially rendering the spheres an effective way to reduce bycatch of small cetaceans.

1. INTRODUCTION

A major threat to various cetacean species worldwide is bycatch in gillnets (Reeves et al., 2013) with some species facing extinction or already having been eradicated due to bycatch (CIRVA, 2019; Turvey et al., 2007). The incidental capture of harbor porpoises (*Phocoena phocoena)* is taking place throughout their distribution range (Baltic Sea and Skagerak/Kattegat: Berggren, 1994; Kindt-Larsen et al., 2016; Koschinski and Pfander, 2009; Trippel et al., 1996; Vinther and Larsen, 2004; U.S. and global fisheres: Read et al., 2006; Northwest Atlantic and North Sea: Reeves et al., 2013; Black Sea: Skóra and Kuklik, 2003; Tonay, 2016).

On way of mitigating bycatch is the use of active acoustic deterrent devices – so-called pingers – which is mandatory in some fisheries (Council of the European Union, 2004). Despite effectively reducing bycatch of harbor porpoises (Kraus et al., 1997; Larsen and Eigaard, 2014; Palka et al., 2008), pingers have a series of drawbacks, including habituation depending on the pinger specifications (Cox et al., 2001, Kindt-Larsen et al., 2018), catch damage due to depredation owed to the “dinner bell” effect for other marine mammals (Gilman et al., 2019, Carretta and Barlow, 2011), and potentially higher bycatch rates when a number of pingers in a series of pingers attached to gillnets fail (Carretta and Barlow, 2011). Furthermore, pingers require regular maintenance such as change of battery and verification of functionality to fulfill their task.

Despite long-term interest in the matter, it remains unclear why harbor porpoises get entangled in the first place. Whereas harbor porpoises are thought to be able to acoustically detect at least parts of the gillnet, i.e. the highly acoustically visible floatline, from a suitable distance (Kastelein et al., 2000; Nielsen et al., 2012), they are regularly bycaught in gillnet fisheries around the world. Assuming harbor porpoises echolocate regularly (Wisniewska et al., 2016), one explanation for entanglement could be their failure to detect the netting itself and hence to classify the net as an obstacle. Furthermore, studies have shown that some species of toothed whales (odontocetes), including harbor porpoises, tend to dive underneath objects they want to avoid (Kastelein et al., 1995; Silber et al., 1994). This, in turn, could make them prone to attempt to dive underneath the highly visible floatline and subsequently be caught in the less visible netting. Modifying the gillnet netting in such a way that it appears as an impenetrable object could thus be an alternative to pingers to reduce bycatch of echolocating marine mammals. Several trials with acoustically enhanced netting material or the addition of objects to the netting have produced negative or at best inconclusive results, i.e. no bycatch reduction or reduced catch of target species (Bordino et al., 2013 ; Dawson, 1991; Larsen et al., 2007). Only one study showed both a bycatch reduction and stable catch of target species (Trippel et al., 2003). The lack of success in reducing bycatch using acoustically enhanced nets is partially due to a lack of fundamental understanding of the acoustic properties of the modified nets, resulting in modifications of the netting filament which led to little or no increase in acoustic reflectivity (Larsen et al., 2007; Mooney et al., 2007).

To develop an acoustically visible, yet catch efficient gillnet, small, highly acoustically reflective objects that could be attached to a gillnet with only small effects on its hydrodynamic properties were systematically identified for a large range of frequencies and therefore echolocating species (Kratzer et al., 2020). The study included systematic simulations with subsequent experimental verification by carrying out a large parameter study investigating the relation between material properties, frequency and size of objects (Kratzer et al., 2020). For harbor porpoises, echolocating in a narrow frequency range around 130 kHz (Villadsgaard et al., 2007), an 8 mm diameter sphere made from acrylic glass (Polymethyl methacrylate or PMMA) was identified as optimal object in the aforementioned study (Kratzer et al., 2020), as it resonates at around 130 kHz. A spherical object was chosen as the echo properties are independent of the angle of ensonification which is the precondition to allow detection at all aspect angles of incidence.

In the present study, two different kinds of gillnets, one multi-monofilament nylon cod net and one multi-filament natural fiber turbot net, were equipped with spheres at different sphere-sphere intervals to systematically determine the dependency of acoustic reflectivity on the number of spheres per m² and potentially identify a compromise between number of spheres needed to substantially increase the echo of the gillnet and the effort and resulting costs that needs to be considered for the production of modified nets. The echo properties were measured with the acoustic beam perpendicularly to the net as well as with the acoustic beam ensonifying the net at two angles of incidence, to investigate any possible effect of that angle on the backscattering strength.

2. MATERIALS & METHODS

The experimental trials were conducted in a sheltered harbour berth at the Bundeswehr Technical Center for Ships and Naval Weapons, Maritime Technology and Research (WTD 71) in Kiel, Germany with a dimension of approximately 40 m by 20 m and a depth of 8 m. Acoustic measurements were conducted with a SIMRAD EK80 scientific wide-band echosounder in a waterproof housing (WBT Tube) operated with three SIMRAD transducers (ES38-18DK, ES70-18CD, ES120-7C). Acoustic reflectivity was measured in a frequency range from 35 kHz to 170 kHz, with the range between 46 and 54 kHz not covered. The transducers were calibrated using a 38.1 mm tungsten carbide sphere (Demer et al., 2015). The echosounder was operated in FM-mode (frequency modulated, i.e. broadband mode) with a pulse duration of 0.512 ms. Nets were slightly shaken to remove bubbles and then ensonified several minutes after having been placed in the water for approximately 180 s at each angle at a ping rate of 1 s^{-1}. All tested gillnets were 10 m long and the specifications are given in TABLE 1 and a graphical illustration of the set-up is shown in the appendix (FIGURE A. 1). To investigate the relationship between acoustic backscattering strength and number of spheres per m² of netting, a standard, new cod gillnet made from nylon was equipped with spheres at different sphere-sphere intervals. A second gillnet type usually used in the Turkish turbot fishery was also investigated, as this net has been used in a commercial fishery trial (total soaking time: 1235 h) testing the efficacy of the modified net in reducing bycatch and investigating the effect on catch efficiency (Kratzer et al, 2021) The main focus of the analysis presented in this study was on the cod net, as this type of net allowed to investigate the impact of number of spheres per m² of netting. The modification of the gillnets with 8 mm spheres was based on the simulated resonance peaks between 90 – 150 kHz (Kratzer et al., 2020) , FIGURE 1).

2.1 Set-up and ensonified area

The transducers were mounted at a depth of approximately 2 m looking horizontally towards the gillnet. The gillnets were suspended from a steel bar which was kept afloat with two large pontoons and placed into the acoustic beam of the transducers with both vertical and horizontal center of the gillnet centered in the acoustic beam and the floatline at 0.5 m depth. To ensure that the same area of gillnet netting was ensonified at a 0° angle and avoid ensonification of the floatline and leadline, the cod gillnets were set at 5 m (ES38-18DK, ES70-18CD) and 13.1 m (ES120-7C) from the respective transducers to accommodate differences in beam angles of the transducers (18° for ES38-18DK/ES70-18CD and 7° for ES120-7C). The turbot gillnets were set at 2 m and 5 m respectively to avoid ensonification of leadline and floatline, as they were lower in height compared to the nylon nets. Each net was measured at 0°, 20° and 45° relative to the perpendicular axis of the transducer. Rotation was done manually by rotating the entire set-up Weights were added on the ends of the gillnet in addition to the heavy leadline to keep the net as straight as possible in the water column. As the nets are inclined relative to the transducer, the ensonified area changes as does the absolute number of spheres that are ensonified and the number of columns of spheres that should become visible as rows in the echogram(TABLE 2, FIGURE 2). As the net is turned to a certain inclination, the minimum and maximum distance from the transducer changes, which becomes visible as a “height” of the gillnet (FIGURE 2), i.e. the vertical axis in the echogram corresponds to the distance of the gillnet from the transducer in the transducer beam. This in turn means that spheres that are attached horizontally adjacent to each other (columns) become visible as spheres on top of each other (rows), since they are inclined in the transducer beam and thus at different distances from the transducer (FIGURE 2). At 0° the transducer ensonfies all of the netting area from almost the same distance, which means that the rows of spheres cannot be resolved as the image shows all spheres at almost the same distance level. The net appears as a thin line in the echogram. At 0° the “height” of the net when ensonified perpendicularly is a result of the longer distance of the netting on the edges of the acoustic beam compared to the center of the beam.

2.2 Determination of area backscattering strength (S_a) and target strength (TS)

In previous studies measuring the acoustic reflectivity of gillnets (Kastelein et al., 2000; Mooney et al., 2004), target strength was used, albeit target strength is more commonly for single targets rather than area targets. As gillnets are area targets, the area backscattering strength (S_a; MacLennan et al., 2002) of tested gillnets was primarily used to describe the acoustic properties, relevant for echolocating whales. S_a-values were determined across a large frequency range (35 kHz to 170 kHz). Additionally, target strength (TS; MacLennan et al., 2002) of the gillnets were calculated to be able to compare our measurements to previous studies.

Echodata from the EK80-echosounder were post-processed and analyzed with EchoView 10 software (*Echoview Software Pty Ltd*, 2019) and the minimum threshold was set to -60 dB re 1 m^{-1} when viewing the pulse-compressed S_v echograms. For all pings during the ensonification, volume backscattering strength ($S_{v,}$ MacLennan et al., 2002) was exported per frequency using the internal EchoView 10 algorithm. Values for target strength (TS) were exported for each single frequency as well as the frequency range between 120 – 140 kHz, which corresponds to the frequency range used by harbor porpoises (Miller and Wahlberg, 2013) using the export function in EchoView 10. S_v and TS were extracted for each pixel, corresponding to the visualization of each data point. Sections containing echoes of fish or fish schools swimming around the gillnet were marked as “bad data” and excluded from the export and subsequently the analysis.

Further data handling and analysis was carried out using the statistical software R (R Core Team, 2019). To automatically separate gillnet echoes from noise and to correct for net movements during each measurement series, an algorithm was applied to determine the first and last S_v or TS value larger than –65 dB for each acoustic ping along the "height" during the measurement of each net/angle combination. This threshold was chosen based on previous work (Au and Jones, 1991; Kastelein et al., 2000; Mooney et al., 2007). As not all pings had values larger than the threshold, the running minimum and maximum distance from the transducer was determined for 10 pings and subsequently the running mean was determined over 50 pings.

For both reference nets (Cod-Ref and Tur-Ref) start and end of the net were determined at a threshold of –70 dB, as some combinations of net and degree did not have enough pings with values above –65 dB to be able to distinguish the netting from noise.

From the exported S_v values, the corresponding volume backscattering coefficients s_v were calculated:

$$\boldsymbol{s_v = 10^{\frac{S_v}{10}}} \qquad \textbf{(1)}$$

To gain the area backscattering coefficient $s_{a,}$ the s_v values for each ping were integrated :

$$\boldsymbol{s_a = \int_{minimum\ distance}^{maximum\ distance} s_v} \textbf{(2)}$$

The area backscattering strength S_a is calculated as:

$$\boldsymbol{S_a = 10 * \log_{10}(s_a)} \qquad \textbf{(3)}$$

To be able to compare the results of this study with previous studies, an equivalent target strength (TS) value was determined. The TS for the full gillnet was determined by both coherent and incoherent (following the same procedure as in Kratzer et al., 2020 using Kinsler et al., 2000) addition of the TS values across the "height" *m* for each ping.

$$\boldsymbol{TS_{coherent} = 10\log_{10}(\textstyle\sum_m \sigma_{bs_m})} \textbf{ (4)}$$

$$\boldsymbol{TS_{incoherent} = 10\log_{10}(\sqrt{\textstyle\sum_m (\sigma_{bs_m})^2})} \textbf{(5)}$$

Coherent addition is the maximum possible TS, where incoherent accounts for possible factors reducing TS such as extinction, small movements of the net or small deviations from perpendicularity. It is the likely mean of the TS of the gillnet.

2.3 Modelling area backscattering strength

The cod nets were chosen for the area backscattering model as they provide a stepwise increase in number of spheres per m² while the turbot nets were measured for the sake of completeness as they already had been used in a commercial fishing trial. The experimental variation in the average area backscattering was modelled as:

$$\boldsymbol{S_{a_{ij}} = \mu_0 + \alpha_i \times angle_i + (\beta_0 + \delta_i) \times n_{ij}^k + g(a, f_{ij}, n_{ij}) + \epsilon_{ij}} \textbf{(6)}$$

In Equation 6, μ_0 is the model intercept representing the average area backscattering strength for the reference gillnet (Cod-Ref) at the reference angle of ensonification (0°). Parameters α_i are deviations from the average, caused by the two additional angles of ensonification tested $i \in \{20°, 45°\}$, entered in the model as categorical levels. The parameter β_0 accounts for the effect of increasing the number of spheres (n_{ij}) per m² attached to the gillnet at reference angle of ensonification. To account for potential non-linear relationship between n_{ij} and $S_{a_{ij}}$, different transformations of the identity n_{ij} (*k*= 1) were considered, including square root (*k*= 0.5), quadratic (*k*=

2) and cubic (k= 3) transformations. Models with quadratic and cubic transformations of n_{ij} also incorporated lower order ($1 \leq k \leq 3$) transformations as polynomial basis. Parameters δ_i are interaction terms representing deviations of β_0 caused by the two additional angle of ensonification i. Further, $g(a, f_{ij}, n_{ij})$ denotes a smooth-by-factor interaction (Roca-Pardiñas et al., 2006) between the tensor product of cubic splines smoothing the effect of transducer frequency (f_{ij}) and number n_{ij} of the spheres per m², and the angle of ensonification $a \in \{0°, 20°, 45°\}$, therefore:

$$g(a, f_{ij}, n_{ij}) = \begin{array}{ll} g^{0}(f_{ij}, n_{ij}) & \text{if a=0}^\circ \\ g^{20}(f_{ij}, n_{ij}) & \text{if a=20}^\circ \text{(7)} \\ g^{45}(f_{ij}, n_{ij}) & \text{if a=45}^\circ \end{array}$$

Note that for this analysis the range of frequencies were restricted to values between f = 100 kHz and f = 160 kHz, as this is the frequency range that the spheres were designed for and thus require an in-depth analysis. The last parameter $\varepsilon_{ij} \sim N(0, \sigma^2)$ in Equation 6 are the model residuals. The model in Equation 6 has a semi-parametric form that involves parametric terms (μ_0 ,α_i, β_0 and δ_i) from standard linear model regressions, and non-parametric terms ($g(a, f_{ij}, n_{ij})$, Equation 7) which require specific algorithms to control the degree of smoothing of each individual smooth term . Therefore, the model was fitted using the P-IRLS algorithm established for generalized additive models, using the mgcv package (Wood, 2006) available in R (R Core Team, 2019).

3. RESULTS

The wideband echograms (FIGURE 3) revealed a clearly visible difference in echo structure of the different types of gillnets in the different inclinations. The height of the gillnet in the echogram corresponds to the distance from the transducer resulting in a broader echo at the 20° and 45° angle, as the gillnet is rotated around its center which is aligned with the center of the transducer beam. At 0°, the netting area inside the acoustic beam is ensonified simultaneously and the small "height" results from the edges of the transducer beam being further away from the center and the fact that the net, despite being strung tightly was never positioned absolutely perpendicular to the acoustic beam, but often rather hung like a slightly wavy curtain. The vertically aligned spheres, or columns of spheres, are visible as distinct rows, as some columns are closer to the transducer than others (FIGURE 2). The spheres are particularly visible when measuring with the 120 kHz transducer as the spheres resonate within the frequency range of that transducer. The number of red rows corresponds to the predicted columns in TABLE 2 for 40 cm and 60 cm at 120 kHz. The echoes of the rows in the 20 cm cod net overlap, thus it is not possible to count the individual rows. The turbot gillnet with spheres (Tur-35cm) only shows five columns of spheres instead of the predicted eight, possibly due to the fact that the net needed to be set very close to the transducer and the acoustic beam did not ensonify all of the netting.

3.1 Area backscattering strength

3.1.1 General comparison of area backscattering strength measurements

The determined area backscattering strength (S_a) per ping is determined for each ping within each frequency and shown as the mean S_a for all pings per frequency (FIGURE 4). The cod reference net made from nylon (Cod-Ref) has the lowest S_a across all frequencies. The turbot net made from natural fiber (Tur-Ref) has slightly higher S_a values, but the echo values are low especially in the high frequency range and when ensonified at a 45° angle, The nets with spheres outcompete their respective reference nets at frequencies above 100 kHz, as this is the frequency range where resonance of the spheres occurs; similarly as in the simulated data between 100 kHz and 150 kHz (FIGURE 1), albeit not being comparable in terms of echo strength, due to the difference in measure (measured S_a vs simulated TS). The values drop for all nets near the edges of the measurable frequency ranges of each transducer, due to the physical limitations of the transducer. To be able to take into account that the area backscattering strength is influenced by the ensonified area, FIGURE 5 shows the mean s_v value of each “height” averaged over all pings in each frequency. While S_a can stay the same with an increase in inclination as more but smaller s_v values are integrated, mean s_v decreases with an increase in inclination, as the echoes are distributed over a larger range.

3.1.2 S_a value for 130 kHz

A more detailed description is given for S_a values at 130 kHz as this is the centroid frequency of harbour porpoise echolocation clicks (Villadsgaard et al., 2007). S_a differs between net types, i.e. modified nets have a higher S_a than their respective reference net (FIGURE 6a). The S_a of nets with spheres also differ between Cod-20 cm, as Cod-20cm has a higher S_a than Cod-40cm and Cod-60cm, which are similar. The S_a values are similar between inclinations within each net type at 130 kHz, except for Cod-20 cm and Tur-35cm between 0° and 45° with higher S_a values at 45° for the Cod-20 cm net and the opposite for the Tur-35cm.

The cod nets with 40 cm and 60 cm sphere-sphere distance have similar S_a values, which has an impact on the effort needed to produce modified nets. If the echo strength is similar with more sparsely distributed spheres the effort could be reduced, e.g. doubling the distance between spheres results in a quarter of spheres needed. Similar results are also shown in the predictive model results (FIGURE 8).

3.1.3 Models for area backscattering strength

Prediction modelling was conducted frequency-wise for the cod nylon nets in the frequency range between 100 – 160 kHz. This selection is based on the fact that the spheres were designed to improve the acoustic visibility in the high frequency range (above 100 kHz), as this is the echolocation range of harbor porpoises.

The model candidates to assess the additive and combined effect of angle of ensonification of the gillnet, number of spheres per m^2 and frequency on the observed area backscattering strength were successfully fitted (TABLE 3). Fit statistics from the model using the square root transformation of number of spheres per m^2 (model 1) were equal to those from the models involving quadratic and cubic polynomial basis (models 3 and 4). The high R^2 achieved demonstrates that models 1, 3 and 4 captured and explained most of the variation of the experimental data ($R^2 = 0.92$, FIGURE FIGURE 7, FIGURE 8, TABLE 4). Model 1 had however a simpler structure than model 3 and 4 (6, 9 and 12 parametric linear predictors, respectively), therefore model 1 was selected and subsequently used for the analysis.

An inspection of predictions from the selected model 1 shows its capability to describe the experimental data (FIGURE FIGURE 7, FIGURE 8, FIGURE 9), capturing sufficiently well even local patterns that occurred throughout the range of transducer frequencies assessed (FIGURE 7).

The predicted values of S_a (FIGURE 8) show a similar trend as the experimental data (FIGURE 4), i.e. an increase in S_a with increasing number of spheres per area of netting. The increase in inclination respective to the transducer face leads to an increase in overall S_a in nets with spheres across all high frequencies. The S_a value of the reference net (Cod-Ref) decreases with an increase in inclination. Even with a low number of spheres (9 m^2) the acoustic backscattering strength increases substantially compared to the reference net when ensonified perpendicularly and at 45°.

3.2 Target strength

3.2.1 General comparison of target strength measurements

The echo data were transformed into TS values per data point using EchoView and subsequently exported for all single frequencies as well as the frequency range 120 – 140 kHz. Both coherent (FIGURE 9a) and incoherent (FIGURE 9b) addition of single TS values were calculated, values are shown without SD for clarification (see appendix for individual nets with SD). The values of both coherent and incoherent single frequency TS values follow the same pattern as the S_a values. Predictive modelling was not applied to the TS values, as S_a is a more representative measure of an area target as opposed to TS. The TS values are presented mainly for comparability to other studies.

3.2.1 TS value for single frequency (130 kHz) vs frequency range (120 – 140 kHz)

The TS values are compared between 130 kHz (FIGURE 10a, c) and the frequency range 120 – 140 kHz (FIGURE 10a b, d). Similarly to the S_a values, the single frequency range TS values differ for both coherent and incoherent addition between the nets, but largely not between inclinations within one net (FIGURE 10a, c and b, d). Overall, the net with 20 cm sphere-sphere distance has the highest incoherent TS, regardless of inclination.

4. DISCUSSION

Developing effective bycatch reduction measures for toothed whales (odontocetes) has been a challenging task for the past 50 years since the IWC first recognized bycatch as an emerging problem for small cetaceans (IWC, 1972). In this study, the acoustic visibility – and hence detectability – of gillnets has been substantially improved by attaching small acrylic glass spheres to the netting, especially in the frequency region above 110 kHz that the spheres were optimized for. Additionally, the acoustic image of the gillnet was altered, i.e. the spheres become highly visible at an angle and the overall pattern of the gillnet is more visible, as the echoes are distributed within the acoustic beam. This could greatly reduce bycatch of echolocating odontocetes as it could enable them to recognize the net as an obstacle and thus avoid entanglement, similarly to the avoidance reactions shown by dolphins (Silber et al., 1994) and the avoidance reaction of harbour porpoises to highly visible structures (Kastelein et al., 1995). Harbor porpoises are used as an exemplary species, as they are well studied and some subpopulations such as in the Eastern Baltic Sea (Hammond, 2008) as well as in the Black Sea (Birkun and Frantzis, 2008) are endangered, due to bycatch among other reasons. Based on a simulation study (Kratzer et al., 2020), the gillnet was acoustically enhanced for a frequency range between 120 – 140 kHz, which is the echolocation range of harbor porpoises (Miller and Wahlberg, 2013).

Porpoises constantly move their heads when scanning their environment and thus it is presumed that they generate the image of their surroundings by integrating the single “flashlights” of their echoes (Wahlberg et al., 2015). In terms of nets, this would mean that they perceive nets as areas. Thus, acoustic reflectivity is primarily regarded in terms of area backscattering strength (S_a), as gillnets are more accurately represented as an area target rather than a single target. Nevertheless, target strength values are also presented for comparability to previous studies (Au and Jones, 1991; Kastelein et al., 2000; Larsen et al., 2007; Mooney et al., 2004).

Two types of gillnets were used as reference nets: a nylon gillnet used in the Baltic Sea cod fishery (Cod-Ref) and a gillnet made from natural fiber (Tur-Ref), usually in use in the Black Sea turbot fishery. The gillnet made from natural fibers has a higher reflectivity than the nylon net, possibly due to the larger diameter of the filament, but also due to the material characteristics of natural fibers. Another reason for higher S_a values of the turbot net compared to the cod net could be the entrapment of air bubbles in the filament strands, which have a high target strength if excited at their resonance frequency (Medwin and Clay, 1998). It should be noted that the bubbles are likely to disappear over the usual soak time of turbot nets (usually several days; (Bilgin et al., 2018; Vinther, 1999), likely resulting in a substantial drop in acoustic visibility (Au and Jones, 1991). Bycatch rates have been associated with long soak times (Northridge et al., 2017), which could, aside from an increase of capture probability through prolonged effort, be caused by an decrease in acoustic visibility of gillnets when they are soaked in water. Below 100 kHz the spheres do not strongly affect the acoustic reflectivity of the nets. At frequencies above 100 kHz, the S_a of nets equipped with spheres is substantially higher than nets without spheres, as it is within the frequency range where the spheres have several resonance peaks (Kratzer et al., 2020). When the nets are set at an angle relative to the transducer, the echo broadens, as some parts of the gillnet are further away from the transducer within the acoustic beam than others; in addition, it is possible that some of the acoustic sidelobes also ensonify the netting area. While the echo appears to be wider and thus stronger on the echogram, there is only a small increase in S_a for the nets with acrylic spheres and a decrease of S_a for the reference net. The increase in S_a is attributed to an increased number of ensonified spheres when the nets are set at an angle relative to the transducer. Effects such as runtime differences, refraction and small interference effects are possible causes of a decrease in S_a of the reference nets.

As the S_a value is obtained by integration of s_v values, the small increase of S_a with increasing inclination of nets with spheres is also reflected in the area under the s_v-splinefunction, which has several smaller peaks, likely from the resonating spheres, when the net is at an angle compared to a single large peak at 0° (exemplarily shown in FIGURE A. 8). That means that at an angle many small s_v values are integrated as opposed to a few larger ones at 0°. This is especially relevant as it is not known whether porpoises integrate the echoes over an area and thus the overall echo strength is crucial or whether they are able to resolve the pattern of echoes in an area target. This means, it remains to be determined whether the S_a values, i.e. value integrated over the entire height, are more relevant or whether the distribution of S_v values will influence the behavior of the porpoise. In either case, the spatial and temporal distribution of the echoes (as shown in the echograms) as well as the echo strength (S_a) are greatly improved at any given angle when spheres are attached to the gillnet. In fact, as the S_a of standard nets decreases with an increase in inclination, the effect of the spheres is even more relevant when the porpoise would be approaching from an angle.

As the S_a turbot net with spheres decreases with inclination, a possible explanation is the challenging experimental set-up required for the turbot nets. Due to the reduced net height compared to the nylon nets (2 m vs 3.6 m), the nets had to be placed very close to the transducer. As the nets were inclined, the net may have been largely outside of the reliable measuring distance of the acoustic transducer, corresponding to the far field. The near field is estimated in the SIMRAD manual between 2 m (38 kHz) and 0.66 m (120 kHz). This, in turn means that conclusions on the perceivability of the inclined nets by harbour porpoises must be handled with caution, however, results show that modified turbot nets are generally more acoustically visible than standard turbot nets.

The TS values are derived from the S_v values in EchoView and subsequentially added coherently and incoherently, where the latter is a more conservative method to account for possible extinctions and runtime differences from the echoes. Other studies ensonified the gillnets with porpoise clicks, thus the incoherent TS value of the frequency range 120 – 140 kHz is used as a comparative value. Compared to other studies the cod reference net made from nylon has a similar TS (TABLE 5), albeit fairly low considering the larger ensonified area. The difference might be caused by differences in acoustic energy per ensonification frequency and different gillnet properties. Similarly to other studies, the TS drops with inclination, as the incident signal on the net is refracted in another direction than the receiver (Goodson, 1997). This effect does not apply to the gillnets with spheres, as their TS increases with inclination, possibly due to the ensonification of more highly acoustically reflective spheres. When target strength is considered as a proxy for detection distance, the 50% detection distance of the Cod-20cm net is likely comparable to the detection distance of a 5 cm water filled stainless-steel-sphere, i.e. approximately 16 m (Kastelein et al., 1999).

The target strength estimated for a frequency range is stronger than for a single frequency, due to the possibility that echoes of some frequencies add coherently (Baus and Radlinski, 1994). Since porpoises emit narrow-band clicks and do not use a fixed frequency, it is possible that the effect may be comparable to the 120 – 140 kHz frequency range measurements in this study, meaning that the animal could perceive the higher TS value.

For some frequency ranges, the echo measurements should be treated with caution, especially in the edge regions of the frequency range of each transducer. In these regions, the measurements are likely to be imprecise, which is reflected in a similar pattern of very low S_a values in these edge regions, due to the physical limitations of the transducers. Care should also be taken with the measurements of the turbot nets (Tur-Ref, Tur-35cm) in the region between 35 – 45 kHz, as the net needed to be placed in the nearfield of the 38 kHz transducer, to avoid ensonification of the floatline and leadline due to the reduced height compared to the cod nets.

Whether the nets with spheres will act as a perceived barrier, is largely dependent on the reaction of the animal and whether it relies more on the absolute echo strength or the distribution of echoes through its echolocation beam. As a next step, the behavior of harbor porpoises around modified nets should be investigated. A preliminary study has shown promising results (Gustafsson, 2020), but should be complemented with visual sightings as well as data on swimming tracks of porpoises. Furthermore, it is unclear whether increased underwater noise is associated with higher bycatch as the animals may be subject to range reduction in their signal perception in high noise levels (Hermannsen et al., 2014). An improved detectability due to higher echo strength of modified gillnets could mitigate the issue of signal reception in noisy environments.

While the increase in acoustic reflectivity is based on the assumption that porpoises echolocate frequently (Wisniewska et al., 2016), they are also known to swim silently for periods (Linnenschmidt et al., 2013). This might imply the need for an additional device that sends a low-impact “wake-up” call to alert the porpoise to an obstacle and increase their alertness.

Furthermore, since the acoustic backscatter might change over time due to water absorption, this change could be quantified by carrying out acoustic measurements at different timesteps, e.g. after 0 hrs, 12 hrs and 24 hrs.

Finally, the modified nets need to be subject to further commercial fishery trials testing both the long-term and spatial efficacy in terms of bycatch reduction as well as the effects on target catch. A recent study (Kratzer et al, 2021) has shown promising, but not ultimately conclusive results on the efficacy of the spheres to reduce small cetacean bycatch, but no effect of the spheres on the catch of bottom-dwelling species like the target species. Prior to the large-scale implementation, if the modified nets turn out to be successful, an automated process to attach the spheres needs to be developed.

ACKNOWLEGEMENTS

We thank Gerd Neeland, Frank Reier Knudsen (Kongsberg Maritime) and Mark Schmidt (LFV Hydroakusik GmbH) for providing the measurement equipment and Toby Jarvis (EchoView Software Pty Ltd) for providing support during the evaluation of the data. We thank WTD71 for providing staff and the harbour berth, as well as support during the measurements. Furthermore, we thank Rainer Stechert, Andreas Herrmann and Ulf Böttcher for technical support and Annemarie Schütz for the illustration. We thank Christopher Zimmermann, Uwe Krumme, and the anonymous reviewers for helpful comments on this manuscript. This work was funded by the German Federal Agency for Nature Conservation (Bundesamt für Naturschutz, project no. 3516821300, Entwicklung von alternativen Managementansätzen und Fangtechniken zur Minimierung der Konflikte zwischen Stellnetzfischerei und Naturschutzzielen in der deutschen AWZ der Ostsee - STELLA).

DATA AVAILABILITY STATEMENT

Data used in the analysis is provided in the supplementary material.

REFERENCES

Akaike, H., 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control 19, 716–723. https://doi.org/10.1109/TAC.1974.1100705

Au, W.L., Jones, L., 1991. Acoustic Reflectivity of Nets: Implications Concerning Incidental Take of Dolphins. Marine Mammal Science 7, 258–273. https://doi.org/10.1111/j.1748-7692.1991.tb00101.x

Baus, T.A., Radlinski, R.P., 1994. Scattering of an FM Signal From an Array of Spheres (No. TD 10.729). Naval Undersea Warfare Center Detachment, New London, Connecticut.

Berggren, P., 1994. Bycatches of the Harbour Porpoise (Phocoena phocoena) in the Swedish Skagerrak, Kattegat and Baltic Seas; 1973-1993. a phocoena) in the Swedish Skagerrak, Kattegat and Baltic Seas 1973-1993. Report of the International Whaling Commission (Special Issue) 221–215.

Bilgin, S., Köse, Ö., Yesilcicek, T., 2018. Incidental catches of endangered (Phocoena phocoena) and vulnerable (Delphinus delphis) cetaceans and catch composition of turbot bottom gillnet fisheries in the southeastern Black Sea, Turkey. Cahiers de Biologie Marine 59, 571–577. https://doi.org/10.21411/CBM.A.E3AED15B

Birkun, A., Jr., Frantzis, A., 2008. Phocoena phocoena ssp. relicta. The IUCN Red List of Threatened Species 2008: e.T17030A6737111. https://doi.org/10.2305/IUCN.UK.2008.RLTS.T17030A6737111.en

Bordino, P., Mackay, A., Werner, T., Northridge, S., Read, A., 2013. Franciscana bycatch is not reduced by acoustically reflective or physically stiffened gillnets. Endangered Species Research 21, 1–12.

Carretta, J.V., Barlow, J., 2011. Long-term effectiveness, failure rates, and “dinner bell” properties of acoustic pingers in a gillnet fishery. Marine Technology Society Journal 45, 7–19.

CIRVA, 2019. Report of the Eleventh meeting of the Comité Internacional para la Recuperación de la Vaquita (CIRVA). La Jolla, CA, USA.

Council of the European Union, 2004. Council Regulation (EC) No 812/2004 of 26 April 2004 laying down measures concerning incidental catches of cetaceans in fisheries and amending Regulation (EC) No 88/98.

Cox, T.M., Read, A.J., Solow, A., Tregenza, N., 2001. Will harbour porpoises (Phocoena phocoena) habituate to pingers? Journal of Cetacean Research and Management 3, 81–86.

Dawson, S.M., 1991. Modifying gillnets to reduce entanglement of cetaceans. Marine Mammal Science 7, 274–282.

Demer, D.A., Berger, L., Bernasconi, M., Bethke, E., Boswell, K., Chu, D., Domokos, R., Dunford, A., Fässler, S., Gauthier, S., Hufnagle, L.T., Jech, J.M., Bouffant, N., Lesbourges-Dhaussy, A., Lurton, X., Macaulay, G.J., Perrot, Y., Ryan, T., Parker-Stetter, S., Stienessen, S., Weber, T., Williamson, N., 2015. Calibration of acoustic instruments (ICES Cooperative Research Report No. 326).

Echoview Software Pty Ltd, 2019. . Echoview Software Pty Ltd, Hobart, Australia.

Gilman, E., Chaloupka, M., Dagorn, L., Hall, M., Hobday, A., Musyl, M., Pitcher, T., Poisson, F., Restrepo, V., Suuronen, P., 2019. Robbing Peter to pay Paul: replacing unintended cross-taxa conflicts with intentional tradeoffs by moving from piecemeal to integrated fisheries bycatch management. Rev Fish Biol Fisheries 29, 93–123. https://doi.org/10.1007/s11160-019-09547-1

Goodson, A.D., 1997. Developing deterrent devices designed to reduce the mortality of small cetaceans in commercial fishing nets. Marine and Freshwater Behaviour and Physiology 29, 211–236. https://doi.org/10.1080/10236249709379007

Gustafsson, S., 2020. Pearls as bycatch mitigation strategy for Harbour porpoise (Phocoena phocoena) (Master Thesis). Swedish University of Agricultural Science, Uppsala.

Hammond, P.S., 2008. Phocoena phocoena (Baltic Sea subpopulation): Hammond, P.S., Bearzi, G., Bjørge, A., Forney, K.A., Karczmarski, L., Kasuya, T., Perrin, W., Scott, M.D., Wang, J.Y. , Wells, R.S. & Wilson, B.: The IUCN Red List of Threatened Species 2008: e.T17031A98831650. https://doi.org/10.2305/IUCN.UK.2008.RLTS.T17031A6739565.en

Hermannsen, L., Beedholm, K., Tougaard, J., Madsen, P.T., 2014. High frequency components of ship noise in shallow water with a discussion of implications for harbor porpoises (*Phocoena phocoena*). The Journal of the Acoustical Society of America 136, 1640–1653. https://doi.org/10.1121/1.4893908

IWC, 1972. Report of the Scientific Committee Appendix IV (Reports of the Scientific Committee). International Whaling Commission, London.

Kastelein, R., Au, W.W., de Haan, D., 2000. Detection distances of bottom-set gillnets by harbour porpoises (Phocoena phocoena) and bottlenose dolphins (Tursiops truncatus). Marine environmental research 49, 359–75.

Kastelein, R.A., Au, W.W.L., Rippe, H.T., Schooneman, N.M., 1999. Target detection by an echolocating harbor porpoise (Phocoena phocoena). The Journal of the Acoustical Society of America 105, 2493–2498. https://doi.org/10.1121/1.426951

Kastelein, R.A., Haan, D. de, Staal, C., 1995. Behaviour of Harbour porpoises (Phocoena phocoena) in response to ropes, in: Nachtigall, P.E., Lien, J., Au, W.W.L., Read, A.J. (Eds.), Harbour Porpoises, Laboratory Studies to Reduce Bycatch. De Spil Publishers, Woerden, The Netherlands, pp. 69–90.

Kindt-Larsen, L., Berg, C.W., Tougaard, J., Sørensen, T.K., Geitner, K., Northridge, S., Sveegaard, S., Larsen, F., 2016. Identification of high-risk areas for harbour porpoise Phocoena phocoena bycatch using remote electronic monitoring and satellite telemetry data. Marine Ecology Progress Series 555, 261–271.

Kindt-Larsen, L., Berg, C.W., Northridge, S., Larsen, F., 2018. Harbor porpoise (*Phocoena phocoena*) reactions to pingers. Marine Mammal Science 35, 552–573. https://doi.org/10.1111/mms.12552

Kinsler, L. E., Frey, A. R., Coppens, A. B., and Sanders, J. V. eds. (2000). *Fundamentals of*

Acoustics. 4th ed. New York: Wiley & Sons

Koschinski, S., Pfander, A., 2009. By-catch of harbour porpoises (Phocoena phocoena) in the Baltic coastal waters of Angeln and Schwansen (Schleswig-Holstein, Germany). Document AC16/Doc 60.

Kratzer, I.M.F., Schäfer, I., Stoltenberg, A., Chladek, J.C., Kindt-Larsen, L., Larsen, F., Stepputtis, D., 2020. Determination of Optimal Acoustic Passive Reflectors to Reduce Bycatch of Odontocetes in Gillnets. Front. Mar. Sci. 7. https://doi.org/10.3389/fmars.2020.00539

Kratzer, I.M.F., Brooks, M.E., Bilgin, S., Özdemir, S., Kindt-Larsen, L., Larsen, F., Stepputtis, D., 2021. Using acoustically visible gillnets to reduce bycatch of a small cetacean: first pilot trials in a commercial fishery. Fisheries Research 243, 106088. https://doi.org/10.1016/j.fishres.2021.106088

Kraus, S.D., Read, A.J., Solow, A., Baldwin, K., Spradlin, T., Anderson, E., Williamson, J., 1997. Acoustic alarms reduce porpoise mortality. Nature 388, 525–525. https://doi.org/10.1038/41451

Larsen, F., Eigaard, O.R., 2014. Acoustic alarms reduce bycatch of harbour porpoises in Danish North Sea gillnet fisheries. Fisheries Research 153, 108–112. https://doi.org/10.1016/j.fishres.2014.01.010

Larsen, F., Eigaard, O.R., Tougaard, J., 2007. Reduction of harbour porpoise (Phocoena phocoena) bycatch by iron-oxide gillnets. Fisheries Research 85, 270–278. https://doi.org/10.1016/j.fishres.2007.02.011

Linnenschmidt, M., Teilmann, J., Akamatsu, T., Dietz, R., Miller, L. a, 2013. Biosonar, dive, and foraging activity of satellite tracked harbor porpoises (Phocoena phocoena). Marine Mammal Science 29, E77–E97. https://doi.org/10.1111/j.1748-7692.2012.00592.x

MacLennan, D., Fernandes, P.G., Dalen, J., 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES Journal of Marine Science 59, 365–369. https://doi.org/10.1006/jmsc.2001.1158

Medwin, H., Clay, C.S., 1998. Fundamentals of acoustical oceanography, Applications of modern acoustics. Academic Press, Boston.

Miller, L.A., Wahlberg, M., 2013. Echolocation by the harbour porpoise: life in coastal waters. Front Physiol 4. https://doi.org/10.3389/fphys.2013.00052

Mooney, T.A., Au, W.W.L., Nachtigall, P.E., Trippel, E.A., 2007. Acoustic and stiffness properties of gillnets as they relate to small cetacean bycatch. ICES Journal of Marine Science: Journal du Conseil 64, 1324–1332. https://doi.org/10.1093/icesjms/fsm135

Mooney, T.A., Nachtigall, P.E., Au, W.W., 2004. Target strength of a nylon monofilament and an acoustically enhanced gillnet: predictions of biosonar detection ranges. Aquatic Mammals 30, 220–226.

Nielsen, T.P., Wahlberg, M., Heikkilä, S., Jensen, M., Sabinsky, P., Dabelsteen, T., 2012. Swimming patterns of wild harbour porpoises Phocoena phocoena show detection and avoidance of gillnets at very long ranges. Marine Ecology Progress Series 453, 241–248.

Northridge, S., Coram, A., Kingston, A., Crawford, R., 2017. Disentangling the causes of protected-species bycatch in gillnet fisheries: Causes of Bycatch. Conservation Biology 31, 686–695. https://doi.org/10.1111/cobi.12741

Palka, D.L., Rossman, M.C., Vanatten, A., Orphanides, C.D., 2008. Effect of pingers on harbour porpoise (Phocoena phocoena) bycatch in the US Northeast gillnet fishery. J. Cetacean Res. Manage 10, 217–226.

R Core Team, 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Read, A.J., Drinker, P., Northridge, S., 2006. Bycatch of Marine Mammals in U.S. and Global Fisheries. Conservation Biology 20, 163–169. https://doi.org/10.1111/j.1523-1739.2006.00338.x

Reeves, R., McClellan, K., Werner, T., 2013. Marine mammal bycatch in gillnet and other entangling net fisheries, 1990 to 2011. Endangered Species Research 20, 71–97. https://doi.org/10.3354/esr00481

Roca-Pardiñas, J., Cadarso-Suárez, C., Nácher, V., Acuña, C., 2006. Bootstrap-based methods for testing factor-by-curve interactions in generalized additive models: assessing prefrontal cortex neural activity related to decision-making. Statistics in Medicine 25, 2483–2501. https://doi.org/10.1002/sim.2415

Silber, G.K., Waples, K.A., Nelson, P.A., 1994. Response of Free-Ranging Harbour Porpoises to Potential Gillnet Modifications, in: Perrin, W.F., Donovan, G.P., Barlow, J. (Eds.), Gillnets and Cetaceans: Incorporating the Proceedings of the Symposium and Workshop on the Mortality of Cetaceans in Passive Fishing Nets and Traps, Reports of the International Whaling Commission, Special Issue. Cambrigde, pp. 579–584.

Simmonds, J., MacLennan, D. (Eds.), 2005. Fisheries Acoustics. Blackwell Publishing Ltd, Oxford, UK. https://doi.org/10.1002/9780470995303

Skóra, K.E., Kuklik, I., 2003. Bycatch as a potential threat to harbour porpoises (Phocoena phocoena) in Polish Baltic waters. NAMMCO Sci. Publ. 5, 303–315.

Tonay, A.M., 2016. Estimates of cetacean by-catch in the turbot fishery on the Turkish Western Black Sea Coast in 2007 and 2008. Journal of the Marine Biological Association of the United Kingdom 96, 993–998. https://doi.org/10.1017/S0025315416000060

Trippel, E.A., Holy, N.L., Palka, D.L., Shepherd, T.D., Melvin, G.D., Terhune, J.M., 2003. Nylon barium sulphate gillnet reduces porpoise and seabird mortality. Marine Mammal Science 19, 240–243.

Trippel, E.A., Wang, J.Y., Strong, M.B., Carter, L.S., Conway, J.D., 1996. Incidental mortality of harbour porpoise (*Phocoena phocoena*) by the gill-net fishery in the lower Bay of Fundy. Canadian Journal of Fisheries and Aquatic Sciences 53, 1294–1300. https://doi.org/10.1139/f96-060

Turvey, S.T., Pitman, R.L., Taylor, B.L., Barlow, J., Akamatsu, T., Barrett, L.A., Zhao, X., Reeves, R.R., Stewart, B.S., Wang, K., Wei, Z., Zhang, X., Pusser, L.., Richlen, M., Brandon, J.R., Wang, D., 2007. First human-caused extinction of a cetacean species? Biology Letters 3, 537–540. https://doi.org/10.1098/rsbl.2007.0292

Villadsgaard, A., Wahlberg, M., Tougaard, J., 2007. Echolocation signals of wild harbour porpoises, Phocoena phocoena. Journal of Experimental Biology 210, 56–64. https://doi.org/10.1242/jeb.02618

Vinther, M., 1999. Bycatches of harbour porpoises (Phocoena phocoena) in Danish set-net fisheries. Journal Cetacean Research Management 1, 123–135.

Vinther, M., Larsen, F., 2004. Updated estimates of harbour porpoise (Phocoena phocoena) bycatch in the Danish North Sea bottom-set gillnet fishery. Journal of Cetacean Research and Management 6, 19–24.

Wahlberg, M., Linnenschmidt, M., Madsen, P.T., Wisniewska, D.M., Miller, L.A., 2015. The Acoustic World of Harbor Porpoises. American Scientist 103, 46–53.

Wisniewska, D.M., Johnson, M., Teilmann, J., Rojano-Doñate, L., Shearer, J., Sveegaard, S., Miller, L.A., Siebert, U., Madsen, P.T., 2016. Ultra-High Foraging Rates of Harbor Porpoises Make Them Vulnerable to Anthropogenic Disturbance. Current Biology. https://doi.org/10.1016/j.cub.2016.03.069

Wood, S.N., 2006. Generalized additive models: an introduction with R, Texts in statistical science. Chapman & Hall/CRC, Boca Raton.

TABLES

TABLE 1: **Characteristics of tested gillnets. Spheres are attached at the given interval across the entire height and length of the net. Hanging ratio is the set length of the net divided by the stretched length of the net**

Net name	Abbreviation	Material	Sphere-sphere interval [cm]	Stretched mesh size [mm]	Height of net [m]	Approximated number *n* of spheres/m^2 $[m^{-2}]$	Hanging ratio
Cod reference	Cod-Ref	Nylon	N/A	110	3.6	0	0.5
Cod 60cm	Cod-60cm	Nylon	60	110	3.6	4	0.5
Cod 40cm	Cod-40cm	Nylon	40	110	3.6	9	0.5
Cod 20cm	Cod-20cm	Nylon	20	110	3.6	25	0.5
Turbot reference	Tur-Ref	Natural fiber	N/A	400	2	0	0.33
Turbot 35cm	Tur-35cm	Natural fiber	vertical: 37; horizontal: 35	400	2	9	0.33

TABLE 2: **Transducer types, aspect angle of ensonification of net, resulting approximate ensonified area and approximate number of ensonified columns of spheres. Ensonified area is related to the distance from the transducer given in the text.**

Transducer type	ES38-18DK			ES70-18CD			ES120-7C		
Transducer Center frequency	38 kHz			70 kHz			120 kHz		
Angle [°]	0	20	45	0	20	45	0	20	45
Ensonified area [m^2]	2.01	2.15	2.92	2.01	2.15	2.92	2.01	2.14	2.85
No. columns Cod-20 cm		9	12	0	9	12		9	12
No. columns Cod-40 cm		6	76	0	6	7		5	6
No. columns Cod-60 cm		3	4	0	3	4		3	4
No. columns Tur-35cm		5	8	NA	5	8		5	8

TABLE 3: **Fit statistics of the candidate models ranked by AIC (Akaike, 1974) and number of parametric terms applied to model the main effect of number of spheres per m^2 and its interaction with angle of ensonification of the gillnet.**

Model	k	Linear predictors (n)	Deviance	AIC	R^2
1	0.5	6	938700	744720	0.92
3	2	9	938700	744720	0.92
4	3	12	938700	744720	0.92
2	1	6	1586693	829678	0.87

TABLE 4: **Model summary of the predictive model 1**

Parametric coefficient	Estimate	Smooth term	edf	Reference
μ_0	-66.73±0.125***	$g^0(f_{ij}, n_{ij})$	84.55***	103.2
α_{20}	-19.97±0.189***	$g^{20}(f_{ij}, n_{ij})$	86.70***	105.7
α_{45}	-19.09±0.189***	$g^{45}(f_{ij},n_{ij})$	85.82***	104.7
β_0	4.62±0.047***			
δ_{20}	7.45±0.071***			
δ_{45}	7.68±0.072***			

TABLE 5: **Comparison of TS values between different studies with diameter/size of transducer beam and ensonified area at the gillnet. Values vary when more than one type of gillnet was used in the measurements. This study uses the incoherent TS from the cod nylon reference net in the frequency range 120 – 140 kHz to be comparable to an ensonification with porpoise clicks as used in the other studies.**

	Mooney et al. (2004)	Kastelein et al. (2000)	Larsen et al. (2007)	Au & Jones (1991)	this study
Diameter/size [m]	0.68	0.52		0.34 by 0.55	1.6
Ensonified area [m²]	0.36	0.87		0.19	2.01
TS [dB] perpendicular	–52	–53 to –61	–53	–42.2 to –60.2	–64.28
TS [dB] small inclination	–60 (20°)			–62 (15°)	–67.65 (20°)
TS [dB] large inclination	–62 (40°)	–54 to –66 (45°)		–60 (45°)	–70.36 (45°)

FIGURES

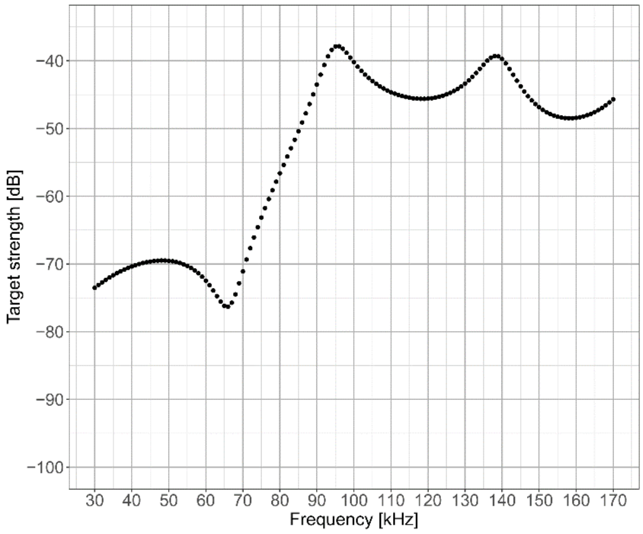


FIGURE 1: **Simulated target strength (TS) of an 8 mm diameter acrylic glass sphere across the frequency range measured in this study**

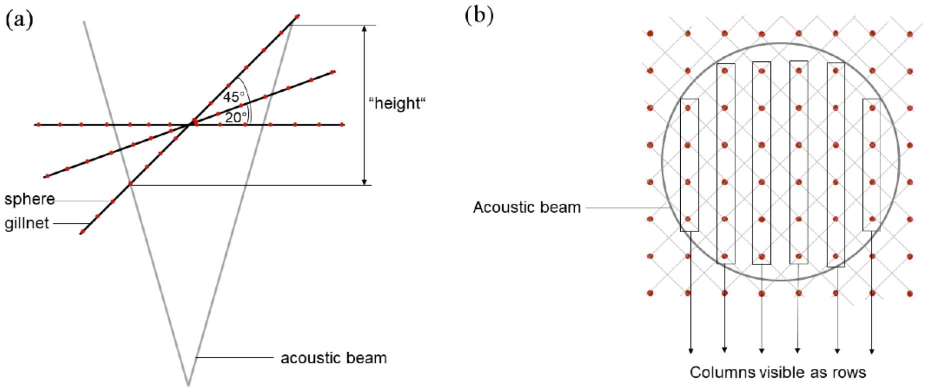


FIGURE 2: **(a) Top view of the experimental set-up from above. Red dots mark the location of sphere columns attached to the gillnet, i.e. underneath each red dot there is a column of spheres mounted at equal distances between the floatline and the leadline. Range between maximum and minimum distance from echosounder is termed "height" as it becomes visible as a "height" in the echogram; (b) front view of the experimental set-up, the columns become visible as rows in the echogram, when the gillnet is ensonified from an angle**

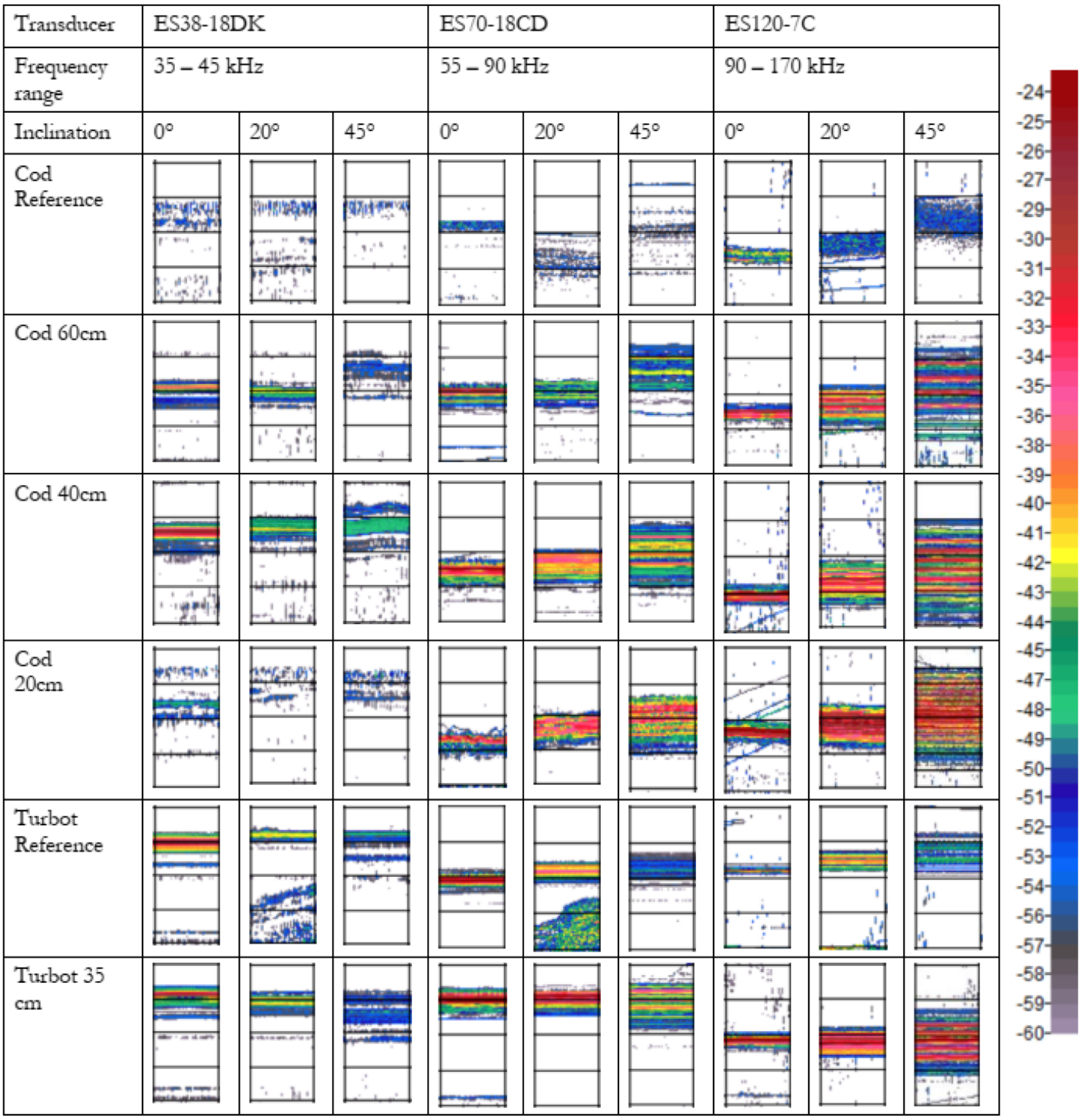


FIGURE 3: Echograms of all measured gillnets at three different angles of incidence from the transducer (pulse-compressed data). Colored scale on the right indicates S_v in dB re 1 m^{-1} at each pixel. Distinct red colored horizontal rows in each panel are the columns of spheres. The x-axis in each panel represents the sequential pings, while the distance from the transducer face is represented in the y-axis. Noise such as fish schools are not removed from the echogram for visualization.

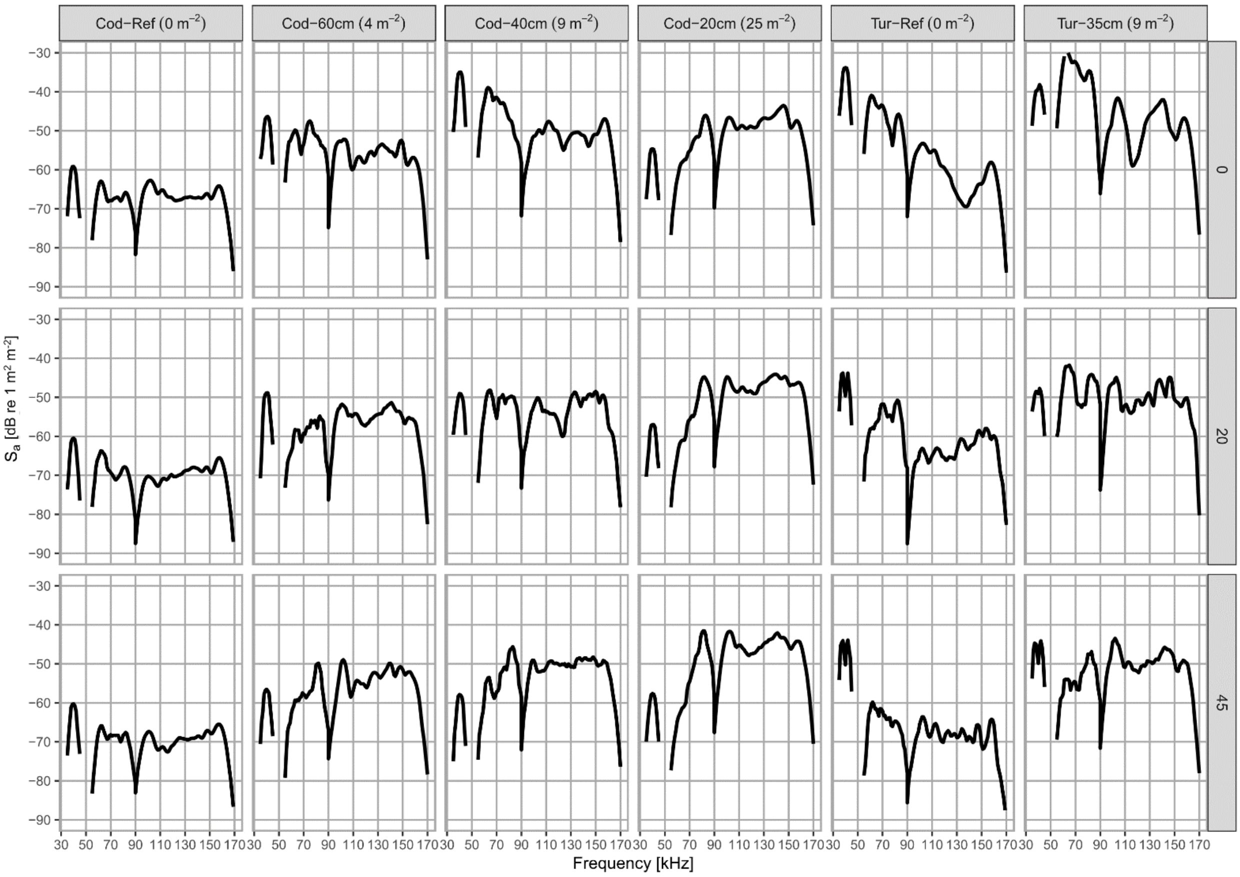


FIGURE 4: **Mean S$_a$ vs incidence frequency for each unique combination of net type and inclination. SD is not shown for clarity, but given in the appendix (FIGURE A. 1). The x-axis indicates incidence frequency, the rows the degrees (0°, 20°, 45°), the columns are the nets; number of sphere/m² provided in brackets. Raw data available in the supplementary material. Data on the edge of the measurable frequencies (55 kHz, 90 kHz and 170 kHz) should be treated with caution and is not used in the further analysis.**

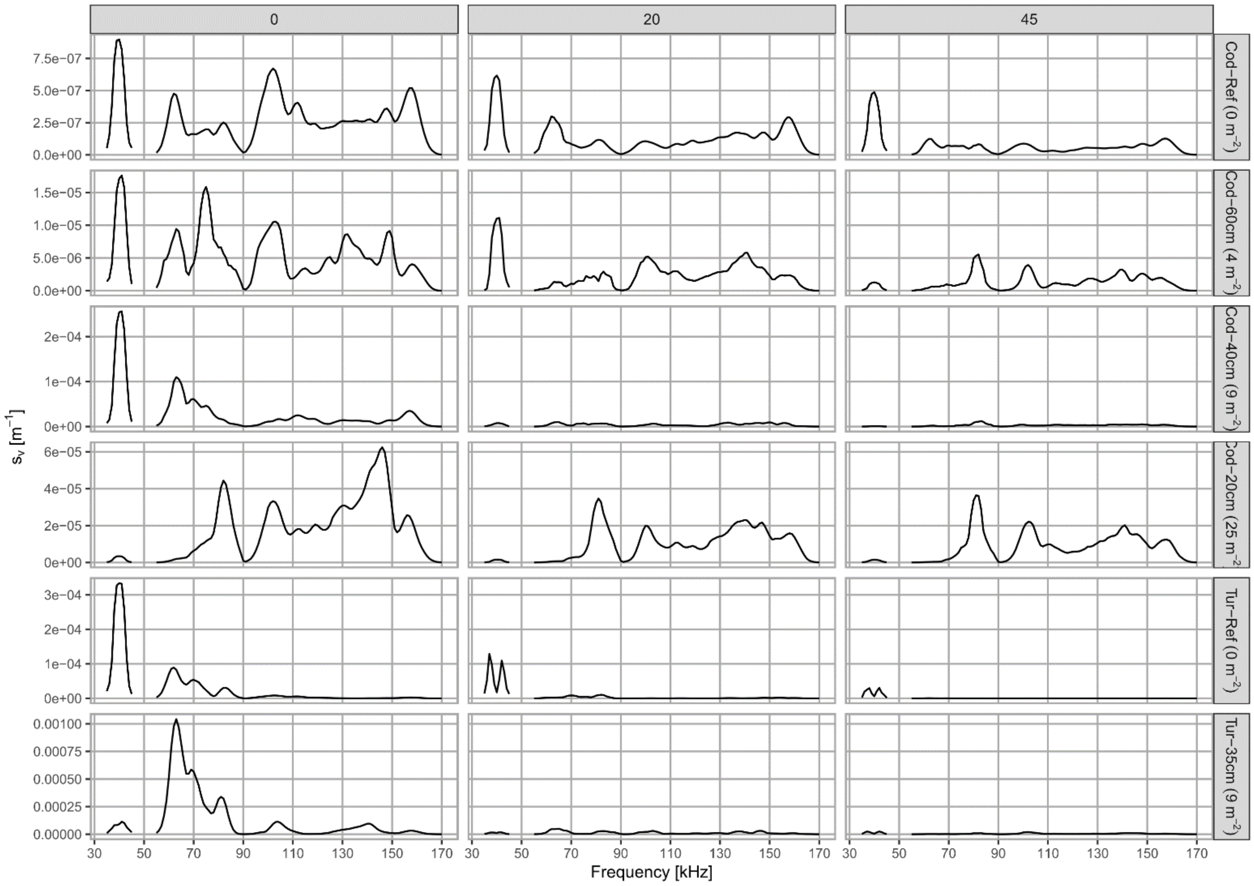


FIGURE 5: **Mean volume backscattering coefficient s_v for each frequency and inclination/net combination. The s_v of each ping were averaged over "height". The x-axis indicates incidence frequency, columns represent inclination (0°, 20°, 45°), and the rows represent the corresponding nets; number of sphere/m² provided in brackets . Note the difference in y-scale for each net (same scale in each net across degrees). Data on the edge of the measurable frequencies (55 kHz, 90 kHz and 170 kHz) should be treated with caution and is not used in the further analysis.**

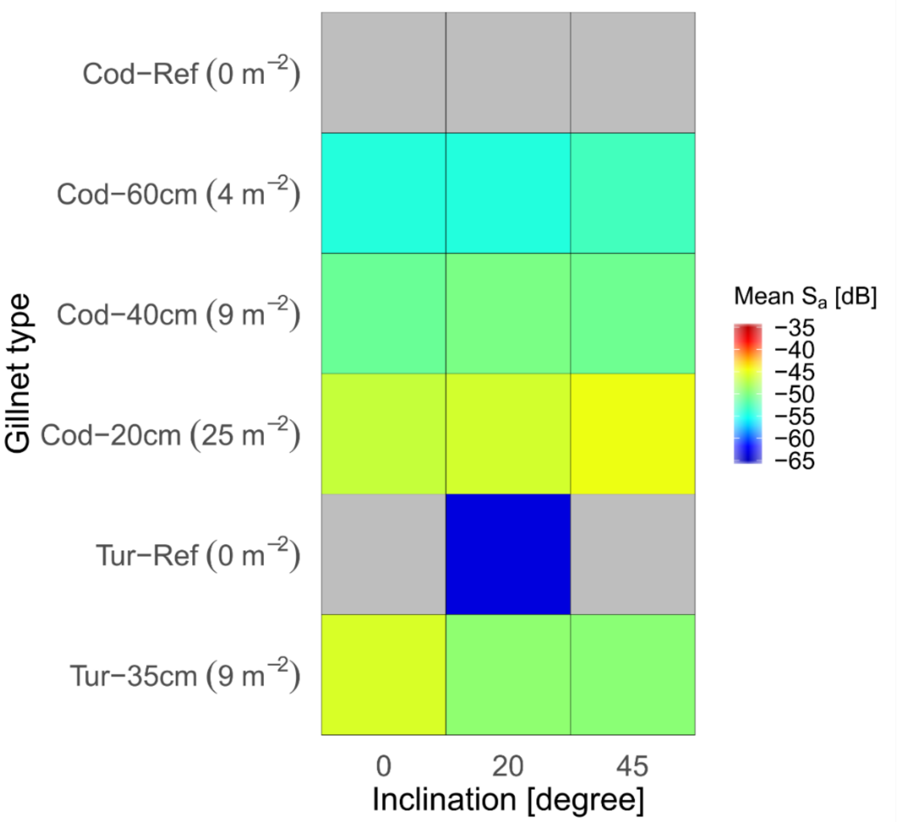


FIGURE 6: Mean Acoustic Backscattering Strength (Sa) at 130 kHz. Grey areas (Tur-Ref and Cod-Ref) represent Sa values below –65 dB. Sa for other frequencies is given in the appendix (FIGURE A. 2). Number of sphere/m² provided in brackets

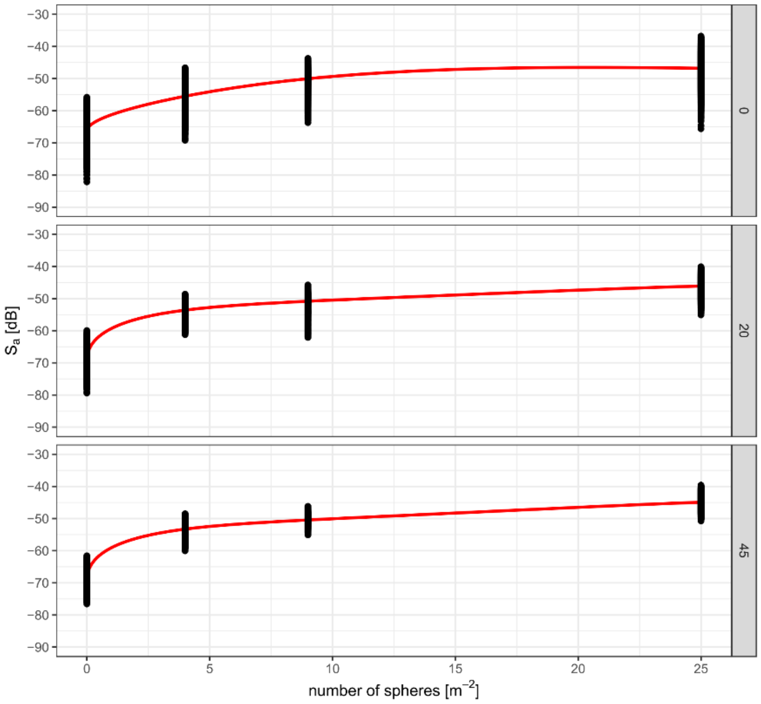


FIGURE 7: Predicted S_a values (solid line) and experimental values (black marks) depending on the number of spheres *n* per m² of netting, exemplarily at 130 kHz

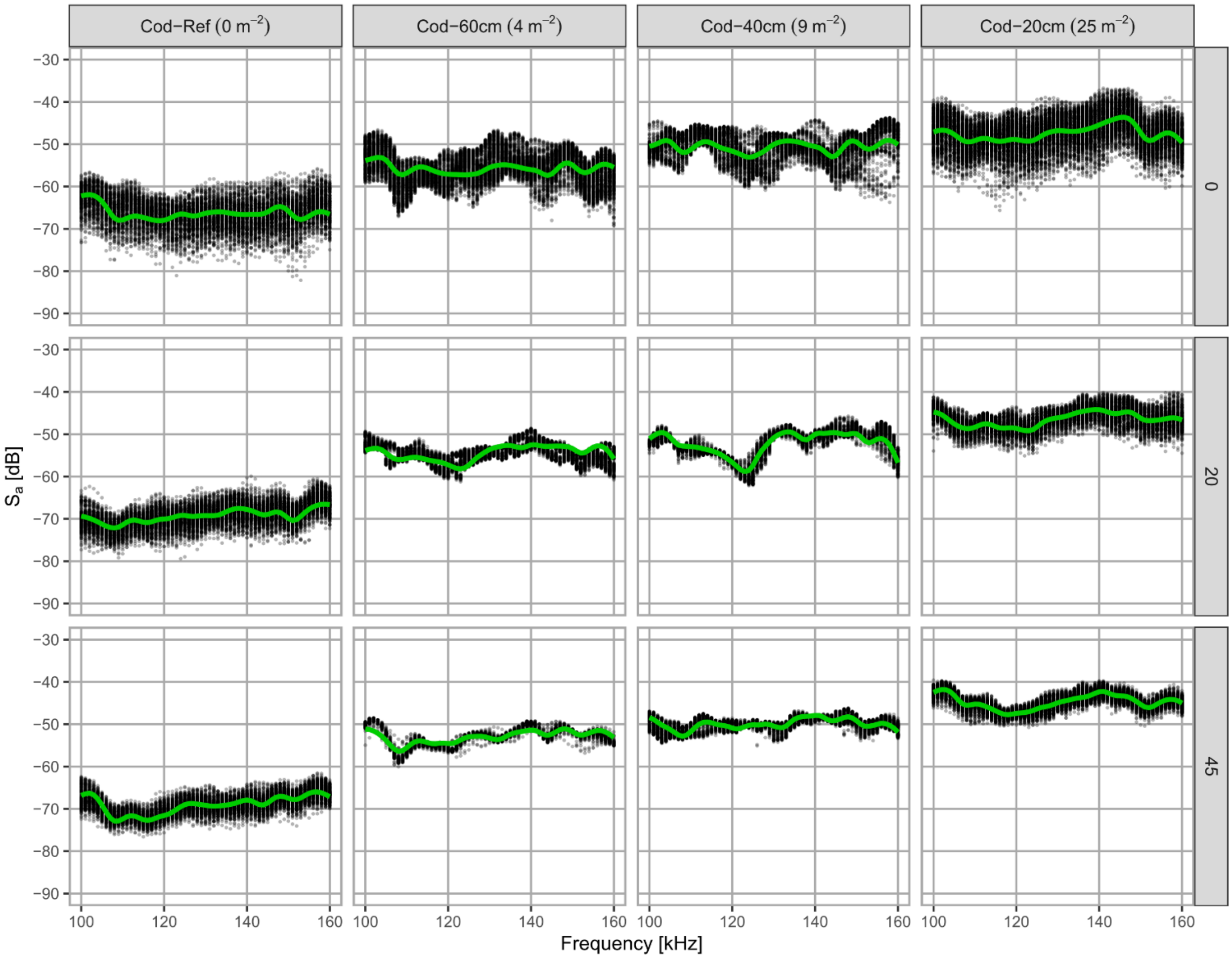


FIGURE 8: **Predicted S_a values (solid line) across frequency range 100 – 160 kHz and experimental data (black marks) for each combination of net/inclination; number of spheres/m² provided in brackets.**

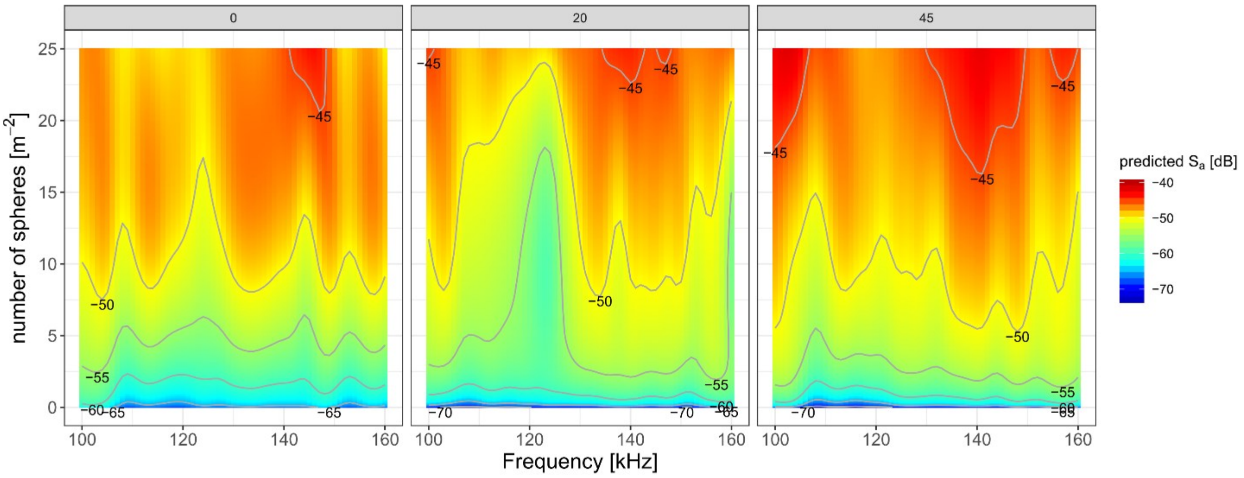


FIGURE 9: **Predicted S_a values (colors) across the frequency range 100 – 160 kHz (x-axis) depending on the number of spheres per m² (y-axis) of cod gillnet for each angle of inclination (0°, 20°, 45°)**

FIGURE 10: **Mean coherent (a) and incoherent (b) TS vs frequency for each unique combination of net type and inclination; number of sphere/m² provided in brackets. SD is not shown for clarity, but given in the appendix (FIGURE A. 4; FIGURE A. 5). Raw data available in the supplementary material. Data on the edge of the measurable frequencies (55 kHz, 90 kHz and 170 kHz) should be treated with caution and is not used in the further analysis.**

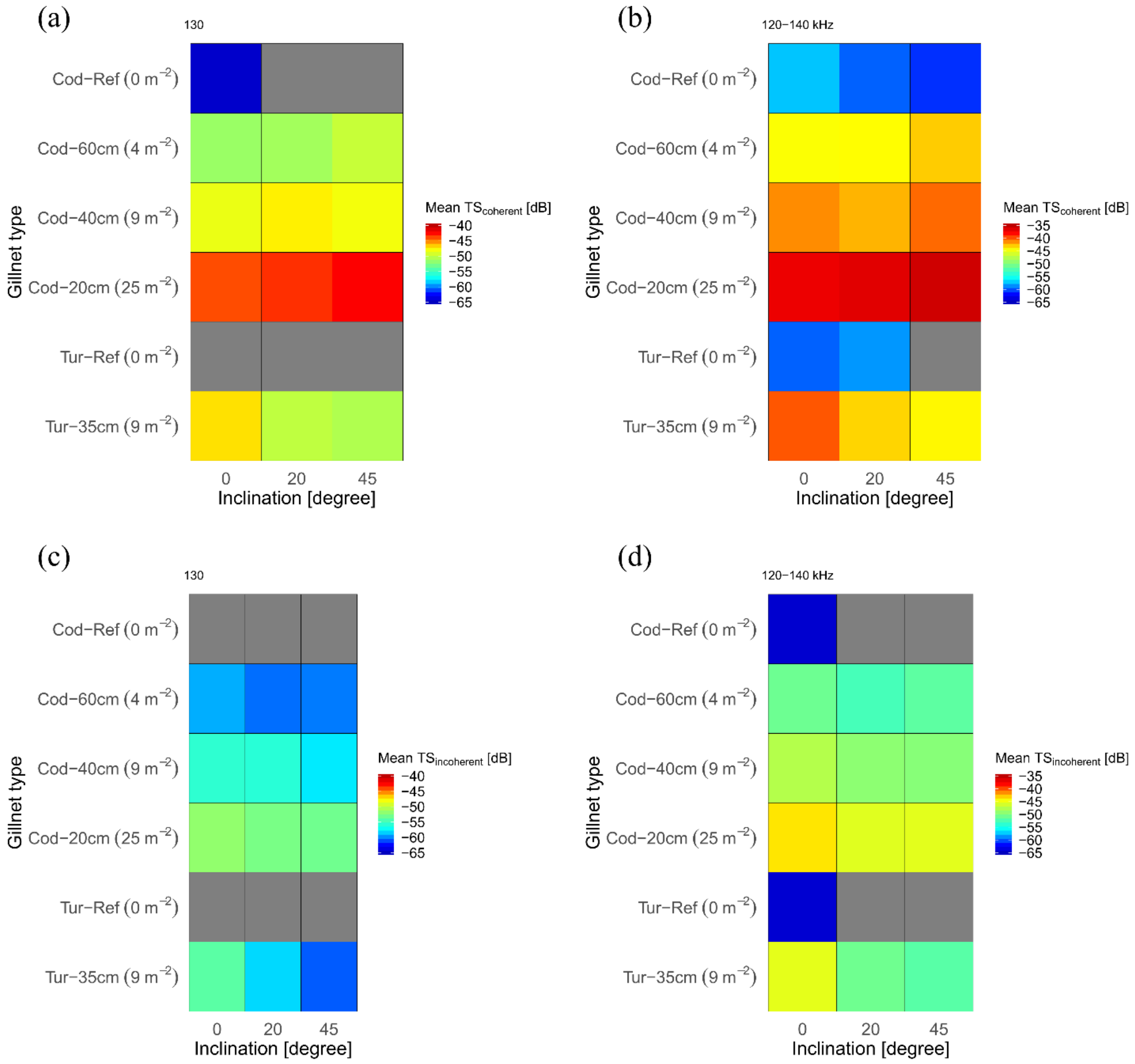


FIGURE 11: **Mean coherent (a, b) and incoherent (c, d) target strength (TS) at 130 kHz (a, c, same color scale) and for a frequency range 120 – 140 kHz (b, d, same color scale). Grey areas (Tur-Ref and Cod-Ref) represent TS values below –65 dB; number of sphere/m² provided in brackets. TS for other frequencies is given in the appendix (FIGURE A. 6; FIGURE A. 7)**

APPENDIX FIGURES

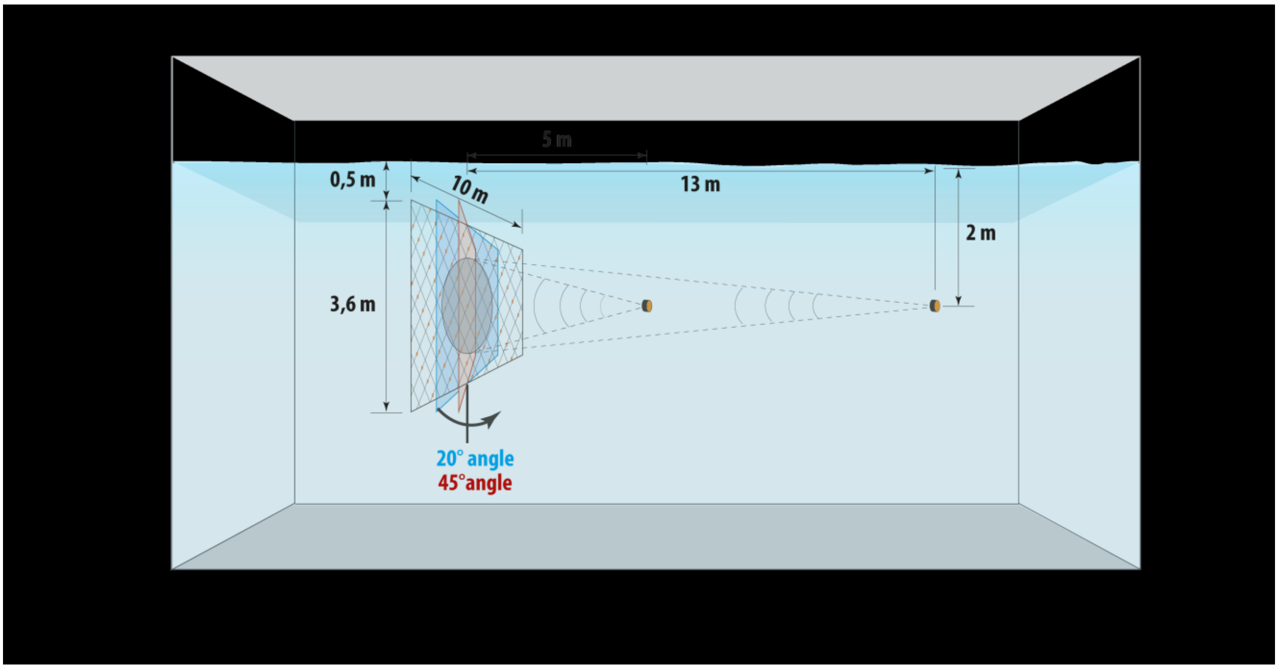


FIGURE A. 1: **Graphic illustration of the experimental set-up.**

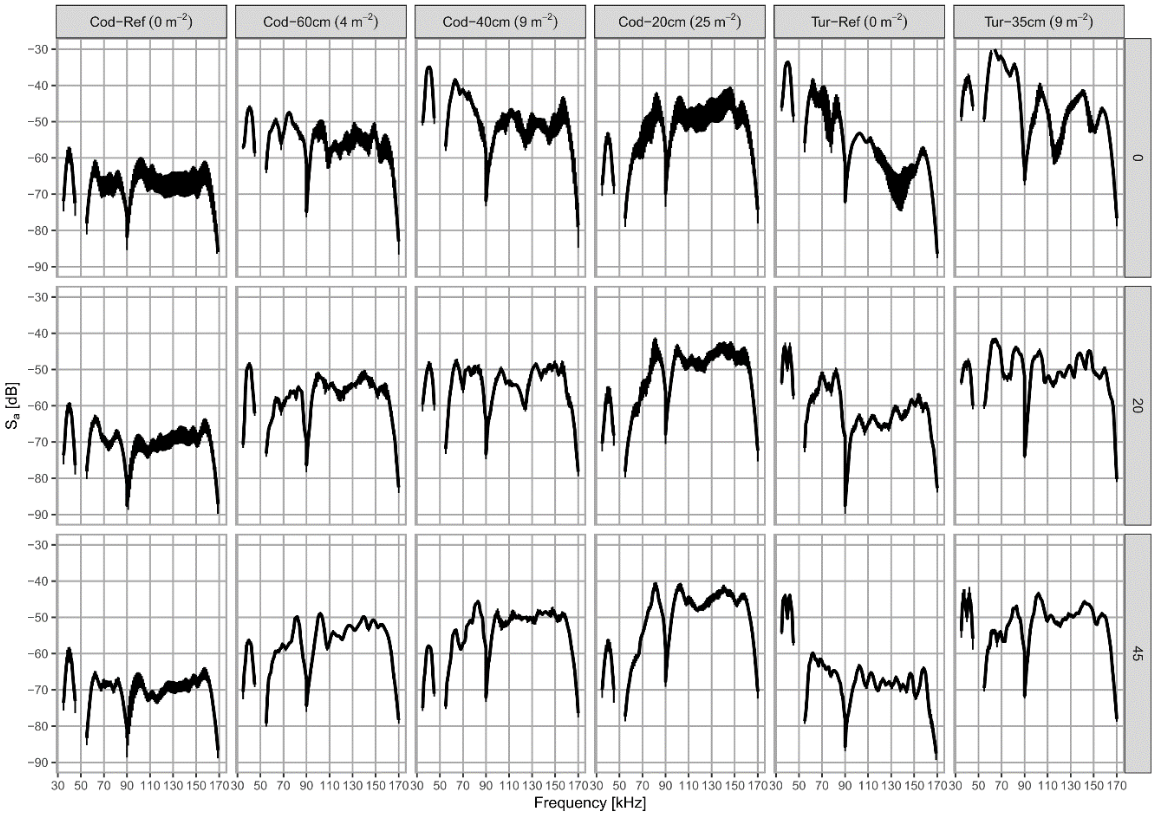


FIGURE A. 2: **Mean S_a vs frequency for each combination of net type and inclination, including SD; number of sphere/m² provided in brackets**

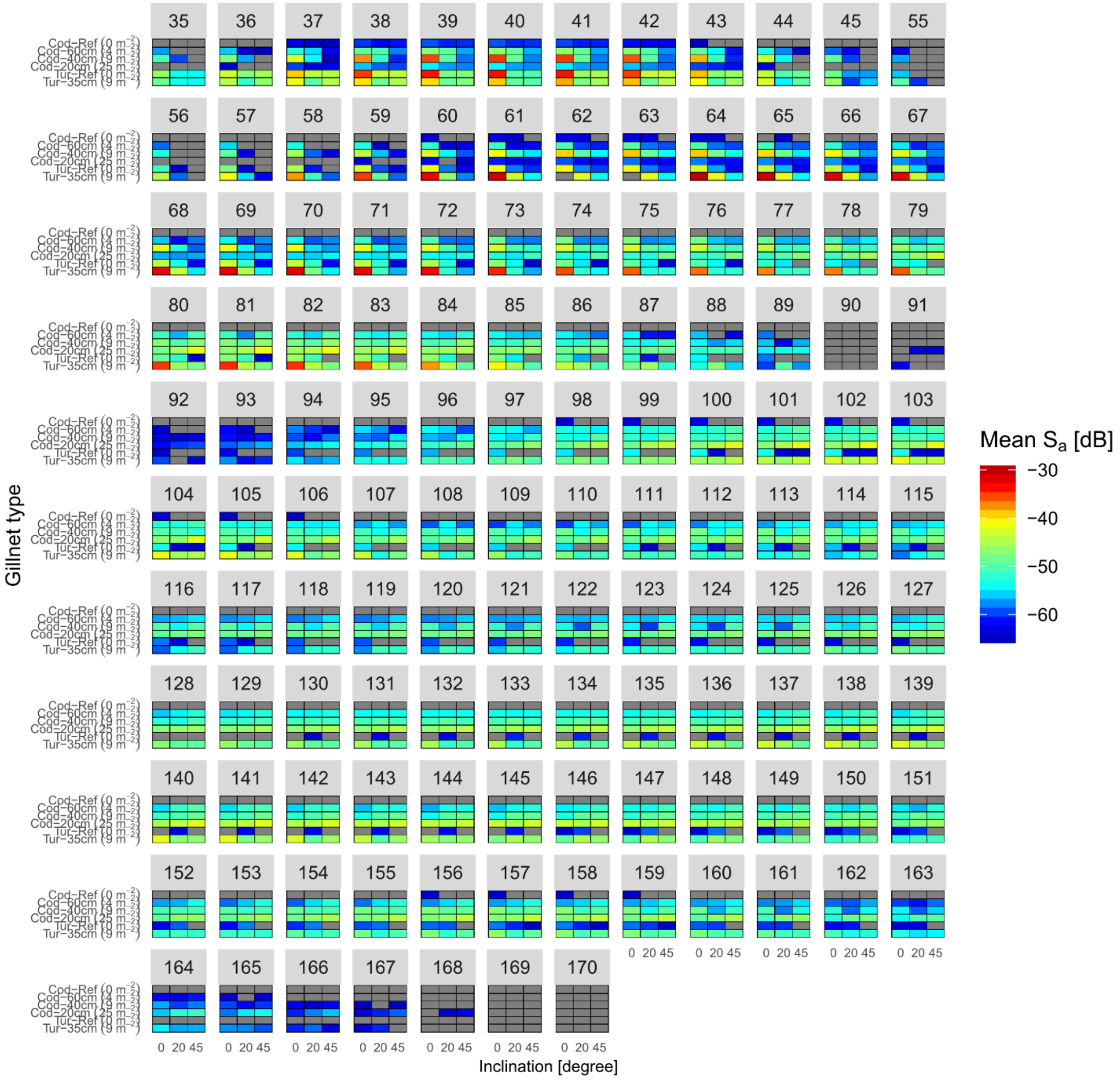


FIGURE A. 3: **Mean S_a for all frequencies according to net and inclination; number of sphere/m² provided in brackets**

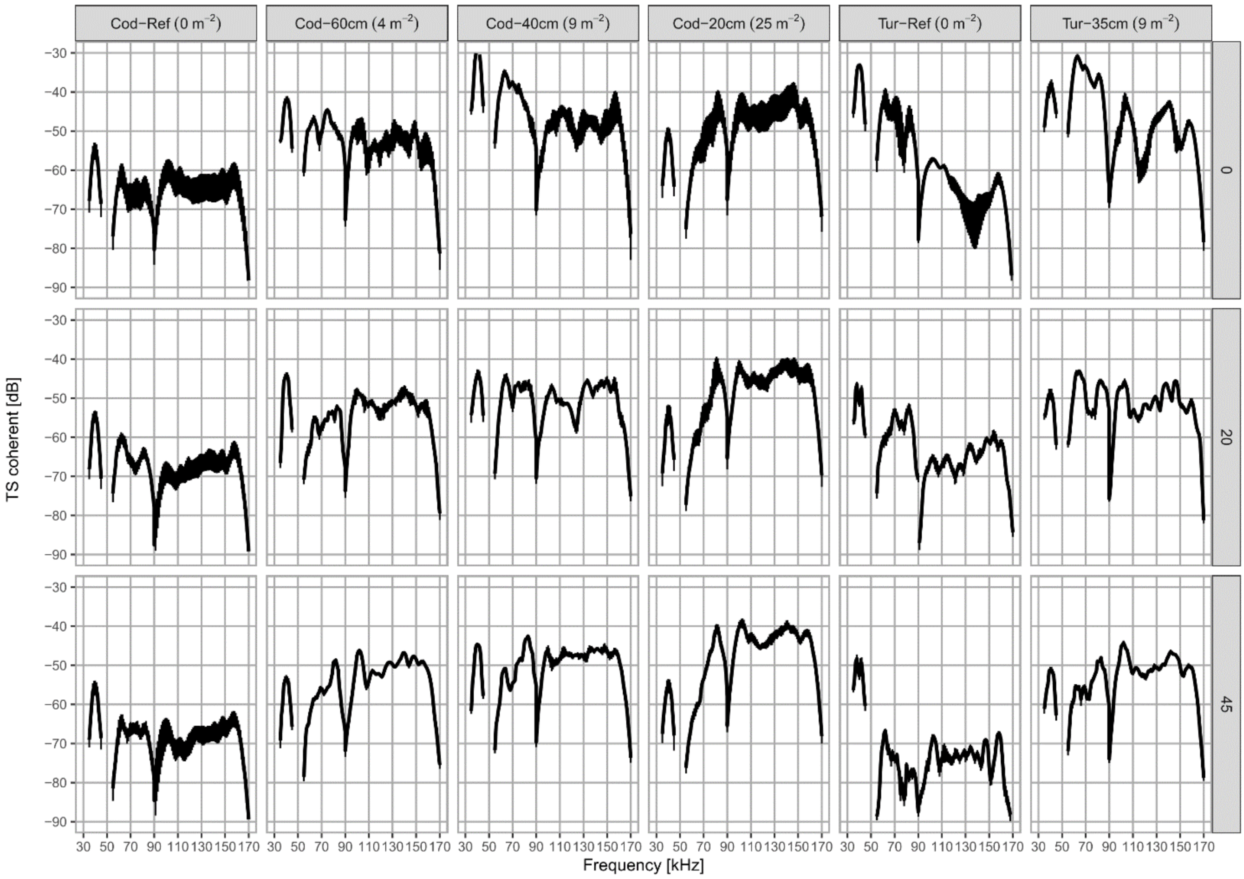


FIGURE A. 4: Mean coherent TS vs frequency for each combination of net type and inclination, including SD; number of sphere/m² provided in brackets

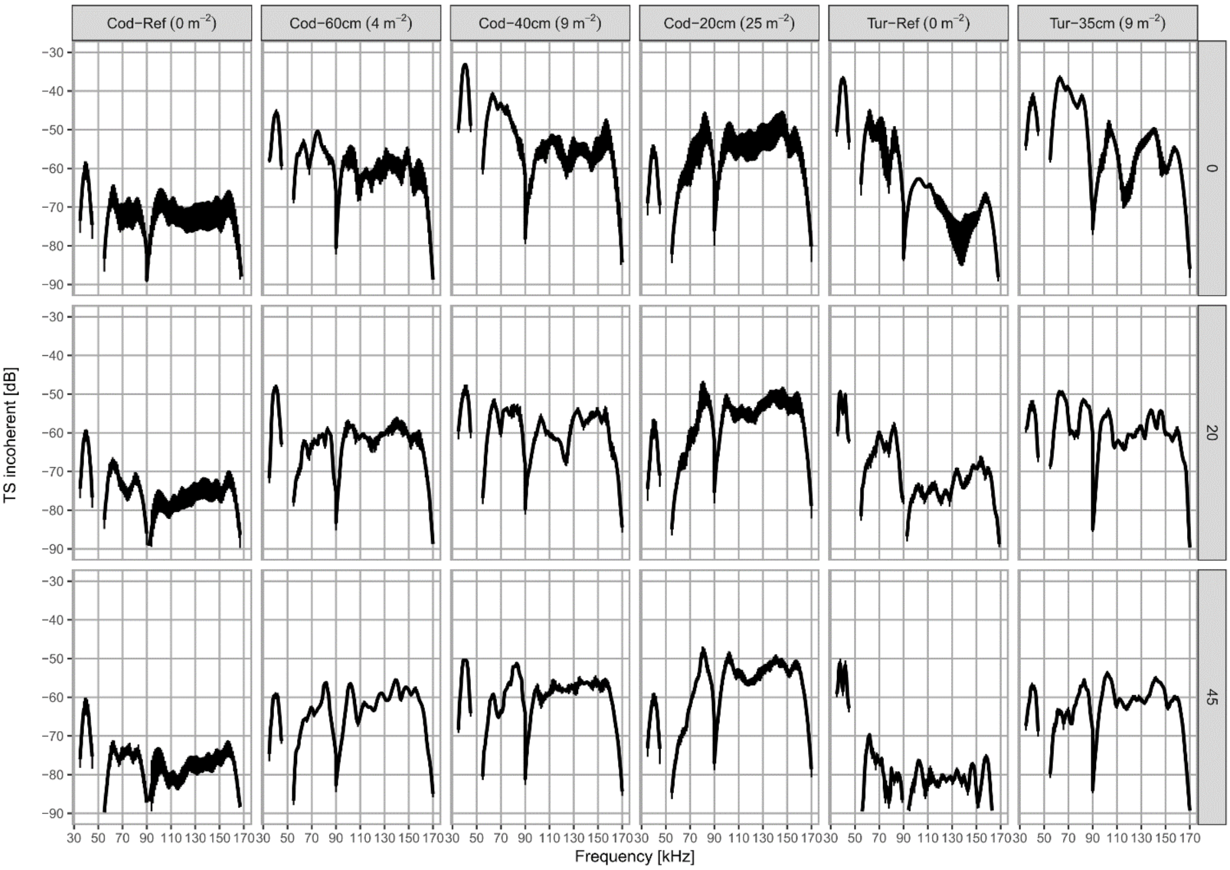


FIGURE A. 5: Mean incoherent TS vs frequency for each combination of net type and inclination, including SD; number of sphere/m² provided in brackets

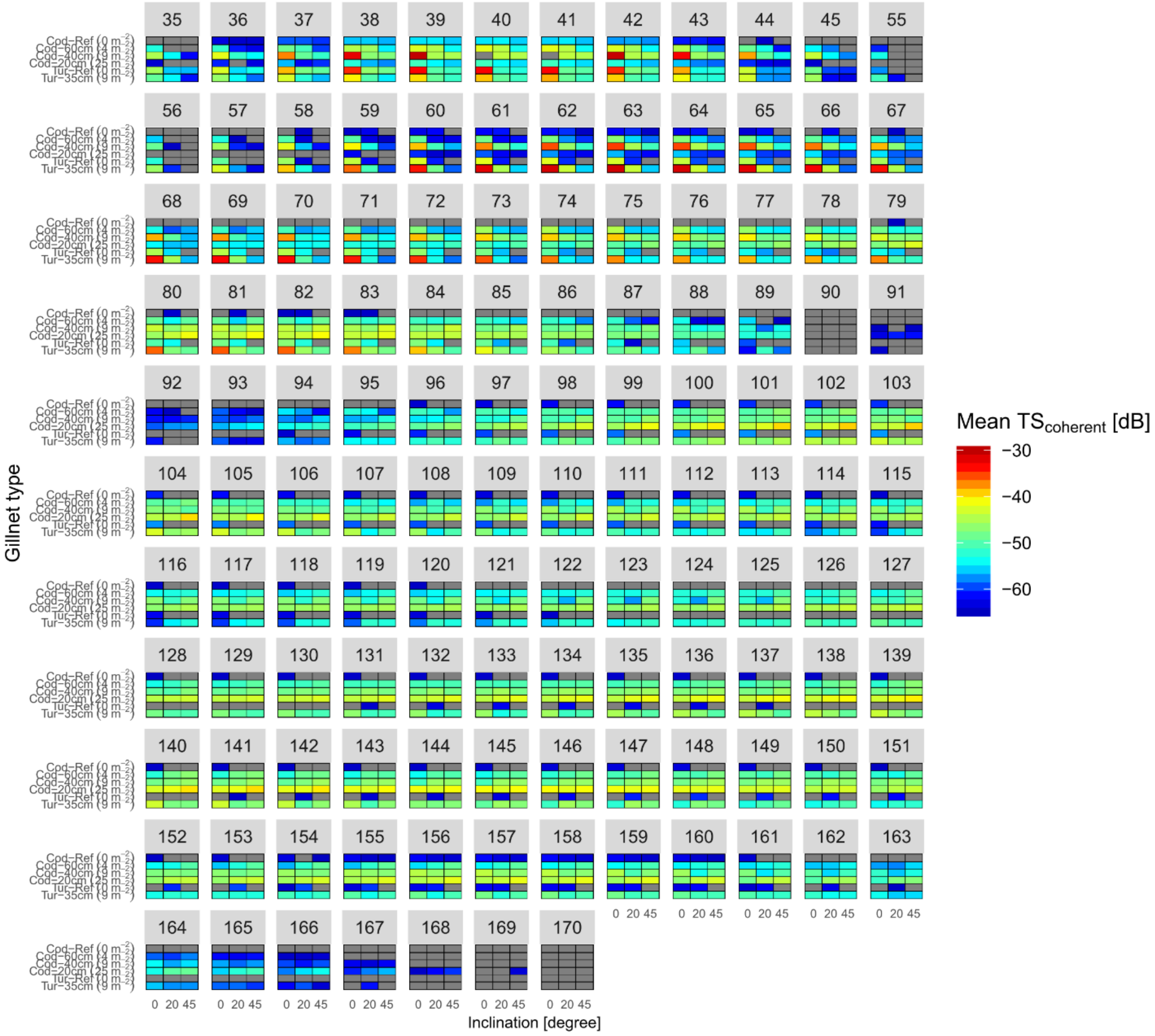


FIGURE A. 6: **Mean coherent TS for all frequencies according to net and inclination; number of sphere/m² provided in brackets**

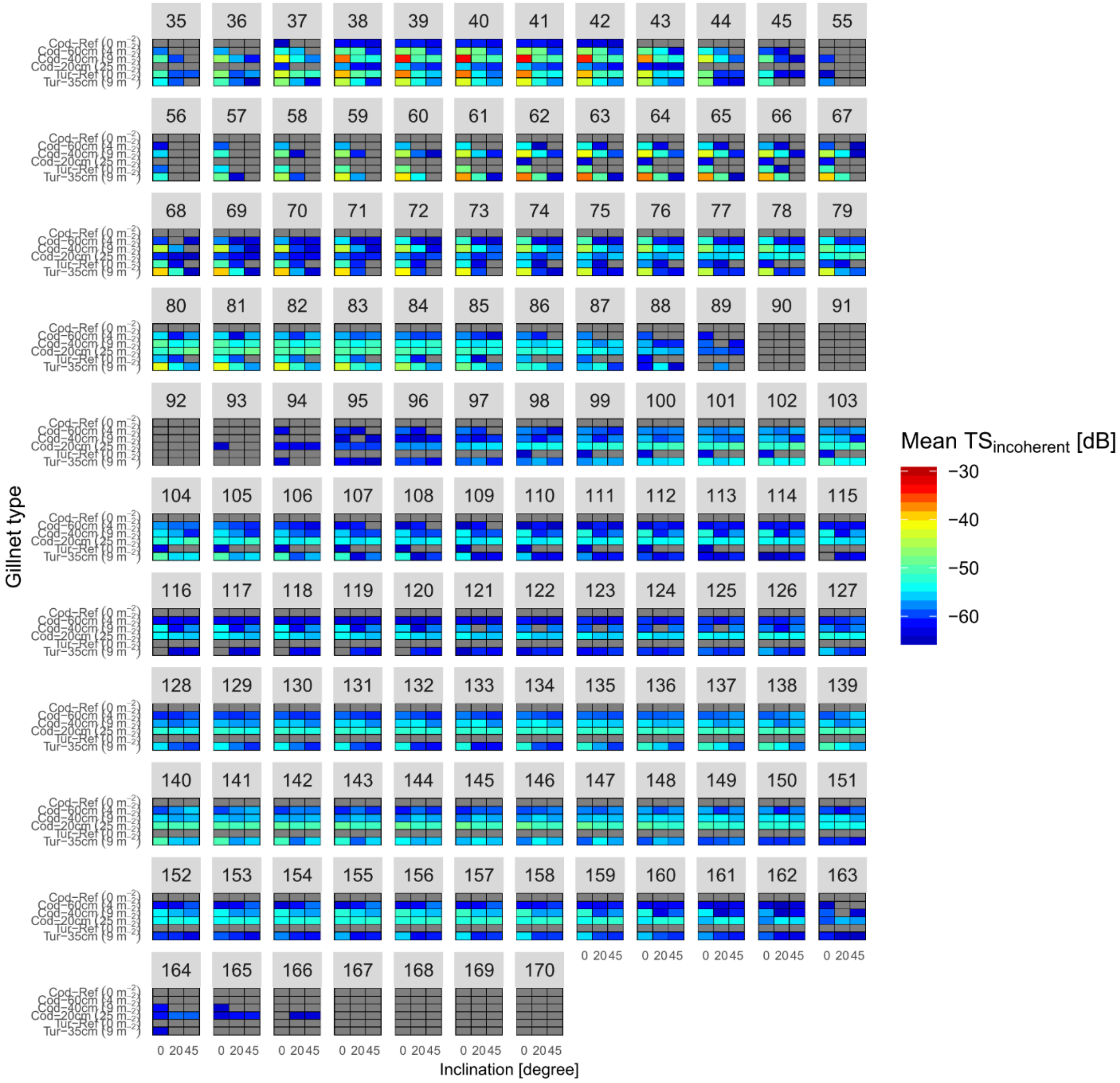


FIGURE A. 7: **Mean incoherent TS for all frequencies according to net and inclination; number of sphere/m² provided in brackets**

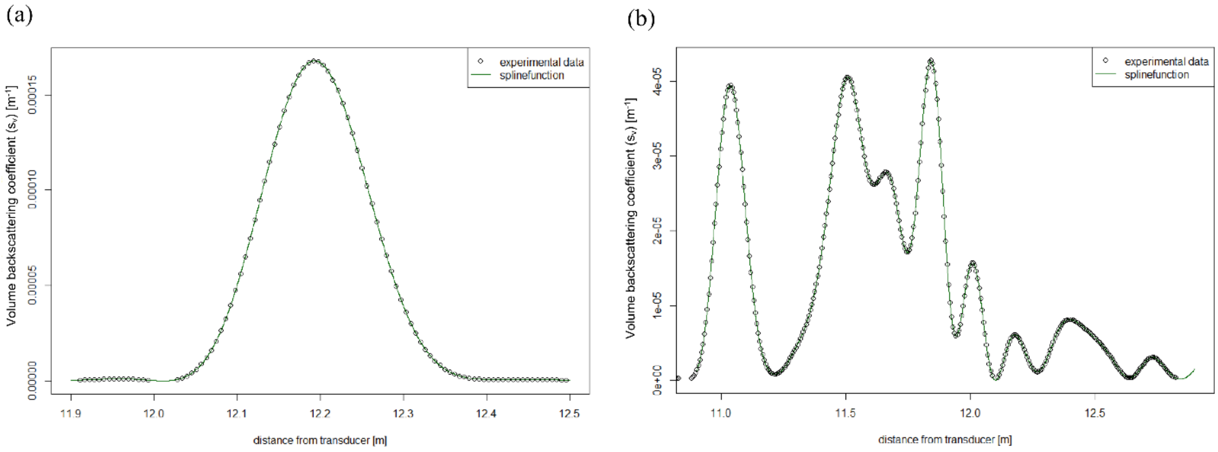


FIGURE A. 8: **Measured volume backscattering coefficient s_v across distance from echosounder for one ping exemplarily and corresponding spline function. Data is shown for Cod-20cm net at 0° (a) and 45° (b)**

Arbeitspaket 2 – Veröffentlichung 3 “Using acoustically visible gillnets to reduce bycatch of a small cetacean: first pilot trials in a commercial fishery.”

Kratzer, I.M.F., Brooks, M.E., Bilgin, S., Özdemir, S., Kindt-Larsen, L., Larsen, F., Stepputtis, D. 2021. Using acoustically visible gillnets to reduce bycatch of a small cetacean: first pilot trials in a commercial fishery. Fisheries Research 243: 106088, doi:10.1016/j.fishres.2021.106088

Vollständige Veröffentlichung (Pre-print Proof)

Abstract

Bycatch of protected species, particularly small cetaceans, in gillnets is a worldwide concern. One hypothesis for this is that echolocating cetaceans entangle because they do not perceive conventional gillnets as impenetrable barriers, owing to the gillnet’s faint echo. A gillnet modified for improved acoustical visibility was tested in a first pilot trial in a commercial gillnet fishery targeting turbot (*Scophthalmus maeoticus*) on the Turkish Black Sea coast. This study is the first demonstration of the viability of using a gillnet equipped with small acrylic glass spheres to reduce bycatch of harbor porpoises in a commercial fishery and provides the basis for full-scale sea trials of the gear in commercial fisheries through a power analysis. In these pilot experiments, the focus lied on the handling of the gear and identification of requirements for a full-scale trial, but results include promising bycatch data for an endangered echolocating marine mammal (*Phocoena phocoena*) and no reduction in catch efficiency of a bottom-dwelling, vulnerable species (*Raja clavata*).

1. Introduction

Harbor porpoises (*Phocoena phocoena* L., 1758) are small, toothed whales that inhabit temperate and Subarctic coastal waters of the Northern hemisphere (Bjørge and Tolley, 2009), including the Black Sea (Notarbartolo di Sciara and Birkun, 2010, subspecies *P. phocoena relicta* Abel, 1905) and Mediterranean Sea (Cucknell et al., 2016). Bycatch mortality in gillnet fisheries (Reeves et al., 2013) is a global threat to cetaceans, including harbor porpoises. Although some populations are stable in size (Hammond et al., 2013), others, such as the Black Sea population, are classified as endangered (Birkun and Frantzis, 2008), with the current population at only 10% of its original size (Fontaine et al., 2012).

The use of acoustic deterrent devices, i.e., pingers, is one way to reduce bycatch in gillnets. In previous trials, pingers have been used successfully to reduce bycatch of harbor porpoises (Dawson et al., 2013; Gönener and Bilgin, 2009; Kraus et al., 1997; Larsen et al., 2013). Pingers emit loud noise to scare porpoises away from a hazard, but they have several drawbacks, e.g., potential habituation (Cox et al., 2001), potential exclusion from habitats (Carlström et al., 2009), potentially higher bycatch rates than for sets without pingers if a subset of pingers fails (Palka et al., 2008), and a potential “dinner-bell” effect on other species such as sea lions that cause depredation (Bordino et al., 2002).

It has been hypothesized that porpoises are unable to perceive the gillnets as obstacles and therefore get entangled (Goodson, 1997). Although some studies have predicted that harbor porpoises should be able to detect gillnet netting from a short distance, i.e. 5 m or less, depending on the angle of incidence, (Kastelein et al., 2000; Mooney et al., 2004), a recent study suggests that porpoises also react to a gillnet from a long distance, i.e. 80 m (Nielsen et al., 2012). Nielsen et al. (2012) used common commercial gillnets, showing that porpoises may have detected highly visible parts of the gillnet, such as the floatline, which is highly acoustically visible. Previous research has demonstrated that some species of toothed whales (odontocetes) exhibit avoidance behavior to objects that have an echo similar to a floatline. These behaviors include swimming around the object (Goodson and Mayo, 1995; Norris and Dohl, 1980; Perrin and Hunter, 1972; Silber et al., 1994) and diving underneath it (R. A. Kastelein et al., 1995; Silber et al., 1994). This points to the possibility of “filling in” the gap between floatline and leadline, rendering the entire netting area highly visible. Either the porpoise could be “guided” along the gillnet until the end in order to swim around, or it would more easily perceive the gillnet as an obstacle between the floatline and the seabed. In either case, improved acoustic detectability of the netting area could be key to avoiding collision and effectively reduce bycatch mortality without significantly decreasing the gillnet’s catch efficiency.

In the past, the gillnet’s echo has been increased by adding high-density fillers to the filament of standard gillnets, thus increasing the twine’s density. Related field experiments with netting that was supposedly acoustically enhanced have reduced catches of target species (Larsen et al., 2007) or have had no effect on bycatch rates of certain cetacean species (Bordino et al., 2013). Only one study demonstrated both reduced harbor porpoise bycatch and stable catches of target species (Trippel et al., 2003). Because subsequent comparisons of the echo strength of standard gillnets and modified gillnets revealed no substantial increase in acoustic detectability, it was hypothesized that increased stiffness was partially responsible for a reduction in the catch of target species and bycatch of harbor porpoises (Larsen et al., 2007; Trippel et al., 2009). The effect of adding high-density fillers to the filament and thereby increasing the acoustic reflectivity was also explored in a simulation study (Kratzer et al., 2020). The simulation study showed that increasing the density of the filament has little to no effect on the target strength, as the diameter of the filament is the limiting factor for an increase in acoustic reflectivity; thus, using fillers will most likely not result in increased acoustic detectability.

An alternative approach to the use of high-density fillers is the use of passive reflectors attached to the gillnet to increase the netting’s acoustic detectability. The goal is to alter the acoustic image recognized by the porpoise so that the netting is perceived as an impenetrable object. To develop an acoustically visible, yet catch-efficient gillnet, Kratzer et al. (2020), through simulations and subsequent experimental assessment, systematically identified small, almost neutrally buoyant objects that have a strong echo. The ideal reflector shape is spherical, because it has the same echo properties regardless of the animal’s angle of approach. The optimal reflector for harbor porpoises is an 8 mm wide acrylic glass sphere. This reflector, owing to its mechanical properties and size, resonates at 130 kHz, the echolocation frequency of harbor porpoises. Thus, the detectability of gillnets when acrylic glass spheres are attached to the gillnets is substantially increased regarding both an increase in target strength as well as an alteration of the acoustic image of the gillnet (Kratzer et al., 2020). Specifically, the target strength of a single 8 mm acrylic glass sphere is -43 dB (Kratzer et al., 2020), while filaments typically used in gillnet fisheries, e.g. nylon or cotton as a proxy for natural fibers, have a target strength of less than -50 dB (Au and Jones, 1991; Kratzer et al., 2020; Mooney et al., 2004). This means that the intercepted acoustic energy is fivefold when comparing a standard gillnet to a single acrylic sphere. Acrylic glass is a widely available transparent thermoplastic. As the objects are neutrally buoyant, there should be minimal effects on the hydrodynamic behavior of the gillnet and thus minimal effect on the catch of target species or other bottom-dwelling wanted and unwanted bycatch species.

In this pilot project, the viability of using such a modified gillnet in a commercial fishery was explored and the efficacy of the passive reflector in reducing the bycatch of harbor porpoises was assessed. We conducted the first systematic catch comparison trials using gillnets modified with acrylic glass spheres in a commercial fishery targeting turbot (*Scophthalmus maeoticus* Pallas, 1814) on the Turkish coast of the Black Sea. This area was selected because previous trials have revealed seasonally high bycatch rates of harbor porpoises in commercial fisheries (Gönener and Bilgin, 2009). This study forms the baseline for future investigations of the use of the newly developed gear by providing first insight into the efficacy of the modification to reduce bycatch, the necessary experimental protocol, an assessment of the needed extent of a full-scale trial as well as effects on the practical handling of the gear.

2. Materials and methods

2.1 Study area and sampling protocol

The study was conducted in the central Black Sea around the Sinop peninsula, Turkey (Fig. 1), using a local gillnet vessel (overall length 14 m). Ten paired hauls were carried out between September and December 2019. During each of the ten trips one set of standard gillnets and one set of gillnets modified by attaching 8 mm acrylic glass spheres to the netting (see details below) was used. All hauls were accompanied by two or more local scientists and the vessel crew. The protocol comprised start and end time of setting and hauling the gillnet, start and end coordinate of the gillnets, number of all animals caught, length and sex determination of elasmobranchs and harbor porpoises, and disc width of thornback rays (*Raja clavata*, L. 1758). Additionally, an electronic monitoring system, consisting of one camera powered by a solar panel, was provided by *shellcatch, inc.* (*Shellcatch VirtualObserver platform*, 2020) mounted to overlook the gillnet hauler and the area on deck where the catch is disentangled from the gillnet. The system was programmed to take an image every second when the vessel was at sea together with time (hh:mm:ss) and GPS position. The videos were analyzed using the *shellcatch* online tool (*Shellcatch VirtualObserver platform*, 2020) to evaluate the handling time of the two gillnet types and verify the reported catch data. All hauls were conducted in pairs, i.e., the gillnets were set and hauled one right after the other at a distance of approximately 500 m to avoid any influence of the modified gear on the standard gear.

2.2 Description of fishing gear

Each gillnet consisted of five individual net panels strung together and resulting in a total rigged length for each gillnet of 2160 m, a stretched mesh size of 400 mm, and a height of approximately 2.5 m (5.5 meshes). The netting material was a multifilament (PA) natural orange-colored fiber with R227tex, as required by Turkish fishing regulations. The gillnet was raised by floats in the headline with a positive buoyancy of 70 N and the sinks, attached to the leadline, had a negative buoyancy of 70 N. Floats and sinks were both mounted on a 6 mm PP rope. Fig. 2 shows a schematic drawing of the gillnets. The standard and modified gillnets were constructed identically. To the modified gillnet, 8 mm acrylic glass spheres were attached at a sphere-to-sphere interval of 350 mm horizontally and 370 mm vertically. In a previous trial, Nakamura et al. (1998) determined that a minimum spacing of 0.7 m by 0.5 m between objects would decrease, although not entirely eliminate, the chance of a porpoise attempting to swim through the objects compared with larger intervals. Therefore, we chose to reduce the interval further. As this was the first trial with a gillnet modified using acrylic glass spheres, the spheres were mounted by hand. To attach the spheres, they were cut to the half with a laser and subsequently glued to the netting using acrylic glass adhesive (*ACRIFIX 1R 0192*). Acrylic glass adhesive has, when dried, the same acoustic properties as acrylic glass, rendering the sphere “solid” again. In a previous study, a gillnet was equipped in the same manner with acrylic glass spheres, at a similar distance (300 mm both horizontally and vertically), rendering the modified gillnet highly acoustically visible, compared to a standard gillnet with the same properties (Kratzer et al., 2020). Furthermore, even if the gap is not filled entirely, simulations showed that a drop in echo only occurs at certain angles of ensonification. Since the spheres are oriented randomly on the gillnet, these effects should be compensated (Kratzer et al., 2020).

2.3 Statistical analysis

Because all species were caught in very small numbers, only the endangered species harbor porpoise and vulnerable thornback ray, which also serve as a proxy for bottom-dwelling species, were considered for in-depth analysis. The bycatch models are described below.

2.3.1 Bycatch models

We used generalized linear mixed models (GLMMs) to describe the relationship between bycatch rate and gear separately for each species. Number of animals (*N*) per trip was estimated as the response in a GLMM with a fixed effect of gear and a normally distributed random intercept for each trip, as each trip corresponds to one haul with one standard and one modified gillnet. For porpoises, a Poisson distribution was used for hypothesis testing, and thornback rays were modeled using a negative binomial distribution; both had log links. No additional terms were included to control for spatial effects or soaktime, because the animal counts did not appear to depend on these factors, based on visual inspection of the graphs. Furthermore, as the data set was so small it is unadvisable to include more terms in the model if they are not expected to explain a pattern. As a rule of thumb, ten informative observations are needed for each parameter to be estimated (Harrell , 2015). GLMMs were fit using the glmmTMB package (Brooks et al., 2017) in the statistical software R Version 3.6.1 (R Core Team, 2019). Tests to check for zero-inflation and to determine whether the choice of distribution was adequate were carried out using the DHARMa package (Hartig, 2020) by comparing the observed variance and zeros with simulated variance and zeros. The observed values were well within the range of the simulated data. Significance of the gear effect was tested by likelihood ratio tests (LRTs) to compare the full GLMMs with corresponding GLMMs without a gear effect.

2.3.2 Size of effect and power analysis for future trials

The effect size of acrylic glass spheres on bycatch reduction of harbor porpoises was determined from both the raw data and the bycatch models. From the raw data (number *N* of animals caught) the change in bycatch was determined using Equation 1.

$$Bycatch\ change\ [\%] = \frac{N_{modified} - N_{standard}}{N_{standard}} * 100 \qquad \text{Equation 1}$$

We determined the effect size of the gear modification from the bycatch model using the emmeans package (Lenth, 2019) to calculate estimated marginal means (EMMs) from the negative binomial GLMM with the random effect of trip and fixed effect of gear.

Regarding potential future experiments, we conducted a power analysis to determine how many trips with one set of each gillnet type would be necessary to detect a significant difference in the bycatch of porpoises in the two gear types, assuming the same bycatch rate as in these trials. We modeled the potential outcomes if more trips were conducted using a GLMM with the fixed effect of gear and the random effect of trip. We used a negative binomial distribution to account for potential overdispersion, although overdispersion was not indicated by DHARMa residual tests. Johnson et al. (2015) recommends accounting for overdispersion, which will lead to more pessimistic predictions for the necessary number of trips. We used the negative binomial GLMM and the simulate() function in glmmTMB to simulate new datasets, each with the same dimension as the original, with random trip effects simulated from their estimated normal distribution. To create a dataset with 240 trips, we combined 24 simulated datasets, each containing 10 trips, with appropriately relabeled trip identifiers. To create smaller datasets with 10 to 240 trips, we randomly selected (without replacement) a subset of the trips. For each dataset, we fit GLMMs with gear as fixed effect, trip as random effect, and a negative binomial distribution with a log link; then performed an LRT with a GLMM without the gear effect. We repeated this process 3000 times and recorded the proportion of times that an LRT was significant. Any model that failed to converge was considered a non-significant test result.

2.3.3 Handling time and effect on size of entangled thornback rays

The viability of using the acoustically visible gillnets in a commercial setting was the focus of the study, thus it is essential to investigate handling of the gear. The handling time between the two gillnet types were compared as we determined the time required to disentangle individual thornback rays as a proxy. Because handling times were non-normally distributed (Shapiro-Wilk Test: p=0.03 and p=0.001 for standard and modified gear respectively), the Mann–Whitney U Test was used to compare handling times between gillnet types. Thornback rays also served as a model species to determine potential influences of the acrylic glass spheres on the hydrodynamic behavior of the gillnet, resulting in different mesh openings and changes in the mechanical catch process, which could lead to a difference in bycatch composition and size. Therefore, a linear model was used to describe the relationship between total length (TL) and disc width (DW) of thornback rays for all individuals as well as for males and females separately (Demirhan et al., 2005; Krstulović Šifner et al., 2009).

3. Results

3.1 Catch composition

The most abundant fish species in the catch was thornback ray (89 %, 195 individuals); only four specimens of the target species turbot were caught. Common stringray (*Dasyatis pastinaca*, L. 1758), spiny dogfish (*Squalus acanthias*, L. 1758), and whiting (*Merlangius merlangus*, L. 1758) occurred only in small numbers. In all, seven harbor porpoises and one loon (family Gaviidae) were caught as bycatch. The number of animals was independent of the soaktime (Fig. 3a), depth (Fig. 3b) and location (Fig. 3c) regardless of species. Table A 1 in the appendix provides details on soaktime and number of individuals per gear and trip.

3.2 Harbor porpoise bycatch

Five harbor porpoises were taken as bycatch in the standard gillnet and two in the modified gillnet (Fig. 4). Five porpoises were male, one was female, and the sex of one was unknown because it dropped out of the gillnet before being hauled on board. The overall observed mean catch per haul of porpoises per gear was 0.5 (standard gear) vs. 0.2 (modified gear). There was no clearly discernible entanglement pattern, i.e. porpoises were caught close to the floatline, leadline and in the mid part of the netting.

The Poisson GLMM revealed no significant difference in harbor porpoise bycatch between the gears (p-value = 0.25). As this study was conducted as a pilot trial and served as an initial estimation of expected bycatch rates, the sample size is small, which makes the detection of statistical significance difficult. Based on the raw data, the bycatch is reduced by 60% when using the gillnet modified with acrylic glass spheres. The estimated marginal mean of the bycatch is 0.5 for the standard gear and 0.2 for the modified gear with wide confidence intervals (Fig A 1). These values need to be refined by a large-scale field trial.

3.3 Thornback ray bycatch and handling time

In all, 81 thornback rays were taken as bycatch in the standard gillnet and 114 thornback rays in the modified gillnet. One juvenile, 80 males, and 114 females were taken (Fig. 5 and Fig. 6 and Table 1). The GLMM detected no significant difference of thornback ray bycatch between the gears (p-value = 0.19). The time used to disentangle animals was determined for 93 thornback rays. The handling time required to disentangle individual thornback rays from the netting was 28% longer for the modified gillnet (mean 21 s) compared with the standard gillnet (mean 15 s); Mann–Whitney U test: p-value = 0.033, W=656.6.

3.4 Power analysis

The power analysis revealed that approximately 130 trips (each trip testing one set of each gear type) would be necessary to have 80 % power to detect a statistically significant difference in porpoise bycatch with the modified gear (Fig A 2). This was mainly the result of the large number of zero catches. The code used is available in the supplementary material.

4. Discussion

These were the first pilot trials in a commercial fishery worldwide using acrylic glass spheres as passive reflectors with the aim of reducing bycatch of harbor porpoises while maintaining the target catch, providing a proof of concept and forming the basis for future trials. The trials were carried out in the commercial turbot fishery on the Turkish coast of the Black Sea in 2019. The 10 hauls yielded relatively few animals, and no significant difference in either catch or bycatch was revealed using generalized linear mixed modeling.

4.1 Target species

Small catches of turbot are common in the period September–December (Bilgin et al., 2018; WGBS, 2017), because most migration to shallow areas where gillnet fishing takes place occurs in spring. However, during the spring period, fishing for turbot is prohibited to allow for reproduction. The Black Sea turbot stock is generally small (WGBS, 2017), but exacting conservation measures (e.g., re-stocking and other measures to reduce fishing mortality, such as the closed season (Ak et al., 2016; FAO, 2018)), indicate that the stock is improving. Furthermore, in 2019, regulation EU 2019/1241 specified the minimum mesh size for turbot gillnets to 400 mm (EU, 2019). Since 2016, Turkey has required the same mesh size, possibly resulting in catches that are even smaller than in previous years. The decrease in fishing pressure on turbot by the new 400 mm mesh size was confirmed by the observation that, during the time of the study, the catches of turbot fishers still using the previously legal mesh size of 320 mm were slightly larger than the catches in our trials (pers. comm. with local fishers).

4.2 Harbor porpoise bycatch

The modified gillnets with greater acoustical visibility used in these trials did reduce the total number of harbor porpoises taken as bycatch, however without statistical significance. This study involved a feasibility trial, thus only 10 trips were carried out, whereas the power analysis suggested that 130 trips each testing one set of standard against one set of modified gillnets are required to reliably identify statistical differences (80 % power). Therefore, a full-scale sea trial is needed to confirm the potential bycatch reduction. Assuming that the porpoise bycatch rate is constant over the year, this could be achieved by, e.g., simultaneous fishing trials with several fishing vessels over one year. Carrying out a trial during the “closed season” for turbot (15 April–15 June; (TCFR, 2016)) could, however, decrease the number of required trips, because bycatch rates of porpoise have been higher (Gönener and Bilgin, 2009) during this season, and local fishers report that late spring is still the highest bycatch season (pers. communication with fishers). Seasonal studies of harbor porpoise bycatch in the Black Sea gillnet fishery are scarce (Bilgin et al., 2018; Radu and Anton, 2014; Vishnyakova and Gol’din, 2015), and sampling effort is not evenly distributed throughout the year. Thus, the low bycatch rate could also be attributed to intra- or interannual variability. Additionally, the distribution of harbor porpoises in the Black Sea has not yet been documented comprehensively, and seasonal movement patterns are studied only locally (Birkun et al., 2014).

Although harbor porpoises are thought to detect at least some parts of the gillnet from a distance (Nielsen et al., 2012), it remains unclear why they still get entangled in the standard and modified gillnets. One hypothesis suggests that, although they can recognize some parts, they do not identify the netting as an obstacle (Goodson, 1997), because the echo of gillnet netting is very faint (Kastelein et al., 2000; Kratzer et al., 2020; Mooney et al., 2004; Pence, 1986). Increasing the acoustic visibility of gillnets addresses this issue, but a key requirement for the increased detectability to be efficient at reducing bycatch is that the porpoise actively echolocates in the direction of the netting. The echolocation beam of harbor porpoises is relatively narrow (Koblitz et al., 2012), hence it is crucial that they are echolocating toward the gillnet to detect it. This might not be the case when they exhibit so-called bottom-grubbing (Lockyer et al., 2001), a feeding behavior where the porpoise is facing straight toward the bottom. Furthermore, porpoises have difficulties detecting signals in high background noise (Kastelein et al., 2011; Kastelein and Wensveen, 2008) or may be distracted by prey in the water column (R. Kastelein et al., 1995). While it is possible that the porpoises are distracted by moving prey, it is unlikely that they mistake the gillnet for food, as fish shoals have a distinctive start and end while the gillnet is an extended structure (Kratzer et al., 2020). A recent study suggests that porpoises are not targeting fish caught in the gillnet, but rather other prey in the vicinity of gillnets, if at all (Maeda et al., 2021). Additionally, harbor porpoises target small prey that is between 3 and 16 cm in length (Sveegaard et al., 2012; Wisniewska et al., 2016), which is much smaller than the size of fish caught in the gillnets used in this study.

Despite their high demand for food and thus almost continuous echolocation (Sørensen et al., 2018; Wisniewska et al., 2016), porpoises have also been observed to be silent or vocalizing at lower sound levels, potentially in periods associated with sleep (Wright et al., 2017). In these periods, they might not be aware of the gillnets or fail to recognize them. To further improve the potentially positive effect of the acoustically visible gillnets tested on harbor-porpoise bycatch reduction, it might be worthwhile to combine the improved visibility with an active device sending a "wake-up" call that increases their alertness toward an obstacle (Goodson, 1997). One example of a recently developed device aiming to increase the awareness of harbor porpoises to gillnets is the PAL (PorpoiseALert) that has been successfully tested in the western Baltic Sea (Chladek et al., 2020; Culik et al., 2015). The exact reason why harbor porpoises become entangled in gillnets in the first place must be better understood, and potential behavioral changes when porpoises encounter a modified gillnet should be investigated. This could be achieved by conducting a behavioral experiment, either in an enclosed environment or in an area where many wild cetaceans are relatively abundant and can be observed both visually to determine changes in surfacing frequency and acoustically to determine underwater swimming paths as well as changes in echolocation behavior upon the encounter of the gillnets. A first, small experiment by (Gustafsson, 2020) explored the behavior of harbor porpoises around gillnets with acrylic spheres using CPODs and has shown that fewer detections are made around gillnets with acrylic glass spheres. Further behavior experiments should also investigate a combination of a "wake-up call" (e.g., PAL) and the modified net to explore the synergistic effects of passive and active devices on potential bycatch reduction.

4.3 Thornback ray bycatch

The bycatch of thornback rays in the modified gillnet is greater than in the standard gillnet but not statistically different. Similar catch numbers of thornback rays have been reported in previous trials in the gillnet fishery (Bilgin et al., 2018; Bilgin and Köse, 2018; Gönener and Bilgin, 2009). No significant change in thornback ray bycatch was expected as these animals do not echolocate and thus the modified gillnet should not be more conspicuous to them. The almost neutral buoyancy of the spheres could have slightly changed the hydrodynamic behavior and thus opening mesh size of the netting resulting in slightly larger individuals caught in the modified gillnet. The relationship between disc width (DW) and total length (TL) described here differs slightly from previous observations, where smaller DW:TL ratios for females and larger or similar DW:TL ratios were reported for males (Demirhan et al., 2005; Krstulović Šifner et al., 2009). If thornback rays are considered a model species, this shows no difference in catch efficiency for bottom-dwelling species. To quantify changes in hydrodynamic gillnet behavior, both types of gillnets should be tested in a flume tank. Furthermore, the changes in selectivity properties due to a change the geometry of the mesh due to the additional obstacle and potential change of the mesh opening could be assessed using FISHSELECT (Herrmann et al., 2009).

Although no official stock assessment has been made, smaller catches indicate that the population of thornback ray is declining (Başusta and Başusta, 2014), and they are considered "vulnerable" in Turkey (Fricke et al., 2007). The fate of thornback rays discarded from gillnets is largely unknown. For gillnets, survival rates at capture have been estimated to be high (Ellis et al., 2012); however, long-term survival rates are not yet available. A survival study to quantify survival rates in gillnet fisheries and their potential effect on the population is advisable (ICES, 2020).

4.4 Handling of gear

To determine how the addition of spheres would affect the process of clearing the catch from the gear, the time to disentangle catch was estimated for thornback rays, as it was the most commonly caught species and serves as a proxy for other species that entangle in the lower part of the gillnet, including the target species turbot. Disentangling thornback rays from the modified gillnets took 28 % longer on average than with the standard gillnet, corresponding to an absolute additional handling time of 6 s per individual ray, which might make the additional time required irrelevant in the overall procedure. The increase in time might be attributable to more "intensive" entanglement of the animals in the netting or the netting itself, due to a change in the mechanical entanglement properties caused by the addition of spheres. This increase in handling time should decrease with times as fishers get more experienced with the gear. Similarly, as in other fisheries, newly introduced bycatch reduction methods need time to be adopted, constantly undergo improvement (Catchpole and Revill, 2008) and are subject to a learning curve to use the new gear. The learning curve already became evident in this pilot trial when looking at the time needed to set the modified gear compared to the standard gear, which was reduced from an additional 45 minutes to an additional 11 minutes from the first haul to the last one. The addition of spheres did not pose a threat to the fishers, as other modifications of gillnets have done in the past (e.g. injuries from broken metal strands (Peddemors et al., 1991)) and the spheres proved to be robust to stay on the gillnet without damage throughout the entire study period. The initial preparation of the nets was quite labor intensive because the spheres had to be glued individually to the gillnet. This is owed to the fact that this was the first trial with gillnets modified with acrylic spheres, hence there is no automation available yet to produce this type of gillnet modification. As the next step before carrying out a full-scale sea trial or introducing the gear on a broad scale, an automated process must be developed to produce this type of modified gillnet.

Following each trip, the modified gear was entangled in itself to a greater extent than the standard gear, which led to a labor-intensive preparation of the net for the following trip. The issue had not occurred in previous research trials with a prototype gillnet (multi-mono nylon filament, stretched mesh opening 70 mm). However, the netting material and mesh size used in this study were different (multi natural filament, stretched mesh size 400 mm). The distance between spheres was similar. The smaller mesh size of the prototype gillnet used in the previous study may have prevented spheres from "falling through" meshes to netting layers underneath, and the netting material (nylon) may have facilitated "untanglement" from the netting itself. Neither the modified nor the standard gillnet tested in these trials was entangled when it was pulled from the water, but both became entangled after passing the gillnet hauler. The typical gillnet hauler used on Turkish gillnetters lifts the gillnet between two narrow, vertically aligned pulleys pressing the gillnet together. Therefore, an alternative solution to preventing the entanglement could be the use of gillnet haulers often used, e.g., on Danish and German vessels that have broad, horizontally aligned rolls made of rubber. Furthermore, the PP-rope connecting the floats was made from twisted strands, which amplified entanglement due to twisting of the netting around the floatline. Replacing the rope with braided line could further facilitate handling. Finally, standard gillnets from many small-scale Turkish gillnet vessels are cleaned manually, which can take up to five days, depending on the amount of seaweed and litter. This process could be facilitated and greatly shortened through the use of an automated gillnet stacker, which is a standard tool on board many gillnetters elsewhere, e.g., in the Baltic Sea and North Sea. The prototype nylon gillnet has been successfully cleared with a gillnet stacker. Standard gillnet stackers may require modification to be successfully introduced in the Turkish fishery where natural fibers are mostly used for gillnets.

4.5 Size of effect and future trials

The bycatch reduction of harbor porpoises by -60% based on the raw data using the gillnet with acrylic glass spheres is promising and warrants a large-scale trial. The estimated marginal mean of bycatch calculated from the model using the standard gear was higher than the bycatch in the modified gear, albeit the confidence intervals were wide. While the reduction in full-scale scientific sea trials using pingers was higher (Gönener and Bilgin, 2009; Kraus et al., 1997; Larsen and Eigaard, 2014; Palka et al., 2008), it has been pointed out that the bycatch reduction rate drops in unaccompanied commercial trials (Palka et al., 2008). This may be due to malfunctioning pingers, lack of compliance or lack of battery life of the pingers. An additional advantage of using a passive reflector over pingers is that battery replacement plays no role and the reflectors cannot malfunction due to electronic issues. Mechanical replacement of the spheres should be minimal, as a first trial using a gillnet stacker has shown that, if the spheres are mounted properly, they do not fall off, even if treated with heavy impacts. Additionally, acrylic glass is durable against UV light, especially compared to nylon, thus deterioration due to sunlight should be minimal and it can be used in environments up to -40°C (Abts, 2016). In trials using gillnets with fillers in the filament higher reductions in bycatch were recorded (Larsen et al., 2007; Trippel et al., 2003), likely due to the increased stiffness of the netting material (Trippel et al., 2009) which also led to a decrease in target catch (Larsen et al., 2007). The use of acrylic glass spheres will not influence the stiffness of the netting and since they are transparent, they are likely to be inconspicuous to fish and thus not influence the catchability in a large-scale trial. This is reflected in the catch of bottom-dwelling thornback rays, which were caught in both the standard and the modified net, without statistical differences.

To optimize effort in a full-scale trial, it is advisable to carry out a power analysis based on data gained in a pilot study. Previous studies have carried out fishing trials based on only rough estimates without conducting a power analysis (Bielli et al., 2020; Larsen et al., 2013; Larsen and Eigaard, 2014; Mangel et al., 2013), resulting in large numbers of hauls (between 195 and 864), which could have potentially been optimized. While these large datasets are certainly valuable, statistically robust and sometimes even necessary – other trials optimized based on a power analysis using observer data (Barlow and Cameron, 2003; Carlström et al., 2002; Gearin et al., 2000) have had similar effort needs due to low bycatch rates – a power analysis will facilitate experimental planning. Knowledge on effort required prior to a large-scale experiment can help reduce observer costs, charter fees and compensation as well as reduce potential scientific fishing effort in addition to the present commercial effort.

For the present study there was no long-term observer data available, thus the pilot experiment was necessary to provide the basis for the future. Conducting a full-scale experiment in the Black Sea could greatly reduce the required effort compared to other fisheries with only 130 hauls needed. As the Black Sea turbot fishery is characterized by long soaktimes, the time required for a full-scale trial could be reduced by equipping several vessels with modified gillnets. If five vessels were equipped, a full-scale trial could be conducted within four months with the given bycatch rate. The code provided in the supplementary material will furthermore facilitate experimental planning for other planned large-scale studies with known bycatch rates.

To equip several vessels with modified gillnets, it is necessary to develop an automated process to build the modified nets. This should be done in cooperation with a netmaker or another polymer industry partner. Within the development of an automated process to build gillnets modified with spheres, alternative – possibly biodegradable – materials to acrylic glass could be taken into consideration. Several materials fall within the same range of mechanical properties as acrylic glass (Kratzer et al., 2020) and thus have the potential to render a gillnet acoustically visible if spheres are attached at the correct distance.

Additional trials could be carried out in other regions that are affected by harbor porpoise bycatch, e.g., the North Sea or Baltic Sea. Because bycatch rates in these regions are possibly lower than in the Turkish Black Sea, the development of industrially produced, modified gillnets to equip the necessary number of vessels and thus be able to gather adequate data is even more essential.

Additionally, the underwater properties of gillnets, both modified and conventional, e.g., in terms of hydrodynamic behavior, self-entanglement, hanging ratio, and response to entanglement by fish and other animals, should be investigated in a flume tank and using camera observation during commercial use. The concept of adding small acrylic glass spheres to make gillnets acoustically visible is not limited to reducing harbor porpoise bycatch (Kratzer et al., 2020). Small, echolocating cetaceans around the world are threatened by gillnets; therefore, additional trials can be conducted in any gillnet fishery with bycatch of small cetaceans.

Acknowledgments

We thank the fishers Murat Yılmazer, Ahmet Arıcı, and Faruk Atal, who participated in the study, and *shellcatch, inc.* for lending the electronic monitoring system. We thank C. Zimmermann, U. Krumme, B. Anthony, J. Santos and the anonymous reviewers for helpful comments on this manuscript. Legal permissions required for carrying out this study were obtained from the following institutions: the Ministry of Foreign Affairs, the Ministry of Agriculture and Forestry, the Ministry of Culture and Tourism, the Higher Education Council, and the Sinop University Administrative Committee. We thank all institutions and organizations for their support. This work was funded by the German Federal Agency for Nature Conservation (Bundesamt für Naturschutz, project no. 3516821300, Entwicklung von alternativen Managementansätzen und Fangtechniken zur Minimierung der Konflikte zwischen Stellnetzfischerei und Naturschutzzielen in der deutschen AWZ der Ostsee – STELLA).

References

Abts, G., 2016. Kunststoff-Wissen für Einsteiger, 3., updated and expanded edition. ed. Hanser, Munich.

ACCOBAMS, 2019a. ACCOBAMS Survey Initiative - Technical Report of the Black Sea survey (No. ACCOBAMS-MOP7/2019/ Inf 33).

ACCOBAMS, 2019b. Resolution 7.11. - Interactions between fisheries and cetaceans (No. ACCOBAMS-MOP7/2019/Doc38/Annex15/Res.7. 1 1).

Ak, O., Ceylan, B., Aydin, İ., Polat, H., Küçük, E., Eroğlu, O., Kapiris, K., 2016. Stock enhancement by hatchery-released turbot, Psetta maxima, in the southeastern Black Sea: capture, migration, growth and diet analyses. Scientia Marina 80, 163–174. https://doi.org/10.3989/scimar.04324.25A

Au, W.L., Jones, L., 1991. Acoustic Reflectivity of Nets: Implications Concerning Incidental Take of Dolphins. Marine Mammal Science 7, 258–273. https://doi.org/10.1111/j.1748-7692.1991.tb00101.x

Barlow, J., Cameron, G.A., 2003. Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. Marine Mammal Science 19, 265–283.

Başusta, N., Başusta, A., 2014. Thornback Skate, Raja clavata (Linnaeus,1758) Fisheries in The Black Sea, in: Düzgüneş, E., Öztürk, B., Zengin, M. (Eds.), Turkish Fisheries in the Black Sea. Turkish Marine Research Foundation (TÜDAV), Beykoz, İstanbul, Türkiye, pp. 396–404.

Bielli, A., Alfaro-Shigueto, J., Doherty, P.D., Godley, B.J., Ortiz, C., Pasara, A., Wang, J.H., Mangel, J.C., 2020. An illuminating idea to reduce bycatch in the Peruvian small-scale gillnet fishery. Biological Conservation 241, 108277. https://doi.org/10.1016/j.biocon.2019.108277

Bilgin, S., Köse, Ö., 2018. Testing two types of acoustic deterrent devices (pingers) to reduce harbour porpoise, Phocoena phocoena(Cetacea:P hocoenidae), by catch in turbot (Psetta maxima) set gillnet fishery in the Black Sea, Turkey. Cahiers de Biologie Marine 59, 473–479.

Bilgin, S., Köse, Ö., Yesilcicek, T., 2018. Incidental catches of endangered (*Phocoena phocoena*) and vulnerable (*Delphinus delphis*) cetaceans and catch composition of turbot bottom gillnet fisheries in the southeastern Black Sea, Turkey. Cahiers de Biologie Marine 59, 571–577. https://doi.org/10.21411/CBM.A.E3AED15B

Birkun, A., Jr., Frantzis, A., 2008. *Phocoena phocoena ssp. relicta*. The IUCN Red List of Threatened Species 2008: e.T17030A6737111. https://doi.org/10.2305/IUCN.UK.2008.RLTS.T17030A6737111.en

Birkun, A., Jr., Northridge, S.P., Willsteed, E.A., James, F.A., Kilgour, C., Lander, M., Fitzgerald, G.D., 2014. Studies for Carrying Out the Common Fisheries Policy: Adverse Fisheries Impacts on Cetacean Populations in the Black Sea. (Final Report to the European Commission). Brussels.

Bjørge, A., Tolley, K.A., 2009. Harbor Porpoise: *Phocoena phocoena*, in: Perrin, W.F., Würsig, B., Thewissen, J.G.M. (Eds.), Encyclopedia of Marine Mammals (Second Edition). Academic Press, London, pp. 530–533. https://doi.org/10.1016/B978-0-12-373553-9.00125-5

Bordino, P., Albareda, D., Palmerio, A., Mendez, M., Botta, S., 2002. Reducing incidental mortalitiy of Franciscana dolphin *Pontoporia blainvillei* with acoustic warning devices attached to fishing nets. Marine Mammal Science 18, 833–842. https://doi.org/10.1111/j.1748-7692.2002.tb01076.x

Bordino, P., Mackay, A., Werner, T., Northridge, S., Read, A., 2013. Franciscana bycatch is not reduced by acoustically reflective or physically stiffened gillnets. Endangered Species Research 21, 1–12. https://doi.org/10.3354/esr00503

Brooks, M.E., Kristensen, K., Benthem, K.J. van, Magnusson, A., Berg, C.W., Nielsen, A., Skaug, H.J., Mächler, M., Bolker, B.M., 2017. glmmTMB Balances Speed and Flexibility Among Packages for Zero-inflated Generalized Linear Mixed Modeling. The R Journal 9, 378–400.

Carlström, J., Berggren, P., Dinnétz, F., Börjesson, P., 2002. A field experiment using acoustic alarms (pingers) to reduce harbour porpoise by-catch in bottom-set gillnets. ICES Journal of Marine Science 59, 816–824. https://doi.org/10.1006/jmsc.2002.1214

Carlström, J., Berggren, P., Tregenza, N.J.C., 2009. Spatial and temporal impact of pingers on porpoises. Canadian Journal of Fisheries and Aquatic Sciences 66, 72–82. https://doi.org/10.1139/f08-186

Catchpole, T.L., Revill, A.S., 2008. Gear technology in Nephrops trawl fisheries. Reviews in Fish Biology and Fisheries 18, 17–31. https://doi.org/10.1007/s11160-007-9061-y

Chladek, J., Culik, B., Kindt-Larsen, L., Albertsen, C.M., von Dorrien, C., 2020. Synthetic harbour porpoise (*Phocoena phocoena*) communication signals emitted by acoustic alerting device (Porpoise ALert, PAL) significantly reduce their bycatch in western Baltic gillnet fisheries. Fisheries Research 232, 105732. https://doi.org/10.1016/j.fishres.2020.105732

Cox, T.M., Read, A.J., Solow, A., Tregenza, N., 2001. Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? Journal of Cetacean Research and Management 3, 81–86.

Cucknell, A.-C., Frantzis, A., Boisseau, O., Romagosa, M., Ryan, C., Tonay, A.M., Alexiadou, P., Öztürk, A.A., Moscrop, A., 2016. Harbour porpoises in the Aegean Sea, Eastern Mediterranean: the species' presence is confirmed. Marine Biodiversity Records 9, 72. https://doi.org/10.1186/s41200-016-0050-5

Culik, B., von Dorrien, C., Müller, V., Conrad, M., 2015. Synthetic communication signals influence wild harbour porpoise (Phocoena phocoena) behaviour. Bioacoustics 24, 201–221. https://doi.org/10.1080/09524622.2015.1023848

Dawson, S.M., Northridge, S., Waples, D., Read, A.J., 2013. To ping or not to ping: the use of active acoustic devices in mitigating interactions between small cetaceans and gillnet fisheries. Endangered Species Research 19, 201–221. https://doi.org/10.3354/esr00464

Demirhan, S.A., Engin, S., Seyhan, K., Akamca, E., 2005. Some Biological Aspects of Thornback Ray (Raja clavata L., 1758) in the Southeastern Black Sea. TrJFAS 5, 75–83.

Ellis, J.R., McCully, S.R., Silva, J.F., Catchpole, T.L., Goldsmith, D., Bendall, V., Burt, G., 2012. Assessing discard mortality of commercially caught skates (Rajidae) – validation of experimental results (Final Report No. MB5202). Cefas.

Enever, R., Catchpole, T.L., Ellis, J.R., Grant, A., 2009. The survival of skates (Rajidae) caught by demersal trawlers fishing in UK waters. Fisheries Research 97, 72–76. https://doi.org/10.1016/j.fishres.2009.01.001

EU, 2019. Regulation (EU) 2019/1241 of the European Parliament and of the Council of 20 June 2019 on the conservation of fisheries resources and the protection of marine ecosystems through technical measures.

FAO, 2018. The State of Mediterranean and Black Sea Fisheries. General Fisheries Commission for the Mediterranean, Rome.

Fontaine, M.C., Snirc, A., Frantzis, A., Koutrakis, E., Ozturk, B., Ozturk, A.A., Austerlitz, F., 2012. History of expansion and anthropogenic collapse in a top marine predator of the Black Sea estimated from genetic data. Proceedings of the National Academy of Sciences 109, E2569–E2576. https://doi.org/10.1073/pnas.1201258109

Fordham, S., Fowler, S.L., Coelho, R., Goldman, K.J., Francis, M., 2006. Squalus acanthias (Black Sea subpopulation): The IUCN Red List of Threatened Species. The IUCN Red List of Threatened Species. https://doi.org/10.2305/IUCN.UK.2006.RLTS.T61410A12474740.en

Fricke, R., Bilecenoglu, M., Sari, H.M., 2007. Annotated checklist of fish and lamprey species (Gnathostomata and Petromyzontomorphi) of Turkey, including a Red List of threatened and declining species. Stuttgarter Beiträge zur Naturkunde Serie A (Biologie) 169.

Gearin, P.J., Gosho, M.E., Laake, J.L., Cooke, L., DeLong, R.L., Hughes, K.M., 2000. Experimental testing of acoustic alarms (pingers) to reduce bycatch of harbour porpoise, *Phocoena phocoena*, in the state of Washington. Journal of Cetacean Research and Management 2, 1–10.

Gönener, S., Bilgin, S., 2009. The Effect of Pingers on Harbour Porpoise, *Phocoena phocoena* Bycatch and Fishing Effort in the Turbot Gill Net Fishery in the Turkish Black Sea Coast. Turkish Journal of Fisheries and Aquatic Sciences 9, 151–157. https://doi.org/10.4194/trjfas.2009.0205

Goodson, A.D., 1997. Developing deterrent devices designed to reduce the mortality of small cetaceans in commercial fishing nets. Marine and Freshwater Behaviour and Physiology 29, 211–236. https://doi.org/10.1080/10236249709379007

Goodson, A.D., Mayo, R.H., 1995. Interactions between free-ranging bottlenose dolphins, *Tursiops truncatus*, and passive acoustic gillnet deterrent devices, in: Kastelein, R.A., Thomas, J.A., Nachtigall, P.E. (Eds.), Sensory Systems of Aquatic Mammals, Proceedings of the “Marine Mammal Sensory Symposium.” De Spil Publishers, Woerden.

Gustafsson, S., 2020. Pearls as bycatch mitigation strategy for Harbour porpoise (*Phocoena phocoena*) (Master Thesis). Swedish University of Agricultural Science, Uppsala.

Hammond, P.S., Macleod, K., Berggren, P., Borchers, D.L., Burt, L., Cañadas, A., Desportes, G., Donovan, G.P., Gilles, A., Gillespie, D., Gordon, J., Hiby, L., Kuklik, I., Leaper, R., Lehnert, K., Leopold, M., Lovell, P., Øien, N., Paxton, C.G.M., Ridoux, V., Rogan, E., Samarra, F., Scheidat, M., Sequeira, M., Siebert, U., Skov, H., Swift, R., Tasker, M.L., Teilmann, J., Van Canneyt, O., Vázquez, J.A., 2013. Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation 164, 107–122. https://doi.org/10.1016/j.biocon.2013.04.010

Harrell , F.E., 2015. Regression Modeling Strategies: With Applications to Linear Models, Logistic and Ordinal Regression, and Survival Analysis, Springer Series in Statistics. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-319-19425-7

Hartig, F., 2020. DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. R package version 0.2.7.

Herrmann, B., Krag, L.A., Frandsen, R.P., Madsen, N., Lundgren, B., Stæhr, K.-J., 2009. Prediction of selectivity from morphological conditions: Methodology and a case study on cod (*Gadus morhua*). Fisheries Research 97, 59–71. https://doi.org/10.1016/j.fishres.2009.01.002

ICES, 2020. Working Group on Methods for Estimating Discard Survival (WGMEDS; outputs from 2019 meeting). (ICES Scientific Reports No. 2:8).

Johnson, P.C.D., Barry, S.J.E., Ferguson, H.M., Müller, P., 2015. Power analysis for generalized linear mixed models in ecology and evolution. Methods in Ecology and Evolution 6, 133–142. https://doi.org/10.1111/2041-210X.12306

Kastelein, R., Au, W.W., de Haan, D., 2000. Detection distances of bottom-set gillnets by harbour porpoises (*Phocoena Phocoena*) and bottlenose dolphins (*Tursiops truncatus*). Marine Environmental Research 49, 359–75. https://doi.org/10.1016/S0141-1136(99)00081-1

Kastelein, R., de Haan, D., Staal, C., 1995. Entanglement of Harbour porpoises (*Phocoena phocoena*) in fishing nets, in: Nachtigall, R.E., Lien, J., Au, W.W., Read, A.J. (Eds.), Harbour Porpoises - Laboratory Studies to Reduce Bycatch. De Spil Publishers, Woerden, The Netherlands, pp. 91–56.

Kastelein, R.A., Haan, D. de, Staal, C., 1995. Behaviour of Harbour porpoises (*Phocoena phocoena*) in response to ropes, in: Nachtigall, P.E., Lien, J., Au, W.W.L., Read, A.J. (Eds.), Harbour Porpoises - Laboratory Studies to Reduce Bycatch. De Spil Publishers, Woerden, The Netherlands, pp. 69–90.

Kastelein, R.A., Steen, N., de Jong, C., Wensveen, P.J., Verboom, W.C., 2011. Effect of broadband-noise masking on the behavioral response of a harbor porpoise (*Phocoena Phocoena*) to 1-s duration 6–7 kHz sonar up-sweeps. The Journal of the Acoustical Society of America 129, 2307–2315. https://doi.org/10.1121/1.3559679

Kastelein, R.A., Wensveen, P.J., 2008. Effect of Two Levels of Masking Noise on the Hearing Threshold of a Harbor Porpoise (*Phocoena Phocoena*) for a 4.0 kHz Signal. Aquatic Mammals 34, 420–425. https://doi.org/10.1578/AM.34.4.2008.420

Koblitz, J.C., Wahlberg, M., Stilz, P., Madsen, P.T., Beedholm, K., Schnitzler, H.-U., 2012. Asymmetry and dynamics of a narrow sonar beam in an echolocating harbor porpoise. The Journal of the Acoustical Society of America 131, 2315–2324. https://doi.org/10.1121/1.3683254

Kratzer, I.M.F., Schäfer, I., Stoltenberg, A., Chladek, J.C., Kindt-Larsen, L., Larsen, F., Stepputtis, D., 2020. Determination of Optimal Acoustic Passive Reflectors to Reduce Bycatch of Odontocetes in Gillnets. Front. Mar. Sci. 7. https://doi.org/10.3389/fmars.2020.00539

Kraus, S.D., Read, A.J., Solow, A., Baldwin, K., Spradlin, T., Anderson, E., Williamson, J., 1997. Acoustic alarms reduce porpoise mortality. Nature 388, 525–525. https://doi.org/10.1038/41451

Krstulović Šifner, S., Vrgoč, N., Dadić, V., Isajlović, I., Peharda, M., Piccinetti, C., 2009. Long-term changes in distribution and demographic composition of thornback ray, Raja clavata, in the northern and central Adriatic Sea. Journal of Applied Ichthyology 25, 40–46. https://doi.org/10.1111/j.1439-0426.2008.01204.x

Larsen, F., Eigaard, O.R., 2014. Acoustic alarms reduce bycatch of harbour porpoises in Danish North Sea gillnet fisheries. Fisheries Research 153, 108–112. https://doi.org/10.1016/j.fishres.2014.01.010

Larsen, F., Eigaard, O.R., Tougaard, J., 2007. Reduction of harbour porpoise (*Phocoena phocoena*) bycatch by iron-oxide gillnets. Fisheries Research 85, 270–278. https://doi.org/10.1016/j.fishres.2007.02.011

Larsen, F., Krog, C., Eigaard, O.R., 2013. Determining optimal pinger spacing for harbour porpoise bycatch mitigation. Endangered Species Research 20, 147–152. https://doi.org/10.3354/esr00494

Lenth, R., 2019. emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.4.3.01.

Lockyer, C., Amundin, M., Desportes, G., Goodson, D., 2001. EPIC – Elimination of Harbour Porpoise Incidental Catches (Final Report No. Project no DG XIV 97/0006).

Maeda, S., Sakurai, K., Akamatsu, T., Matsuda, A., Yamamura, O., Kobayashi, M., Matsuishi, T.F., 2021. Foraging activity of harbour porpoises around a bottom-gillnet in a coastal fishing ground, under the risk of bycatch. PLOS ONE 16, e0246838. https://doi.org/10.1371/journal.pone.0246838

Mangel, J.C., Alfaro-Shigueto, J., Witt, M.J., Hodgson, D.J., Godley, B.J., 2013. Using pingers to reduce bycatch of small cetaceans in Peru's small-scale driftnet fishery. Oryx 47, 595–606. https://doi.org/10.1017/s0030605312000658

Mooney, T.A., Nachtigall, P.E., Au, W.W., 2004. Target strength of a nylon monofilament and an acoustically enhanced gillnet: predictions of biosonar detection ranges. Aquatic Mammals 30, 220–226. https://doi.org/10.1578/AM.30.2.2004.220

Nakamura, K., Akamatsu, T., Goodson, A.D., Kagoshima, K., Shimazaki, K., 1998. Gillnet Passive Acoustic Deterrents: Investigating Inter-Reflector Spacings with a Harbor Porpoise *Phocoena phocoena*. Fisheries science 64, 648–649. https://doi.org/10.2331/fishsci.64.648

Nielsen, T.P., Wahlberg, M., Heikkilä, S., Jensen, M., Sabinsky, P., Dabelsteen, T., 2012. Swimming patterns of wild harbour porpoises *Phocoena phocoena* show detection and avoidance of gillnets at very long ranges. Marine Ecology Progress Series 453, 241–248. https://doi.org/10.3354/meps09630

Norris, K.S., Dohl, T.P., 1980. Behavior of the Hawaiian spinner dolphin, Stenella Longirostris. Fisheries Bulletin 77, 829–849.

Notarbartolo di Sciara, G., Birkun, A., Jr., 2010. Conserving whales, dolphins and porpoises in the Mediterranean and Black Seas: an ACCOBAMS status report. ACCOBAMS, Monaco.

Palka, D.L., Rossman, M.C., VanAtten, A.S., Orphanides, C.D., 2008. Effect of pingers on harbour porpoise (*Phocoena phocoena*) bycatch in the US Northeast gillnet fishery. Journal of Cetacean Research and Management 10, 217–226.

Peddemors, V., Cockcroft, V., Wilson, R.B., 1991. Incidental dolphin mortality in the Natal shark nets: A pre-liminary report on prevention measures (UNEP Marine Mammal Technical Report No. 3), UNEP Marine Mammal Technical Report. United States Environmental Programme, Nairobi, Kenya.

Pence, E.A., 1986. Monofilament Gill Net Acoustic Study (No. APL-UW 2-86). Applied Physics Laboratory, University of Washington, Seattle, Washington.

Perrin, W.F., Hunter, J.R., 1972. Escape behavior of the Hawaiian Spinner porpoise (Stenella cf. S. longirostris). Fisheries Bulletin 70, 49–60.

R Core Team, 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Radu, G., Anton, E., 2014. Impact of turbot fishery on cetaceans in the Romanian Black Sea area. Scientia Marina 78, 103–109. https://doi.org/10.3989/scimar.04029.27A

Reeves, R., McClellan, K., Werner, T., 2013. Marine mammal bycatch in gillnet and other entangling net fisheries, 1990 to 2011. Endangered Species Research 20, 71–97. https://doi.org/10.3354/esr00481

Saygu, İ., Deval, M.C., 2014. The Post-Release Survival of Two Skate Species Discarded by Bottom Trawl Fisheries in Antalya Bay, Eastern Mediterranean. TrJFAS 14, 947–953.

Serena, F., Mancusi, C., Morey, G., Ellis, J.R., 2009. *Dasyatis pastinaca*: The IUCN Red List of Threatened Species. The IUCN Red List of Threatened Species. https://doi.org/10.2305/IUCN.UK.2009-2.RLTS.T161453A5427586.en

Shellcatch VirtualObserver platform, 2020. . Newark, CA, USA.

Silber, G.K., Waples, K.A., Nelson, P.A., 1994. Response of Free-Ranging Harbour Porpoises to Potential Gillnet Modifications, in: Perrin, W.F., Donovan, G.P., Barlow, J. (Eds.), Gillnets and Cetaceans: Incorporating the Proceedings of the Symposium and Workshop on the Mortality of Cetaceans in Passive Fishing Nets and Traps, Reports of the International Whaling Commission, Special Issue. Cambrigde, pp. 579–584.

Sørensen, P.M., Wisniewska, D.M., Jensen, F.H., Johnson, M., Teilmann, J., Madsen, P.T., 2018. Click communication in wild harbour porpoises (*Phocoena phocoena*). Scientific Reports 8. https://doi.org/10.1038/s41598-018-28022-8

Sveegaard, S., Andreasen, H., Mouritsen, K.N., Jeppesen, J.P., Teilmann, J., Kinze, C.C., 2012. Correlation between the seasonal distribution of harbour porpoises and their prey in the Sound, Baltic Sea. Mar Biol 159, 1029–1037. https://doi.org/10.1007/s00227-012-1883-z

TCFR, 2016. The commercial fish catching regulations in seas and inland waters in 2016-2020 fishing period (No. Turkish Commercial Fishery Regulations 4/1, Numbered 2016/35). Ministry of Food, Agriculture and Livestock, General Directorate of Fisheries and Aquaculture, Ankara, Turkey.

Trippel, E.A., Holy, N.L., Palka, D.L., Shepherd, T.D., Melvin, G.D., Terhune, J.M., 2003. Nylon barium sulphate gillnet reduces porpoise and seabird mortality. Marine Mammal Science 19, 240–243.

Trippel, E.A., Holy, N.L., Shepherd, T.D., 2009. Barium sulphate modified fishing gear as a mitigative measure for cetacean incidental mortalities. Journal of Cetacean Research and Management 10, 235–246.

Vishnyakova, K., Gol’din, P., 2015. Seasonality of strandings and bycatch of harbour porpoises in the Sea of Azov: the effects of fisheries, weather conditions, and life history. ICES J. Mar. Sci. 72, 981–991.

WGBS, 2017. Report of the Workshop on the assessment of management measures (WKMSE) on Black Sea turbot fisheries. FAO, GFCM, Constanta , Romania.

Wisniewska, D.M., Johnson, M., Teilmann, J., Rojano-Doñate, L., Shearer, J., Sveegaard, S., Miller, L.A., Siebert, U., Madsen, P.T., 2016. Ultra-High Foraging Rates of Harbor Porpoises Make Them Vulnerable to Anthropogenic Disturbance. Current Biology 26, 1441–1446. https://doi.org/10.1016/j.cub.2016.03.069

Wright, A.J., Akamatsu, T., Mouritsen, K.N., Sveegaard, S., Dietz, R., Teilmann, J., 2017. Silent porpoise: potential sleeping behaviour identified in wild harbour porpoises. Animal Behaviour 133, 211–222. https://doi.org/10.1016/j.anbehav.2017.09.015

Tables

Table 1. **Coefficients of disc-width (DW) – total length (TL)-relationship of thornback ray according to gear type and sex.**

	standard	modified
Male	$DW = 0.637 \cdot TL + 3.2$ $R^2 = 0.94$	$DW = 0.585 \cdot TL + 6.21$ $R^2 = 0.85$
Female	$DW = 0.548 \cdot TL + 11.42$ $R^2 = 0.76$	$DW = 0.639 \cdot TL + 4.57$ $R^2 = 0.899$
Total	$DW = 0.59 \cdot TL + 7.27$ $R^2 = 0.86$	$DW = 0.611 \cdot TL + 5.58$ $R^2 = 0.847$

Figures

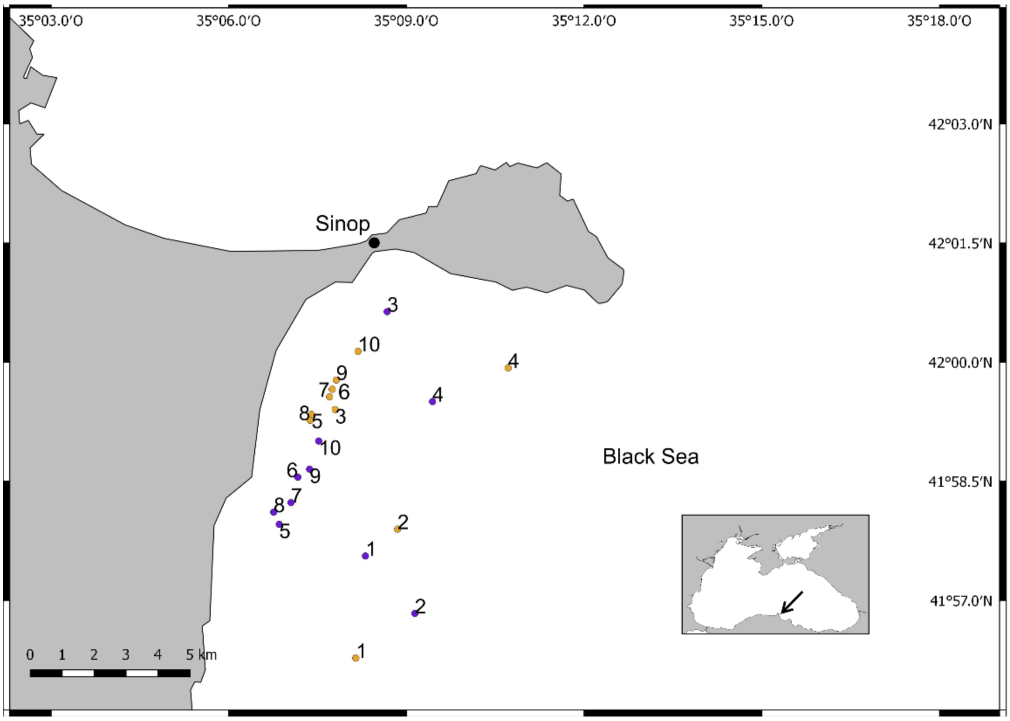


Fig. 1. **Study area in the Southern Black Sea (indicated by arrow). Colored dots: center points of gillnets (purple = standard gillnet, orange = modified gillnet) set during 10 fishing trips in the sampling area.**

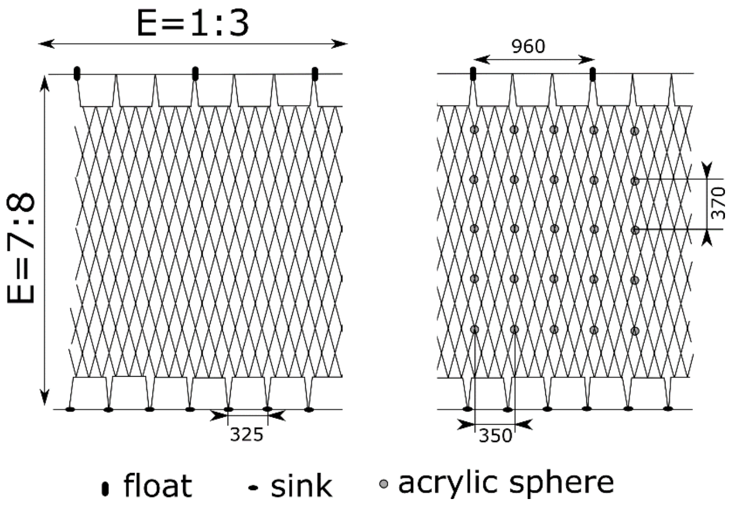


Fig. 2. **Schematic drawing of a standard gillnet (left) and a modified gillnet (right). Both gillnets have the same characteristics; the only difference is the addition of acrylic spheres to the modified net. All measures are in mm; E is the hanging ratio of the netting; the drawing is not to scale.**

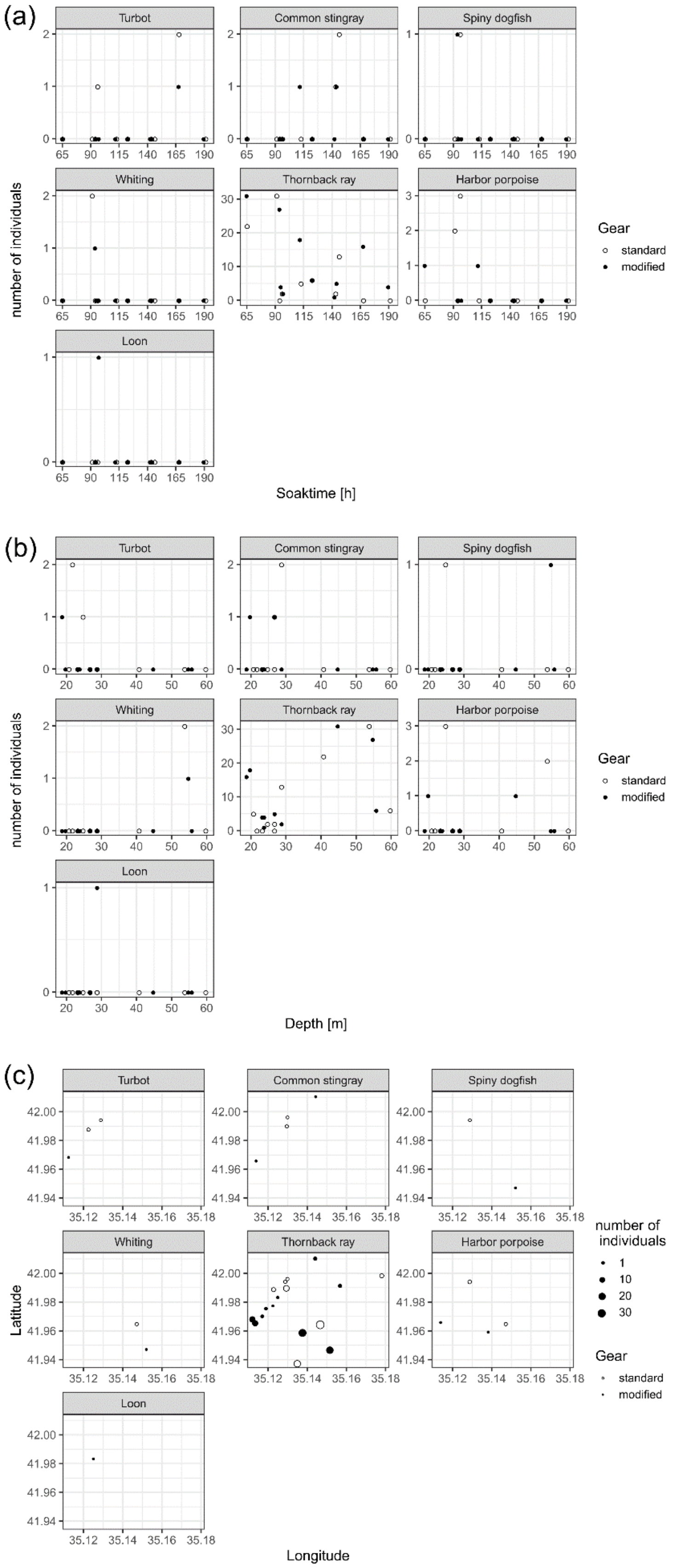


Fig. 3. **(a) Soaktime, (b) depth vs. number of animals caught per species. (c) Geospatial position per species, size of dot indicates number caught**

Fig. 4. **Number of harbor porpoises taken as bycatch per gillnet type and haul (numbers 1–10) by sex. Each porpoise represents one individual.**

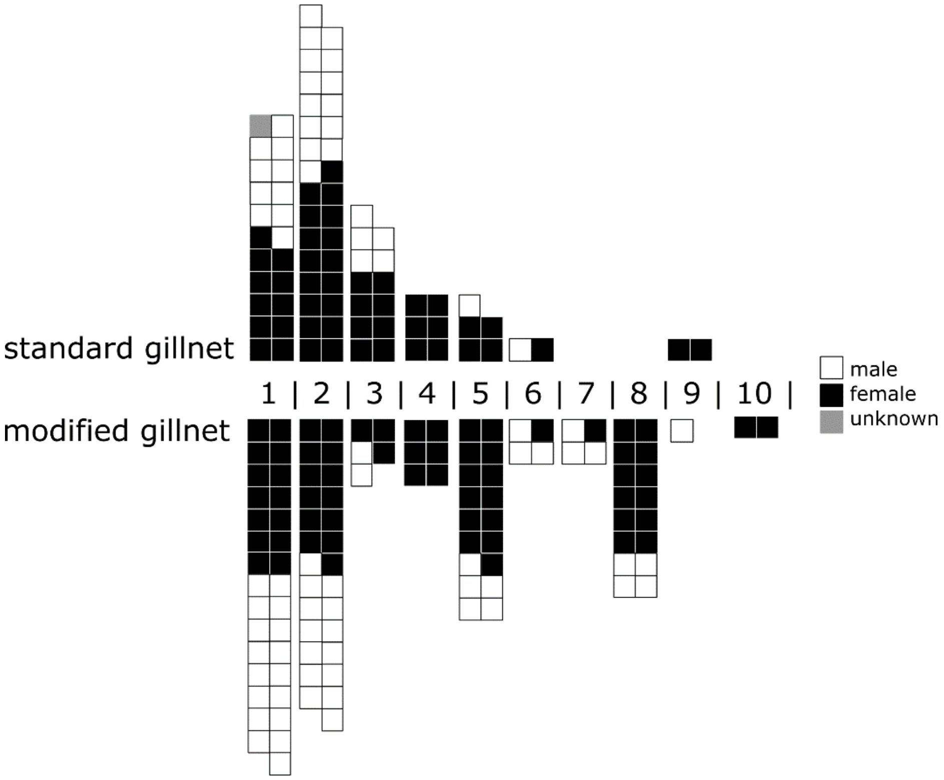


Fig. 5. **Number of thornback rays taken as bycatch per gillnet type and haul (numbers 1–10) by sex. Each box represents one individual.**

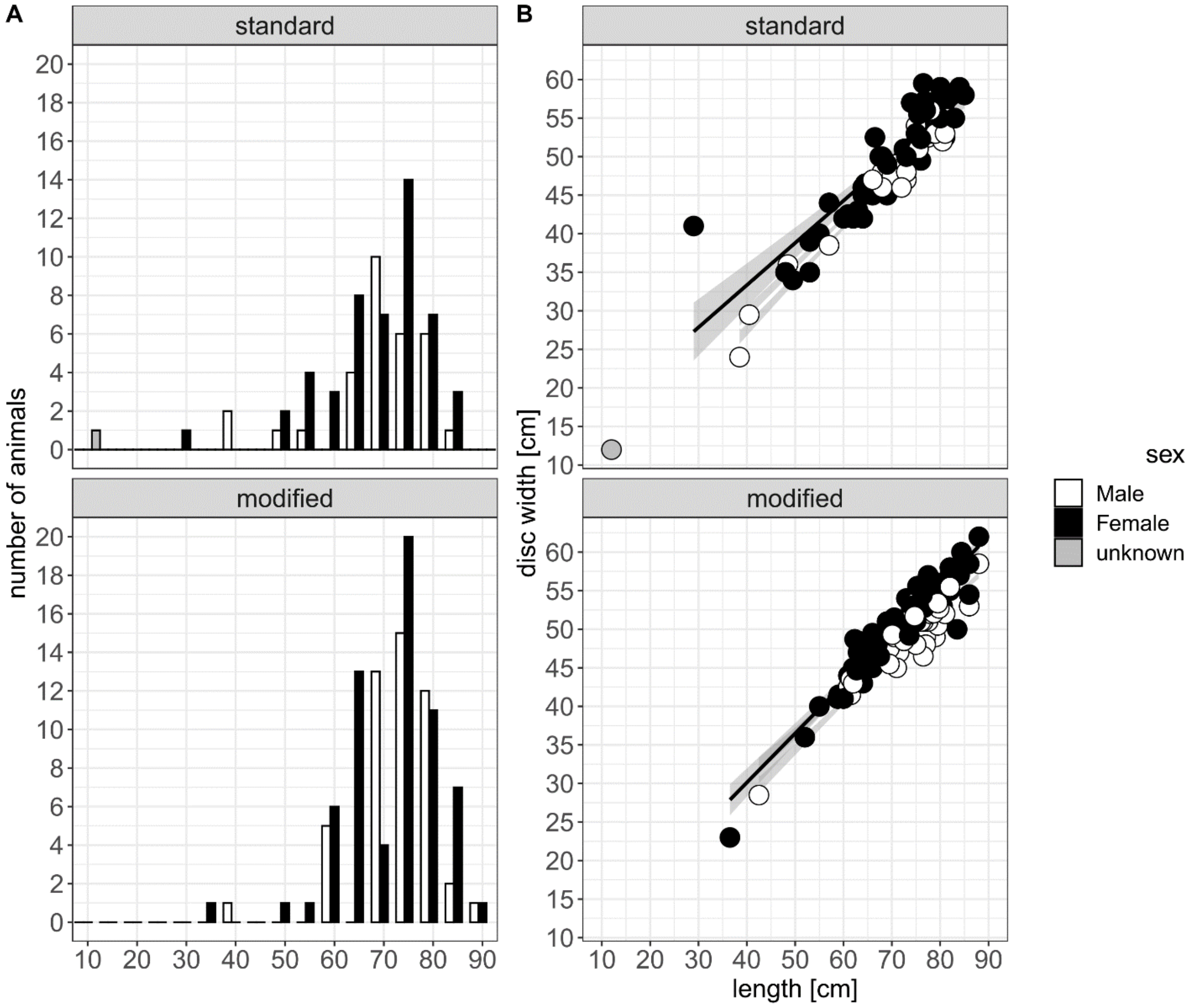


Fig. 6. **Length distribution of thornback rays by sex and gear type (left, column A). Disc width–length relationship by sex and gear type (right, column B).**

Appendix

Table A 1: Overview of hauls and number of species caught per haul and gillnet type. All hauls carried out in 2019. (S = standard gear, M = modified gear).

Trip	Start date [DD-MM-YY]	Gear	Soak time [h]	Turbot (*Scophthalmus maeoticus*)	Common stingray (*Dasyatis pastinaca*)	Spiny dogfish (*Squalus acanthias*)	Whiting (*Merlangius merlangus*)	Thornback ray (*Raja clavata*)	Harbor porpoise (*Phocoena phocoena relicta*)	Loon (Gaviidae)
1	09-09-19	S	66	0	0	0	0	22	0	0
		M	66	0	0	0	0	31	1	0
2	18-09-19	S	92	0	0	0	2	31	2	0
		M	94	0	0	1	1	27	0	0
3	02-10-19	S	147	0	2	0	0	13	0	0
		M	145	0	1	0	0	5	0	0
4	15-10-19	S	123	0	0	0	0	6	0	0
		M	123	0	0	0	0	6	0	0
5	25-10-19	S	114	0	0	0	0	5	0	0
		M	112	0	1	0	0	18	1	0
6	04-11-19	S	97	1	0	1	0	2	3	0
		M	96	0	0	0	0	4	0	0
7	10-11-19	S	192	0	0	0	0	0	0	0
		M	190	0	0	0	0	4	0	0
8	20-11-19	S	169	2	0	0	0	0	0	0
		M	168	1	0	0	0	16	0	0
9	05-12-19	S	144	0	1	0	0	2	0	0
		M	143	0	0	0	0	1	0	0
10	13-12-19	S	95	0	0	0	0	0	0	0
		M	98	0	0	0	0	2	0	1
	Total			4	5	2	3	195	7	1

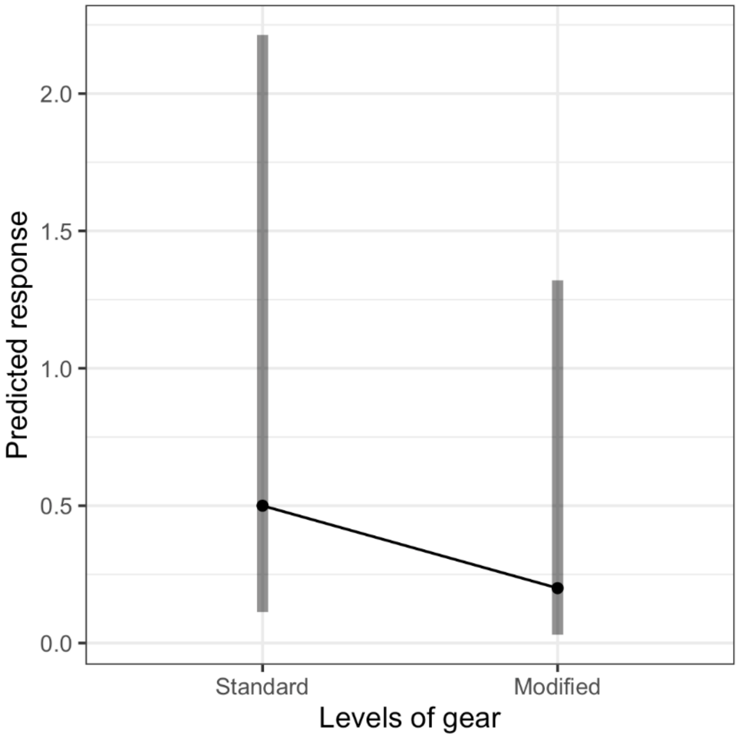


Fig A 1: **Estimated marginal means and CI of harbor porpoise bycatch by gear**

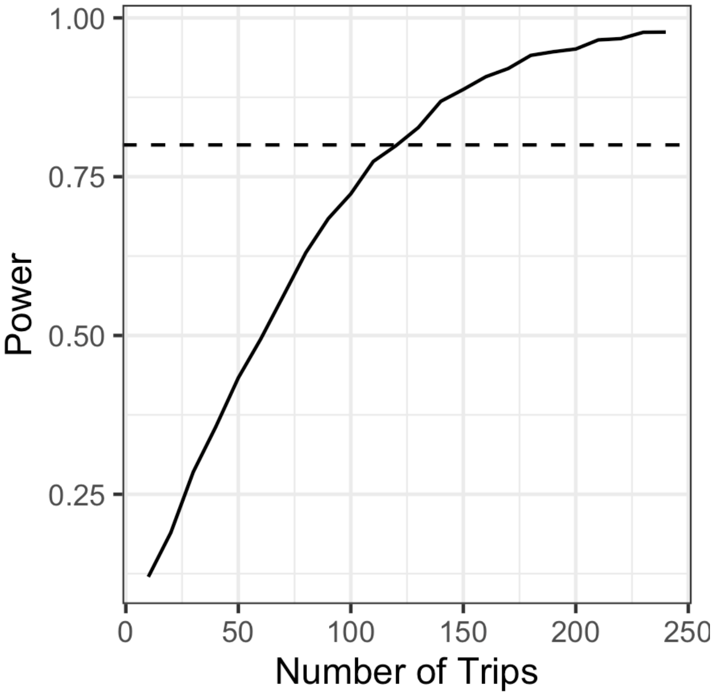


Fig A 2: **estimated power vs number of trips, each trip setting one set of standard and one set of modified gillnets. An 80% power can be achieved with approximately 130 sets**

Arbeitspaket 2 – Dissertation “Using Gillnet modifications to reduce bycatch of harbor porpoises.”

Kratzer, I.M.F. 2021. Gillnet modifications to reduce bycatch of harbor porpoises. Dissertation. Technical University of Denmark, Kopenhagen. National Institute of Aquatic Resources. 172 pp.

Summary

Gillnets are passive fishing gears that belong to the oldest and most frequently used gears worldwide, providing income and food for millions of people. They are most used in small-scale and artisanal coastal fisheries and operated from small boats often less than 12 m in length. Gillnet fisheries provide approximately 20% of the global catch of consumption fish. Gillnets are easy to handle, very fuel efficient due to their passive nature, have almost no impact on the sea bottom and are very size selective. The operating principle is very simple: a net is set vertically in the water column like a curtain, marked with buoys on the water surface and left to soak for a given time. Fish do not see the very thin filaments of the netting and get entangled. To obtain the catch, the net is hauled in and fish are removed. Often, the net is directly set again afterwards. The main drawback of gillnets is the incidental bycatch of marine megafauna, including small toothed whales (odontocetes) like harbor porpoises (*Phocoena phocoena*). Several populations of odontocetes are classified as “endangered” with bycatch playing a major role among other reasons. Odontocetes echolocate at high frequencies, but seem to be unable to sufficiently classify gillnet netting as impenetrable barriers, i.e. they entangle and drown. Increasing the acoustic detectability of gillnets for odontocetes by making the netting highly acoustically visible could reduce the bycatch of harbor porpoises and other odontocetes, given that the animals actively echolocate in the direction of the net. Within this thesis, an optimal acoustic reflector was systematically identified (**Paper I**), the acoustic properties of gillnets were determined for various gillnet modifications using this optimal reflector (**Paper II**) and a first commercial trial to assess the effect of the reflectors on bycatch of harbor porpoises was carried out (**Paper III**).

In **Paper I**, optimal acoustic reflectors that substantially increase the acoustic reflectivity of gillnets were identified across a large frequency range, and thus for many odontocetes species, through a systematic simulation study. Best results were achieved for small acrylic glass spheres. The simulation results were experimentally verified for selected objects in an acoustic tank. A single acrylic glass sphere of approximately 8 mm in diameter has almost the same acoustic reflectivity as an air-filled table tennis ball which is five times larger in diameter and gives a very strong echo. A single sphere also has a higher or equal acoustic reflectivity as the area of a gillnet at 130 kHz, the echolocation frequency of harbor porpoises. The spheres have almost the same density as seawater, should thus be almost neutrally buoyant and hence not significantly influence the hydrodynamic properties and catch efficiency of the modified gillnet.

Paper II describes the angle-dependent acoustic properties across a large frequency range of a nylon gillnet and a gillnet made from natural fiber, and modifications of these gillnets. The nets were modified with different numbers of acrylic glass spheres per m² of netting. Acoustic reflectivity was quantified in terms of area backscattering strength (S a) and target strength (TS). Acoustic spatial patterns were visualized in echograms. Gillnets modified with acrylic glass spheres have a higher acoustic reflectivity than the standard nets, even when equipped relatively sparsely with acrylic glass spheres. The standard nets become less acoustically visible when ensonified from an angle, while the gillnets equipped with spheres largely stay equally visible or become even more visible with increasing inclination. Furthermore, the spheres create a clear spatial pattern that could aid harbor porpoises to perceive the gillnets as impenetrable barriers.

In **Paper III** the first pilot fishery trial using a gillnet equipped with acrylic glass spheres was carried out in the Turkish Black Sea turbot fishery to quantify the efficacy of bycatch reduction of the modified gillnet. Ten pairwise hauls were carried out, each with a modified and a standard gillnet. The gillnet with acrylic glass spheres caught less harbor porpoises than the standard gear (2 vs. 5 animals) and there was no difference in

catch of demersal species such as thornback ray (*Raja clavata*) or turbot (*Scophthalmus maeoticus*). As only ten hauls were carried out, there was low statistical power and the difference in bycatch of harbor porpoises was not statistically significant. Nevertheless, the results are a promising step forward and form the basis for further improvement and upcoming large-scale fishery trials.

Vollständige Dissertation (Open Access)

https://orbit.dtu.dk/en/publications/gillnet-modifications-to-reduce-bycatch-of-harbor-porpoises

Arbeitspaket 3 – Veröffentlichung 1 “Using an innovative net-pen-based observation method to assess and compare fish pot-entrance catch efficiency for Atlantic cod (*Gadus morhua*).”

Chladek, J.C., Stepputtis, D., Hermann, A., Kratzer, I.M.F., Ljungberg, P., Rodriguez-Tress, P., Santos, J., Svendsen, J.C. 2021. Using an innovative net-pen-based observation method to assess and compare fish pot-entrance catch efficiency for Atlantic cod (*Gadus morhua*). Fisheries Research 236: 105851, doi:10.1016/j.fishres.2020.105851

Vollständige Veröffentlichung (Pre-print Proof)

Abstract

In many places, gillnet fishing is considered a conservation threat for air-breathing marine species. Fish pots represent an alternative to gillnetting; however, due to their low catch efficiency pots are rarely taken up by commercial fisheries. To improve pot efficiency for Atlantic cod (*Gadus morhua*), we used a novel enclosure to observe cod interacting with pot entrances, and investigated several entrance design parameters, including funnel colour, entrance funnel presence, length and entrance form. We demonstrate that the key factor for entrance passage is to give cod an unobstructed view of the inside or outside when they try to enter or exit the pot, respectively. Funnel colour (colours tested: white, green and transparent) influences entrance passage rates, with significantly higher entrance passage rates for the transparent funnel. Funnel presence increases the entrance encounter rate by enlarging the outer opening of the entrance. It decreases exit rates by deflecting cod away from the inner entrance opening and by reducing the area in which the exit is perceptible to cod inside the pot. Increasing funnel length further reduces this area and may deter cod by the longer passage length. This is the first study to observe cod–pot interactions day and night using an infrared camera, revealing a pronounced diurnal pattern with few nocturnal entrance passages, suggesting that cod–pot interactions are primarily guided by vision. The findings underline the importance of funnels and reveals promising avenues for their further improvement, e.g., by using transparent fish retention devices. The new pen-based method is superior in several ways to conventional field-pot catch-rate comparisons: It allows identification of differences in catch efficiency and describes the underlying cod behavioural mechanism leading to these differences. Thus, it allows targeted, efficient and iterative cod-pot catch-efficiency enhancements.

Introduction

Worldwide, fishery bycatch threatens several taxa of marine birds, mammals and turtles (e.g., Lewison et al., 2014; Read et al., 2006; Wiedenfeld et al., 2015). Although gillnets have limited effect on the benthic environment (Grabowski et al., 2014) and may be adjusted to target specific species and size classes of fish (Suuronen et al., 2012), gillnet fishing is often associated with substantial bycatches of birds, mammals and turtles (Gilman et al., 2010; Northridge et al., 2016; Žydelis et al., 2013). Many of these are endangered and protected under diverse national and international laws and regulations, e.g., the European Union (EU) Habitats and Species Directive (CEC, 1992). Furthermore, gillnets are susceptible to catch depredation by marine mammals, making the economic viability of gillnet fisheries difficult in some places (e.g., Buscaino et al., 2009; Geraci et al., 2019; Königson et al., 2015b).

To address these issues, alternative gears are discussed for many fisheries around the world (Žydelis et al., 2013), e.g., the Baltic SSF fisheries (ASCOBANS, 2016). Fish pots are passive, easily transportable, typically baited, stationary fishing gears consisting of small, net enclosures with entrances that facilitate entry while impeding exit for target species (Königson et al., 2015a; Ljungberg et al., 2016; Meintzer et al., 2017; Thomsen et al., 2010). The negative environmental impacts of fish pots are relatively inconsequential (Grabowski et al., 2014; Ovegård et al., 2011; Shester and Micheli, 2011; Suuronen et al., 2012; Thomsen et al., 2010). Importantly, pots have low to no bycatch potential for harbour porpoises (*Phocoena phocoena*) and seabirds, because the risk of entanglement or accidental catch in the pots is assumedly lower than with gillnets (Martin and Crawford, 2015; Žydelis et al., 2009). Additionally, seal-proof pot designs are available to protect the fish inside the pot from depredation (Königson et al., 2015b; Ljungberg et al., 2016). Also, pots allow the catch to be collected alive, increasing catch quality and maximising survival rates for unwanted bycatch (Furevik, 1994; Humborstad et al., 2016; Ovegård et al., 2011; Suuronen et al., 2012). However, catch rates of pots are still low in many fisheries, including pot fisheries for Atlantic cod (*Gadus morhua*; henceforth termed cod) in the Baltic Sea (Anders et al., 2017; Jørgensen et al., 2017; Suuronen et al., 2012), prompting many studies in recent decades to improve pot design and thereby improving catch efficiency (e.g., Bjordal and Furevik, 1988; Carlile et al., 1997; Furevik et al., 2008; Furevik and Løkkeborg, 1994; Jørgensen et al., 2017; Ovegård et al., 2011). Studies have revealed that only a small number of the cod approaching a pot find the entrance and manage to enter the pot (e.g., Meintzer et al., 2017; Valdemarsen et al., 1977). Such findings indicate that pot entrances are catchability bottlenecks (Furevik, 1994; Thomsen et al., 2010). Key performance characteristics include ‘perceptibility’ (how probable are fish to find the entrance), ‘attractivity’ (how probable are fish to attempt entering through the located entrance), ‘ease of access’ (how probable are fish to then successfully pass the entrance), and ‘retention capacity’ (how probable are fish to remain inside the pot), determined by the entrances’ position in the pot (Furevik et al., 2008; Hedgärde et al., 2016; Thomsen et al., 2010), as well as by their design (Furevik, 1994; Furevik and Løkkeborg, 1994; Ljungberg et al., 2016; Olsen, 2014). Pot entrances are typically funnel shaped (Furevik, 1994), with the funnel design strongly influencing catch efficiency (e.g., Furevik and Løkkeborg, 1994; Ljungberg et al., 2016). Examples of relevant design aspects of the funnel are opening size (e.g., Carlile et al., 1997; Furevik and Løkkeborg, 1994), shape (Königson et al., 2015b), angle (Carlile et al., 1997; Ljungberg et al., 2016), and material (High and Ellis, 1973). A thorough understanding of the fish–gear interaction is essential to improving catch efficiency (He, 2010). For fish pots, this is difficult to investigate with catch-per-unit-effort metrics, i.e., the number of fish in a pot after hauling, which do not provide direct information regarding the sequence of fish–pot interaction, including the crucial relationship between entry- and exits rates, causing the observed differences in catch efficiency between different pot designs (Furevik and Løkkeborg, 1994; Hedgärde et al., 2016). Pot catch efficiency is thus a function of entry probability and exit probability (see Fig. 1 for a schematic catch efficiency illustration). Consequently, observational studies of fish–pot interactions, particularly using *in situ* video, have shed light on the basic principles of fish-pot catch efficiency (e.g., Hedgärde et al., 2016; Ljungberg et al., 2016; Meintzer et al., 2017; Renchen et al., 2012).

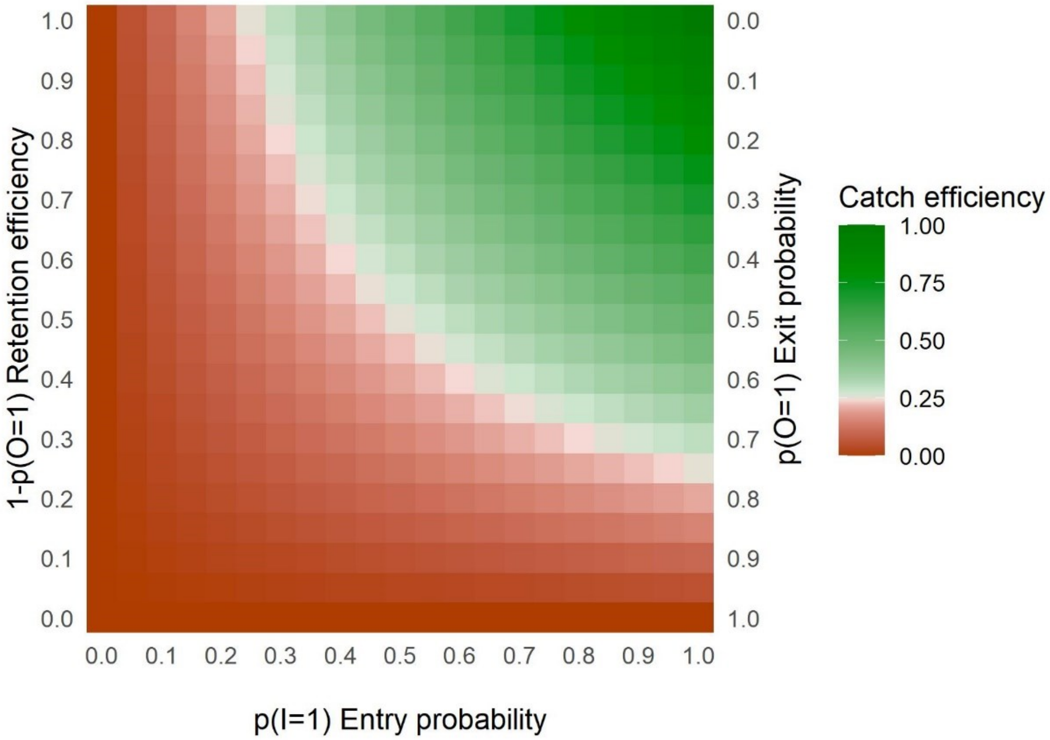


Fig. 1. **Schematic representation of the dependence of pot-catch efficiency on access and escape probability of pot entrances.**

The explanatory power of field observational studies, however, is limited, because this approach does not include controlling the intrinsic (e.g. fish hunger) and extrinsic (e.g. fish density, temperature) parameters that affect pot catch rates (e.g., Stoner, 2004, 2003; Stoner and Ottmar, 2004; Stoner and Sturm, 2004). Therefore, we developed a novel method for faster, more efficient and direct comparison of pot design in the controllable environment of a net pen. To determine optimal cod-pot design parameters, we address the following questions:

(1) How does the diel period affect cod–gear interaction? So far, video studies of cod interaction with pots have been conducted either only by day (Anders et al., 2017, 2016; Ljungberg et al., 2016; Meintzer et al., 2017) or during the day and at night under strong artificial lighting (Hedgärde et al., 2016) in the spectral visual range of cod (Bowmaker, 1990). Therefore, these studies have limited explanatory power for a general description of the diurnal pattern of cod–pot interactions, which could influence cod-pot catch efficiency. Therefore, we used an infrared camera system (IR) to observe cod during the day and at night.

(2) How do entrance design parameters affect cod entry and exit rates? First, we studied the effect of funnel colour, because the colour of fishing gear is important in shaping cod–gear interaction, and thus catch success (Arimoto et al., 2010). Colour influences the perceptibility of the entrance by determining its visibility and its contrast to the background and other parts of the pot. Then, we tested the effect of funnel presence and length, because the findings concerning the effect of funnel length on entry and exit probabilities have been inconclusive so far (Li et al., 2006a, 2006b; Walsh and Hiscock, 2005). Finally, we studied the effect of entrance shape by studying cod interactions with a narrow funnel entrance. Such entrances are commonly used in some fisheries (Furevik and Løkkeborg, 1994; Li et al., 2006b, 2006a), although results for cod are limited (Furevik and Løkkeborg, 1994; He and Winger, 2010).

(3) How does cod social behaviour affect entrance interaction? Cod entrance probability into pots is influenced by social foraging behaviour (Anders et al., 2017; Hedgärde et al., 2016). We investigated

if leader–follower dynamics (e.g., Björnsson et al., 2018; Millot et al., 2012) modify pot-entrance interactions.

Material and Methods

Experiments were conducted during December 2018 and March–April 2019 in the sporting marina of Rostock-Warnemünde, Germany (Fig. A1, 54°10'52.7''N 12°05'18.0''E).

Cod used in experiments

A total of 544 cod were caught using bottom trawl, fish pot, or hook and line and of these 152 were included in the experiment (Table 1). To minimise cod stress and exhaustion, fishing depth was shallower than 20 m, and trawl haul duration was limited to 30 min. Most cod were caught off the coast of Rostock-Warnemünde near the location of the experiment and transported in a fish tank with constant seawater supply to the holding net pen the same day. All cod were transferred to the holding net pen (see below) the same day they were caught and had at least 4 days acclimation time before inclusion in an experimental trial. Cod were fed *ad libitum* with thawed and cut herring (*Clupea harengus*) once a week. Before they were included in an experiment, cod were not fed for at least a week, because elevated hunger levels in fish are linked to greater motivation to enter fish pots (Thomsen et al., 2010; Ljungberg et al., 2019; Ovegård et al., 2012). Because the motivation of cod to enter pots is socially mediated (Anders et al., 2017) and cod pots are usually encountered by more than one cod during their soak time (e.g., Anders et al., 2016; Hedgärde et al., 2016; Ljungberg et al., 2016), groups of eight cod were used in each trial. Because cod are cannibalistic (e.g., Hardie and Hutchings, 2011) and to avoid social stress, cod groups in trials were within a similar length range (30–39 cm, 40–49 cm and 50–59 cm). Since cod possess complex learning strategies and long-term memory (Meager et al. 2018), only naïve cod were used and cod were not re-used in subsequent trials.

Table 1: Catch date and gear for experimental cod. Please note that 'Total number of caught cod' is the total number of cod caught, of which only a fraction were included in the experiment. 'In experiment' is the number of the caught cod included in the experiments.

Fishing gear	Date caught	Total number caught cod
Fish pot	27.11.2018	48
Bottom trawl	05.12.2018	67
Bottom trawl	15.01.2019	100
Bottom trawl	12.02.2019	156
Fish pot/hook& line	11.04.2019	26
	Sum	544
	In experiment	152

Experimental setup

Two identical net pens (dimensions 3 × 3 × 3 m = 27 m^3; Mieske, 1998; see Fig. A2) were used; one was used for experimental treatments, the other for holding the fish before experiments. An experimental pot (W 250 cm; D 140 cm; H 100 cm) with two side-by-side entrances was constructed and positioned inside the net pen (Figs. A3 and A4). The pot frame was made of standard PVC tubes and had green PE netting (Polyethylene, 25 mm bar length). Fish pot entrances were mounted on (120 × 100 cm) PVC-tube frames and could be exchanged. We used a funnel as baseline entrance type for indirect comparisons (white PA (Polyamide) netting, L 50 cm, 60 × 60 cm outer opening and 20 × 20 cm inner opening; Fig. 2; hereafter 'control entrance'). The control entrance and all test funnels had a 25 mm mesh bar length. The general design of the funnels was based on the two-chambered cod pot developed by Furevik et al. (2008) and used in several pot studies (e.g., Bryhn et al., 2014; Jørgensen et al., 2017; Ovegård et al., 2011). Because we were limited in size by the space available in the net pen, we used a square opening design instead of the rectangular opening used by Furevik et al. (2008).

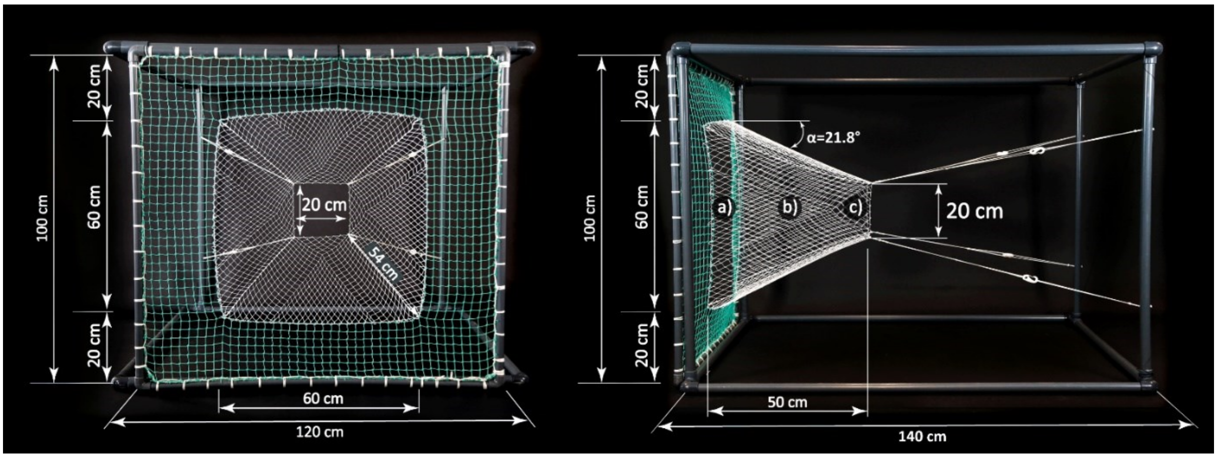


Fig. 2. **Control entrance (white PA funnel, 25 mm mesh size, 60 × 60 cm outer opening and 20 × 20 cm inner opening, L 50 cm) used for experiments. Left front, right side view. The nomenclature used for parts of a cod entrance is indicated on the side view: (a) outer opening; (b) funnel; (c) inner opening. The single opening of the 'No funnel' entrance is also referred to as 'Inner opening' in the analysis. Illustration of all other entrance types is available in the appendix.**

Movements were not limited inside the pot, and cod could freely move from one entrance to the other. Olfactory bait (e.g. cut herring) could not be used, as it typically rapidly loses most of its effectiveness after 1.5 h (Løkkeborg, 1990; Westerberg and Westerberg, 2011). Furthermore, olfactory bait plumes are current dependent (Løkkeborg, 1998, 1990; Vabø et al., 2004), thus possibly introducing a side bias where the experimental cod prefer one entrance side to the other. To provide a long-lasting attractant to lure the cod into the pot, we placed a green fishing bait light (model "Deep water fishing light", 523 nm peak wave length, intensity 124 µW, Manufacturer Artisan fisheries consultants, Spain; Bryhn et al., 2014; Utne-Palm et al., 2018) at mid-pot height in the pot centre, in equal distance to both entrances. Data were collected in paired trials, each experimental trial consisting of a test entrance set in the pot together with the control entrance. To avoid possible bias caused by cod side preferences, at least two replicates were conducted for each comparison, while switching the side of entrance types between replicates. For each trial of a particular test entrance–control entrance combination, eight cod of the same length classes were randomly fetched and set into the experimental pen. After at least 15 minutes acclimation time the pot was then lowered into the net pen, indicating the start of the experiment. Each trial was conducted from ~14:00 to 13:30 the following day. Water temperature ranged from 4.0 °C to 5.0 °C in December 2018 trials and from 3.5 °C to 10.0 °C at the end of the experiment on 28. April 2019.

Tested entrance types

To test the influence of funnel colour, length and shape, we used pot entrances, differing from the control entrance by only one design parameter (Table 2; pictures included in appendix (Fig. A5)).

Table 2: **Description of pot entrances included in the experiments. Each modified entrance type was compared with the 'White funnel' control entrance. Illustrations of entrance types can be found in Fig. 2 (control entrance) and Fig. A5 (control and all other entrance types). Abbreviations: PA = Polyamide; PE = Polyethylene; d = diameter.**

Name	Twine type	Mesh size [mm]	Outer opening dimension [cm]	Funnel length [cm]	Inner opening dimension [cm]	Parameter tested
White funnel (control entrance)	PA white multifilament d = 0.9 mm	25	60 × 60	50	20 × 20	Control
Green funnel	PE green multifilament d = 1.2 mm	25	60 × 60	50	20 × 20	Funnel colour
Transp. funnel	PA transparent monofilament d = 0.5 mm	25	60 × 60	50	20 × 20	
No funnel	–	–	–	–	20 × 20	Funnel length
Long funnel	PA white multifilament d = 0.9 mm	25	60 × 60	75	20 × 20	
Narrow funnel	PA white multifilament d = 0.9 mm	25	60 × 60	50	Height: 20 cm & Width: 2.5 cm	Funnel shape

Fish observation

Infrared (IR) camera system

To study fish, including cod, in darkness without influencing their behaviour, IR light is often used (e.g., Meager et al., 2006; Utne-Palm et al., 2018). Therefore, we developed an infrared (IR) lamp and camera system, 'infrared Fish Observation' (iFO; Hermann et al., *in press*) to observe cod day and night in this study. The system can record videos at visible as well as IR light and has a minimum observation range of 1.8 m, video data storage capacities for several weeks, a rapidly swappable datadisk, and remote access connection through a webserver with live stream. In this study, we used two iFO systems, each with one camera and two IR lamps (Figs. A3 and A4; centroid frequency 850 nm).

Radio-frequency identification (RFID) of cod

Cod were implanted with passive integrated transponders (PIT tags; 32 mm long half-duplex; manufactured by Oregon RFID, Oregon, USA; animal welfare permit 7221.3-1-009/18 of the Agency for agriculture, food safety and fishery of the Federal State Mecklenburg-West Pomerania in Germany), and each entrance was equipped with two radio-frequency identification (RFID) antennae (Figs. A3 and A4). However, owing to technical difficulties, we refrained from analysing these data. Nevertheless, they were used to improve the manual analysis of the video recordings (see below) by allowing us to pinpoint periods of increased entrance interaction before detailed video analysis and by helping us to disaggregate event timings when several cod interacted simultaneously with an entrance.

Behavioural analysis

To provide a comprehensive description of the event chain of cod interacting with the pot entrances, we constructed a detailed ethogram and a behavioural flow diagram (Fig. 3; Table 3), adapting prior behavioural analysis approaches (Anders et al., 2016; Ljungberg et al., 2016; Meintzer et al., 2017; Santos et al., *in press*). Most behavioural units were mutually exclusive events with quantifiable duration. The exception was the brief (<1 sec) touching of entrance structures that occurred when individuals were inside the funnel or near the inner entrance opening (event 'net contacts'). These contacts could be directed, inquisitive touches, usually during the day, or inadvertent bumps with the entrance when trying to pass, most often at night. Additionally, inspection and herding (leader–follower) events were also logged, with 'herding' defined as one or more fish following the swimming path of a leader cod. Inspection of the different structural entrance elements involved reduced swimming speed, contorted swimming paths to approach different parts of the entrance, gaze directed not ahead of their swimming path but directed at the entrance/funnel and sometimes targeted net contacts. Cod leaving the camera field of view (FOV) for <5 sec were considered staying within the same event. Videos were analysed with the software BORIS (Behavioural Observation Research Interactive Software) version v. 7.9.7 (Friard and Gamba, 2016). Each trial was fully analysed by one observer.

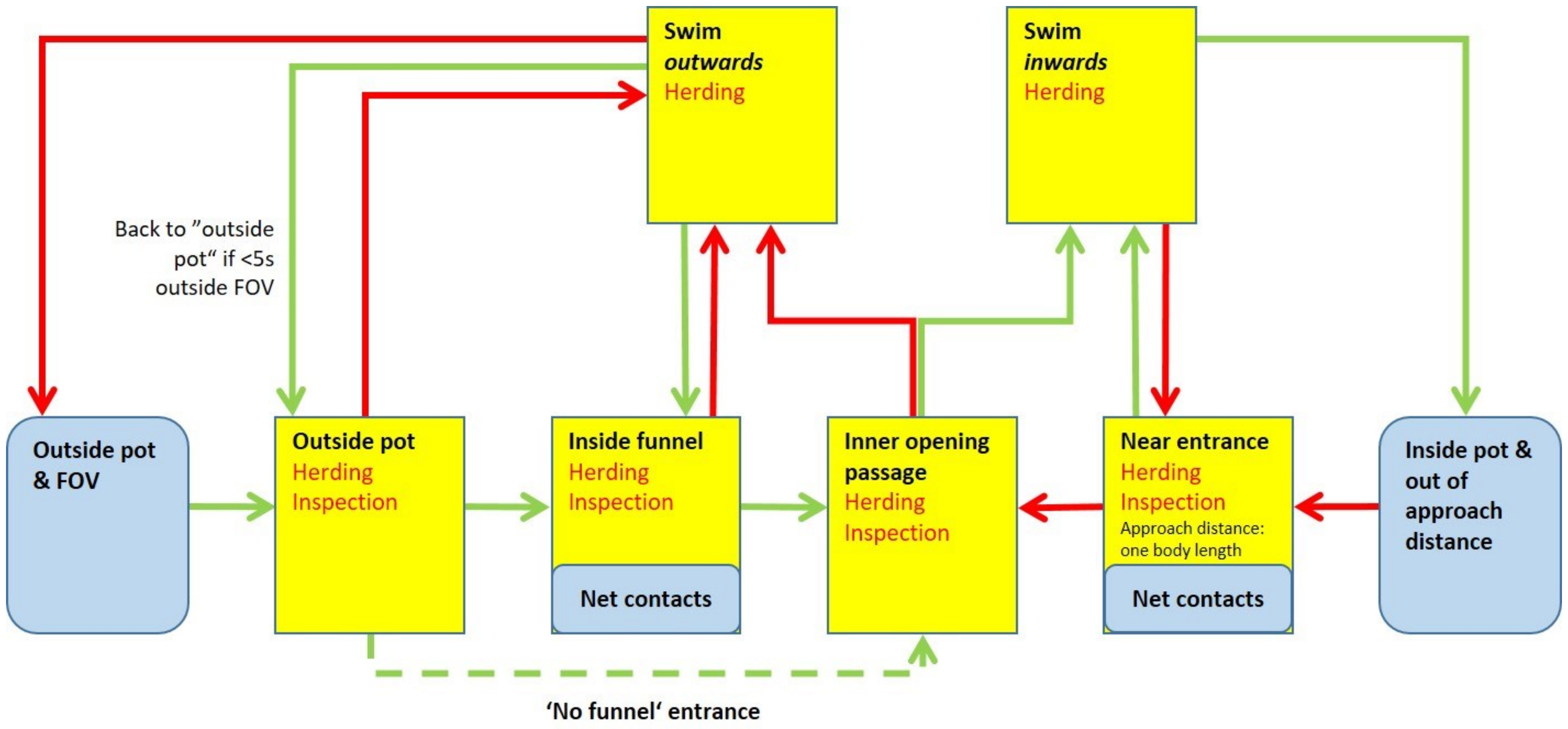


Fig. 3. Behavioural flow diagram of pot-interaction event chains. Blue boxes: point events (no duration); yellow boxes: state events (with duration); black: event type name; red: event modifier; green arrows: movements from the outside inwards; dashed green arrow: movement for 'no funnel' entrance; red arrows: from inside the pot outwards. Definition of event modifier: 'Herding' is defined as one or more fish following the swimming path of a leader cod; 'Inspection' indicates that a cod is inspecting structural elements during the event (see text for explanation). On the outside, an event chain starts or ends when a cod enters or leaves the camera field of view (FOV) outside the pot (event 'Outside pot and FOV'). On the inside, an event starts or ends when a cod approaches the inner entrance opening to within one body length or increases its distance from it to more than one body length.

Table 3: **Behavioural ethogram of cod interactions with pot entrances illustrated in the behavioural flow diagram (Fig. 3). For “Starting point” and “Endpoint”, “*Inwards*” describes a cod swimming *towards* the pot inside while “*Outwards”* describes a cod swimming towards the pot exterior.**

Event	Event type	Description	Starting point	Endpoint	Event modifier*
Outside pot	State	Cod is outside the pot entrance, gaze directed at entrance.	*Inwards:* Cod enters FOV (event chain begins). *Outwards:* When two-thirds of body length has passed outer entrance opening and cod does not directly leave FOV (previous event: ‘Swim outwards’).	*Inwards:* Tip of cod snout passes outer entrance opening (next event: ‘Inside funnel’ or ‘Inner opening passage’ if ‘No funnel’ entrance). *Outwards:* Cod turns and starts to swim outwards (next event: ‘Swim outwards’).	Herding, Inspection
Inside funnel	State	Cod is inside the funnel (excluding direct outward swimming) Note: Does not apply to ‘No funnel’ entrance.	*Inwards:* Tip of cod snout passes outer entrance opening (previous event: ‘Outside pot’). *Outwards:* Cod aborts swimming outwards (previous event: ‘Swim outwards’).	*Inwards:* Tip of cod snout passes inner entrance opening (next event: ‘Inner opening passage’). *Outwards:* Cod turns and starts to swim outwards (next event: ‘Swim outwards’).	Herding, Inspection
Swim outwards	State	Cod swims towards pot outside (outside inner opening).	*Inwards:* Cod turns and starts to swim outwards (previous event: ‘Outside pot’ or ‘Inside Funnel’). *Outwards:* Two-thirds of cod passed entrance inner opening and cod starts swimming outwards (previous event: ‘Inner opening passage’).	*Inwards:* Cod swims backwards or turns >90° towards pot inside (next event: ‘Outside pot’ or ‘Inside funnel’). *Outwards:* Cod leaves FOV outside the pot (end of event chain).	Herding
Inner opening passage	State	Cod passes inner opening of entrance in either direction.	*Inwards*: Cod snout enters inner opening (previous event: ‘Inside funnel’ or ‘Outside pot’ for ‘No funnel’ entrance). *Outwards:* Cod snout enters inner opening (previous event: ‘Near entrance’).	*Inwards:* Two-thirds of cod body length passes the inner opening towards inside of pot (next event: ‘Swim inwards’). *Outwards:* Two-thirds of cod body length passes the inner opening towards outside pot (next event: ‘Swim outwards’).	Herding, Inspection

Event	Event type	Description	Starting point	Endpoint	Event modifier*
Near entrance	State	Inside pot, when (a) cod is within one body length of inner opening, (b) its gaze is towards the inner opening, (c) swimming path deviation towards inner opening, usually concurrent with an abrupt prior deceleration.	*Inwards*: Cod aborts inward swimming and turns back towards inner opening (previous event: 'Swim inwards'). *Outwards:* Cod approaches opening to within one body length, attention directed towards opening (begin of event chain).	*Inwards:* Cod turns away from entrance (next event: 'Swim inwards'). *Outwards:* Cod snout enters inner opening (next event: 'Inner opening passage').	Herding, Inspection
Swim inwards	State	Cod swims towards pot inside (inside pot).	*Inwards*: Cod starts swimming towards pot inside (previous event: 'Inner opening passage'). *Outwards:* Cod aborts inner opening approach and turns towards pot inside (previous event: 'Near entrance').	Inwards: Cod is more than one body length away from entrance/funnel inner opening (end of event chain). If cod re-approaches the opening to within one body length in <5 sec, it is still considered in the same event pass. *Outwards:* Cod turns back again towards opening (next event: 'Near entrance').	Herding
Net contacts	Point	Cod touches entrance netting with snout.	–	–	-

*Event modifier:

Herding: Cod exhibit a behavioural pattern involving one leader and one or more followers.

Inspection: Cod in event is visually inspecting any parts of the entrance. Inspection is discernible from the eye movement as well as the body position that cod dynamically adjust to inspect their point of interest.

Statistical analysis

The pot-entrance catch-efficiency metric is a function of entry and exit/retention probability (Fig. 1). 'Entry' is defined as the passage of a cod from outside the pot to inside the pot; 'exit' is defined as the passage of a cod from inside the pot to outside the pot. For each entry or exit event, a cod could choose either the test or the control entrance, respectively. Therefore, observed entries and exits for each experiment were treated as paired (control entrance vs. test entrance) comparison data. To address the study's research topics, we used two different methods.

Using the first method, we compared the number of successful entries and exits of both entrance types, using a generalised linear model (GLM). A successful entry or exit is defined as an event chain starting outside the pot and ending inside the pot, or vice versa. In an exploratory data analysis, potential covariables on entrance interactions were evaluated to determine if they could have influenced the entrance interactions and should be included in the analysis. The following were chosen for inclusion: (1) To account for possible side preference, the side of the control entrance was included as a blocking factor in the full model. (2) Although most entrance interactions occurred during the day, we also included 'day period' in the full model with two states: 'day' (time between sunrise and sunset) and 'night' to reflect possible differences in diurnal entrance/exit patterns. Day period information (sunset, sunrise, civil dawn, civil dusk) was acquired using R suncalc package (Thieurmel and Elmarhraoui, 2019). Time is in local time (CET = UTC + 1h). For each pairwise comparison, the entry and exit proportion was modelled as follows:

Being I/O, the binary variable expressing the entrance used by the observed fish to enter (I) or exit (O) the pot (0 = control, 1 = test), and X a three-dimensional vector including the model intersect, and the dummy variables representing side where the test is positioned (0 = left, 1 = right) and day period (0 = day, 1= night), then $p(X) = p(\gamma = 1|X)$ is the expected probability of either entry or exit in the test, conditioned to side and day period. A $p(X)$ of 0.5 indicates no difference between test and control entrance, while values less than 0.5 indicate lower entry or exit rates for the test entrance than for the control entrance. The product of both probabilities ($p(I = 1) * p(O = 1) = 0.25$) would then express equal catch efficiencies between control and the paired test entrance. Following the same argumentation, unequal catch efficiency resulting in values greater than 0.25 would indicate higher catch efficiency of the test entrance relative to the control, while values below 0.25 would indicate the opposite. The binary GLM applied expresses $p(X)$ as:

$$\log(p(X)/(1 - p(X))) = \beta_0 + \beta_1 * side + \beta_2 * dayperiod \quad (1)$$

On the right hand model side, the coefficient β_0 is the model intercept, and β_1 and β_2 quantify the potential effect of side and day period on entry and exit probability in the test entrance. The models were fitted with the statistical software R (3.6.3, R Core Team, 2020). In addition to Model (1), all possible simpler models were calculated, and the final model selected from the candidates via AIC (Akaike, 1973). To calculate the isolated entrance effect on the catch entry and exit from the final models with more than one covariate, we used the r contrast.sum() function to access the intercept value contrasted with the other covariates. The GLM analysis is a coarse first approach that allows the inference of strong differences between the control and the test entrance. This, however, does not reveal the underlying mechanism leading to possible differences in interaction and does not allow the incorporation of the information provided by aborted atempts at entry or exit.

Therefore, we used the second method to determine at which point in the event chain control- and test-entrance types provoked different reactions by the interacting cod. We adapted and applied a hierarchical tree classification method of Santos et al. (*in press*). The individual event chains of cod entrance interactions were pooled for each experiment and across replicates. These event chains were then arranged in an inverted tree-like structure with the root containing the total number of observations on top. Each behavioural node in the level immediately below the root contained counts of observed entry/exit events, either in the test or control entrance. After this first level, different event chains were encompassed in one branch up to the parent node, where they differed. At this point, the event chains split into branches. Then, each one could once again contain several event chains that separated at lower event levels, creating the tree. The terminal leaves at the end of each event chain represented the final fate of the observed cod 'Inside pot' or 'Outside pot.' Based on the information contained in the tree, the marginal probability (MP) for a given behavioural event to happen is calculated as:

$$MP = P(N_i) = \frac{N_i}{Root} \tag{2}$$

where N_i is the number of cod performing the event i (node i), and *Root* is the total number of observed interactions. Similarly, the conditional probability (CP) that an event i could happen, given the MP of its parent link k in the level immediately above, is:

$$CP = P(N_i|N_k) = \frac{N_i}{N_k} \tag{3}$$

Trees were constructed for each experiment once for entrance interactions starting at the pot outside and once starting at the pot inside. To account for behavioural variability that occurs naturally between and within experimental replicates, we adapted and applied a double bootstrap method often used in trawl selectivity studies (Millar, 1993). Each iteration of the bootstrap produces an artificial tree after resampling experimental replicates and observations within the resampled replicates. This procedure was repeated B=1000 times, leading to 1000 artificial trees, allowing calculation of 95% Efron-percentile Confidence Intervals associated with the average probabilities (Equations 2 and 3) from the empirical tree (Santos et al., *in press*; 2016). The resulting trees were inspected for differences in event-chain flows and event links of both main entrance branches, based on MP and CP. Little or no CI overlap between the same event-chain links of both entrance types indicated significant differences.

Results

In total, we analysed 19 trials with a total duration of 435.0 h (Table 4 and Table A1). In rare cases, the video cameras stopped recording for short periods (seconds to minutes). For instances when the video cameras stopped recording, the periods were excluded from analysis for both entrances within the trial.

Table 4: Overview of entry and exit numbers of all trials conducted by different entrance types (Test) compared with 'White funnel' entrance (Control); 'Position control' indicates on which pot side the control entrance was situated. Total entries, respectively, exits through test/control entrances. Cod mean length given with standard deviation.

Tested entrance	Trial number	Position control	Entries		Exits		Cod mean length [cm]
			Control	Test	Control	Test	
Green funnel	1	Left	4	3	0	2	43.3 ± 1.4
Green funnel	2	Right	3	12	2	5	44.8 ± 2.9
Green funnel	3	Right	14	7	9	5	44.8 ± 2.2
Green funnel	4	Right	9	17	6	13	36.5 ± 1.7
Green funnel	5	Right	22	7	15	7	43.1 ± 2.8
Green funnel	6	Left	12	12	6	11	35.6 ± 2.4
		Sum	64	58	38	43	
Transparent funnel	7	Left	3	6	0	2	36.4 ± 2.8
Transparent funnel	8	Right	1	3	0	2	37.0 ± 2.6
Transparent funnel	9	Right	10	3	3	3	44.5 ± 2.3
Transparent funnel	10	Left	6	21	1	19	37.1 ± 1.3
Transparent funnel	11	Left	10	1	2	1	44.4 ± 2.3
Transparent funnel	12	Right	14	31	3	33	54.9 ± 3.1
		Sum	44	65	9	60	
No funnel	13	Left	17	15	0	24	44.5 ± 3.2
No funnel	14	Right	34	65	2	91	35.3 ± 2.3
No funnel	15	Left	115	17	9	111	34.5 ± 3.4
		Sum	166	97	11	226	
Long funnel	16	Right	4	6	2	0	36.3 ± 1.7
Long funnel	17	Left	37	37	66	0	53.3 ± 2.0
		Sum	41	43	68	0	
Narrow funnel	18	Right	11	2	6	0	41.3 ± 1.1
Narrow funnel	19	Left	7	1	0	0	36.5 ± 1.7
		Sum	18	3	6	0	

Diurnal activity pattern

Throughout all trials, we observed a pronounced activity decrease at night (Fig. 4). In the first hours after starting each trial, cod interacted intensively with the entrances. This activity decreased towards the evening, after which almost no nightly interaction with the entrances occurred. Most of the few nightly interactions are approaches to the entrances from the inside (shown as aborted exits in Fig. 4).

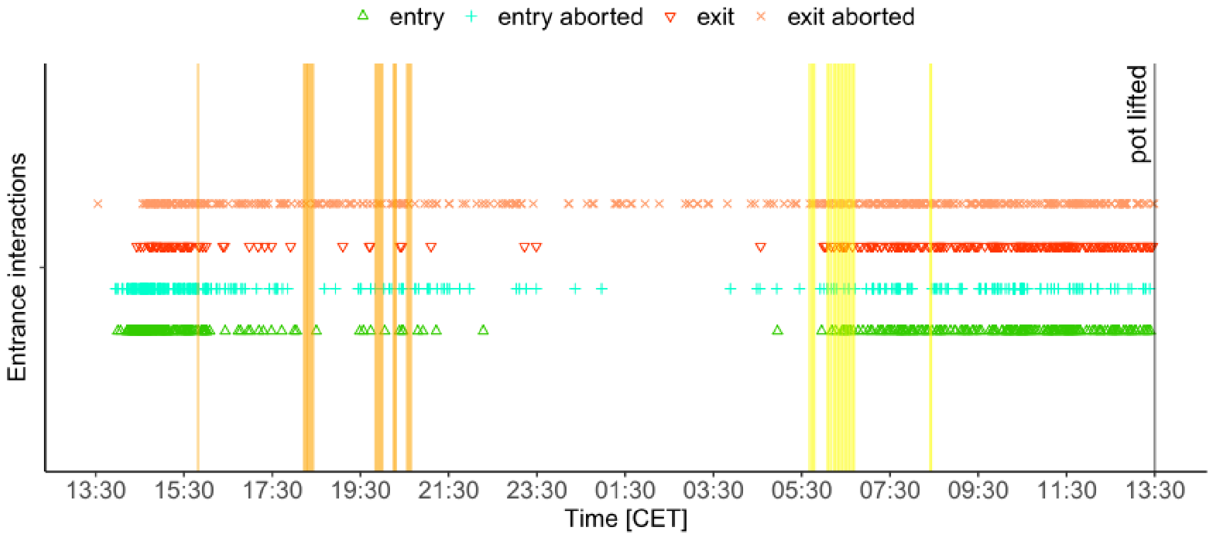


Fig. 4. **Gantt chart of entry, aborted entry, exit, and aborted exit events of all trials with entrances including funnels (16 trials). Orange vertical lines indicate sunset; yellow vertical line indicate sunrise. All vertical lines have identical thickness, but trials on consecutive days appear as thicker lines. Pots were always lifted at 13:30 h, except for one replicate where the pot was lifted at 13:56 h. Start times varied between 13:35 and 15:57 h. The Gant chart for each of the experiments included here can be found in the appendix (Figs. A6 to A9).**

The IR-camera system did not illuminate the whole pot inside. Cod moved less during morning and evening twilight, and almost no movement occurred during the night proper. Cod inside the pot appeared to follow a net-wall-guided search pattern where they swam along the net wall and frequently touched it with the snout or pectoral fins. When swimming into a pot corner, or against the funnel, fish usually turned to the side away from the net wall and then continued swimming (Fig. 5A). When the cod thus passed the inner opening of the funnel (Fig. 5B), they would continue towards the pot wall opposite and not exit through the inner opening. In contrast, the ‘No funnel’ entrance lacked this deflection mechanism (Fig. 5C). Here, cod exited notably more during twilight (‘No funnel’ exits = 36, control entrance exits = 2; Fig. 6). For night and twilight entries, there was no strong difference between both entrances, with fewer entries through the ‘No funnel’ (entries = 15, control entrance entries = 19).

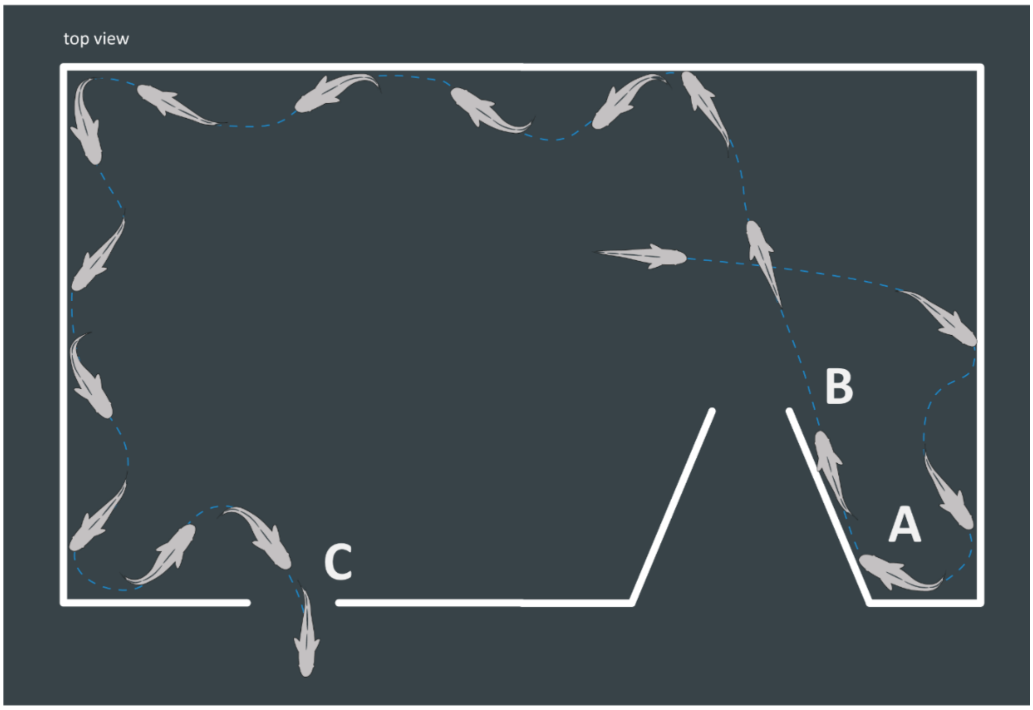


Fig. 5. **Net-wall-guided search pattern at twilight; left side without funnel and right pot side with funnel.**

Starting around civil dawn, cod activity increased, swimming actively throughout the pot. But for all entrances, except the ‘No funnel’ (Fig. 6), cod started passing the entrances again only shortly after sunrise, and the highest entrance-passage rates were observed in the period after sunrise.

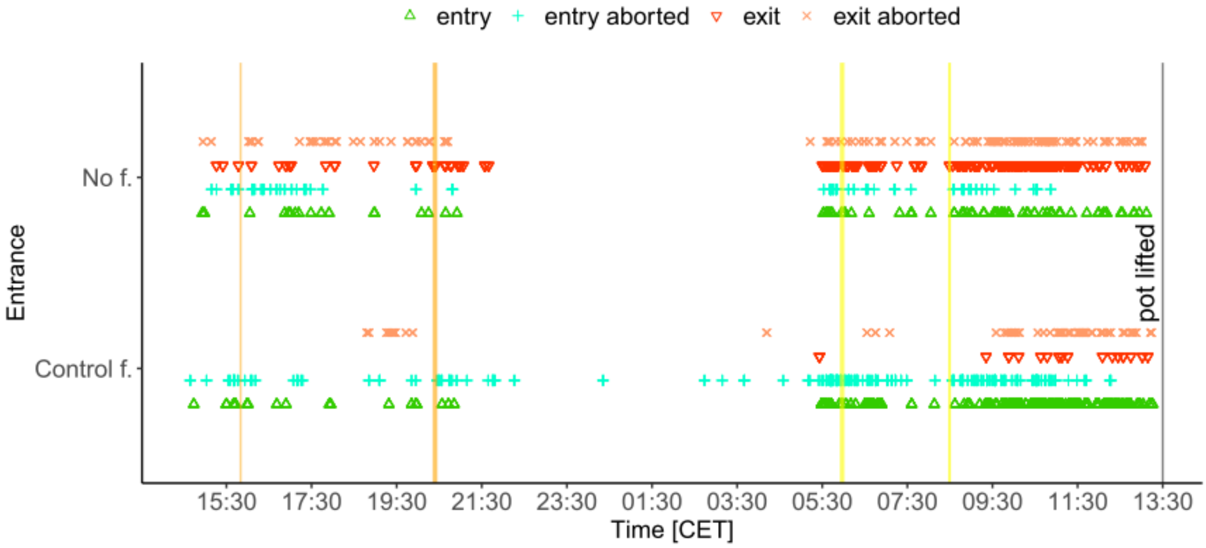


Fig. 6. **Gantt chart of entry, aborted entry, exit, and aborted exit events in the ‘No funnel’ experiments (three replicates). Orange and yellow vertical lines indicate sunset and sunrise, respectively.**

Table 5: GLM parameters of all experiment final models. 'Test entrance' indicates the experiment, 'Model' indicates if the model is for the entries or the exits of the experiment, 'Side' and 'Day period' are the covariates, 'D. o. f.' are the model degrees of freedom, and p(I/O = 1) indicates the probability that an entry or exit occurred through the test entrance. Note that *, **, and * denote that the Wald-test *p*-value is <0.05, <0.01, and <0.001, respectively. Significant values in are bold. N/I stands for 'Not included' in the final model.**

Test entrance	Model	Intercept	Side	Day period	Deviance	D. o. f.	p(I/O = 1)
Green funnel	Entries	−0.098 ± 0.181	N/I	N/I	168.83	121	0.48 (0.39–00.56)
	Exits	1.022 ±0.587	0.405 ±0.281	−0.769 ±0.564	107.20	78	0.74 (0.47–0.90)
Transparent funnel	Entries	0.390* ±.195	N/I	N/I	147.03	108	0.60 (0.50–0.68)
	Exits	1.897*** ±.357	N/I	N/I	53.44	68	0.87 (0.77–0.93)
No funnel	Entries	−0.385** ±0.145	−1.033*** ±0.145	N/I	289.26	261	0.41 (0.34–0.47)
	Exits	3.263*** ±0.397	−0.555 ±0.397	N/I	86.65	235	0.96 (0.92–0.98)
Long funnel	Entries	0.048 ±0.218	N/I	N/I	116.40	83	0.51 (0.41–0.62)
	Exits	No exits through 'long funnel'					
Narrow funnel	Entries	−1.792** ±0.624	N/I	N/I	17.23	20	0.14 (0.05–0.36)
	Exits	No exits through 'long funnel'					

Funnel colour effect on catch efficiency

Green funnel

Six replicates were conducted for the comparison of the 'White funnel' (control entrance) with the 'Green funnel' (Table 4). The final model for the expected probability to enter through the 'Green funnel' included only the intercept, indicating that side and day period had no influence on the entry (Table 5). Entry rate $p(I = 1)$ was 0.48, so very similar to the control entrance. As both main branches are almost identical, the behavioural event-chain tree underlines this pattern (Fig. 7).

The final exit model included side and day period (Table 5), with a higher, but not significant, exit rate through the 'Green funnel' ($p(O = 1)$ = 0.74). The behavioural event-chain tree reveals that this was possibly because more cod approached the 'Green funnel' inner opening (Fig. 8). However, the CI of the first level nodes as well as of the following nodes overlap, indicating no significant difference. Therefore, the observed difference is at least partly the result of a side effect and more nightly exits through the 'Green funnel' (night exits: 'Green funnel' n = 5, control n = 1).

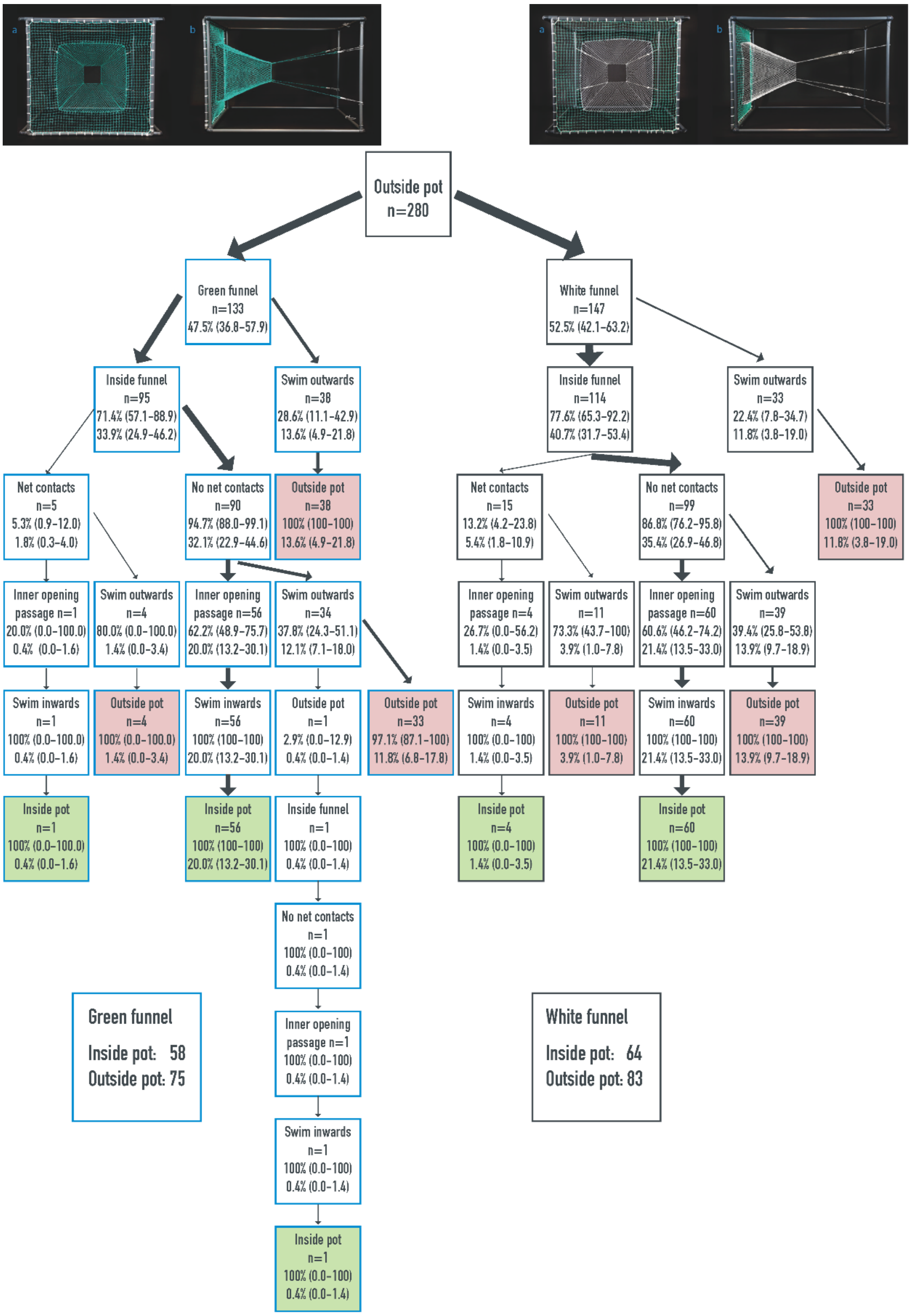


Fig. 7. **Behavioural event-chain tree comparing the 'Green funnel' (Test) with the 'White funnel' (Control) for cod interactions with pot entrances starting outside. Each box represents an event type; the first line gives the event type name; the second line gives number of times this event was observed at this point of the event chain; the third line gives the marginal probabilities (MP), related to the total number of interactions; and the last line gives the conditional probabilities (CP), related to the number of interaction in the parent link (the link above a respective link). Confidence intervals are based on 1000 bootstrap iterations. The thickness of each arrow is representative of the MP the arrow is pointing to.**

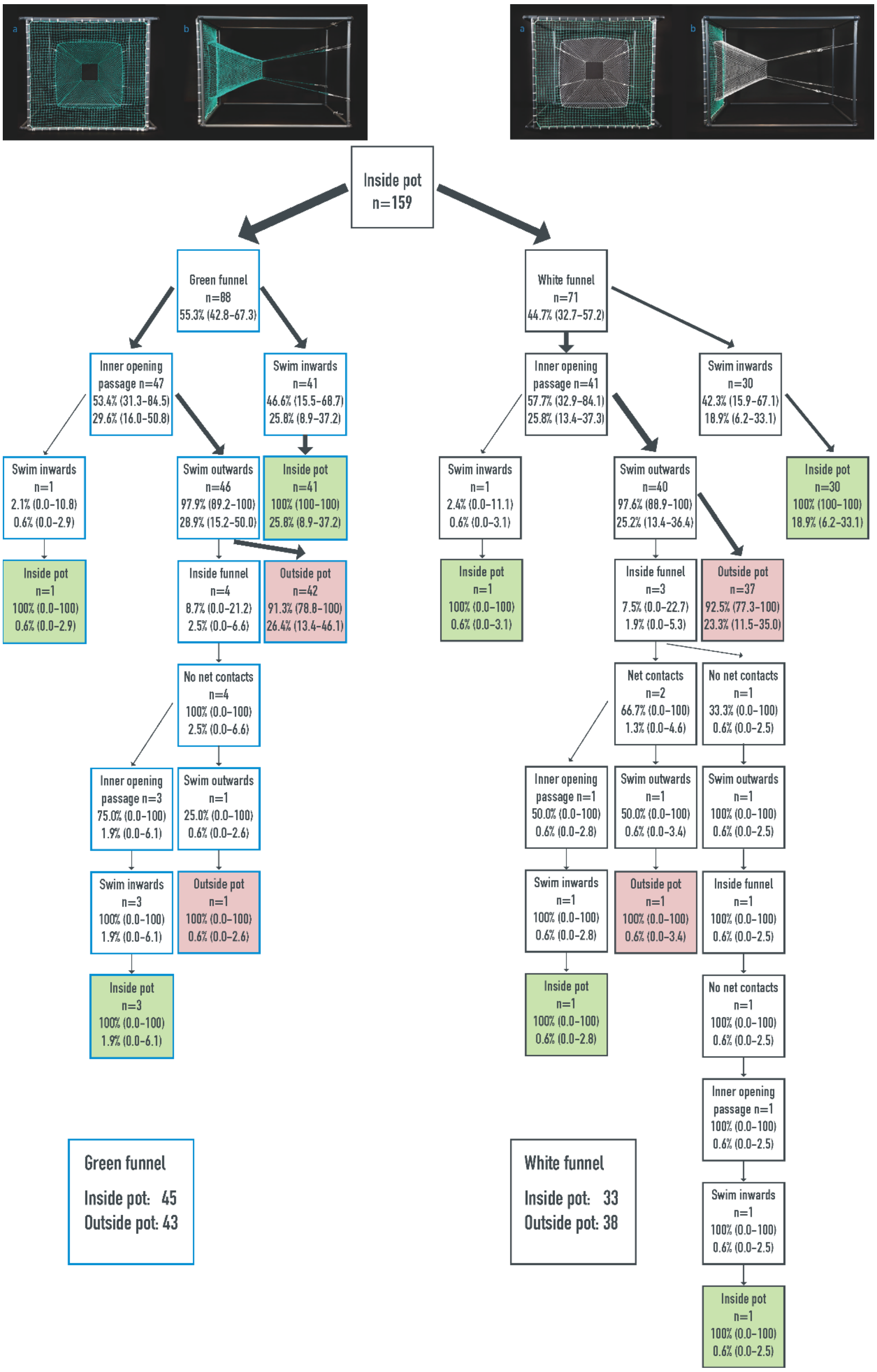


Fig. 8. **Behavioural event-chain tree comparing the 'Green funnel' (Test) with the 'White funnel' (Control) for interactions of cod with pot entrances starting inside. Each box represents an event type; the first line gives the event type name; the second line gives number of times this event was observed at this point in the event chain; the third line gives the marginal probabilities (MP), related to the total number of interactions; and the last line gives the conditional probabilities (CP), related to the number of interaction in the parent link (the link above a respective link). Confidence intervals are based on 1000 bootstrap iterations. The thickness of each arrow is representative of the MP the arrow is pointing to.**

Transparent funnel

Six replicates were conducted to compare the ‘White funnel’ (control entrance) with the ‘Transparent funnel’ (Table 4). The final models included only the intercept (Table 5). Cod passed more often through the ‘Transparent funnel,’ with the difference between entries ($p(I = 1) = 0.60$) being weaker than for the exits ($p(O = 1) = 0.87$). The higher entry probability through the ‘Transparent funnel’ is driven mainly by a higher, but non-significant, interaction rate with this entrance (Fig. 9). Furthermore, more, cod entered the transparent funnel, with little CI overlap. In all, 30 out of 36 contacts in the ‘Transparent funnel’ were accidental when cod tried to pass into the pot through the transparent netting, whereas only six net contacts were deliberate tactile probing contacts. In contrast, only five funnel netting contacts in the control entrance were accidental, whereas six were deliberate probing contacts. This difference indicates that cod did not always perceive the ‘Transparent funnel’ or at least did not perceive it as an obstacle.

For exit events, there were fewer interactions in total, but more aborted exit attempts were observed for the ‘White funnel’ (control), resulting in strong differences in exit probabilities (Fig. 10).

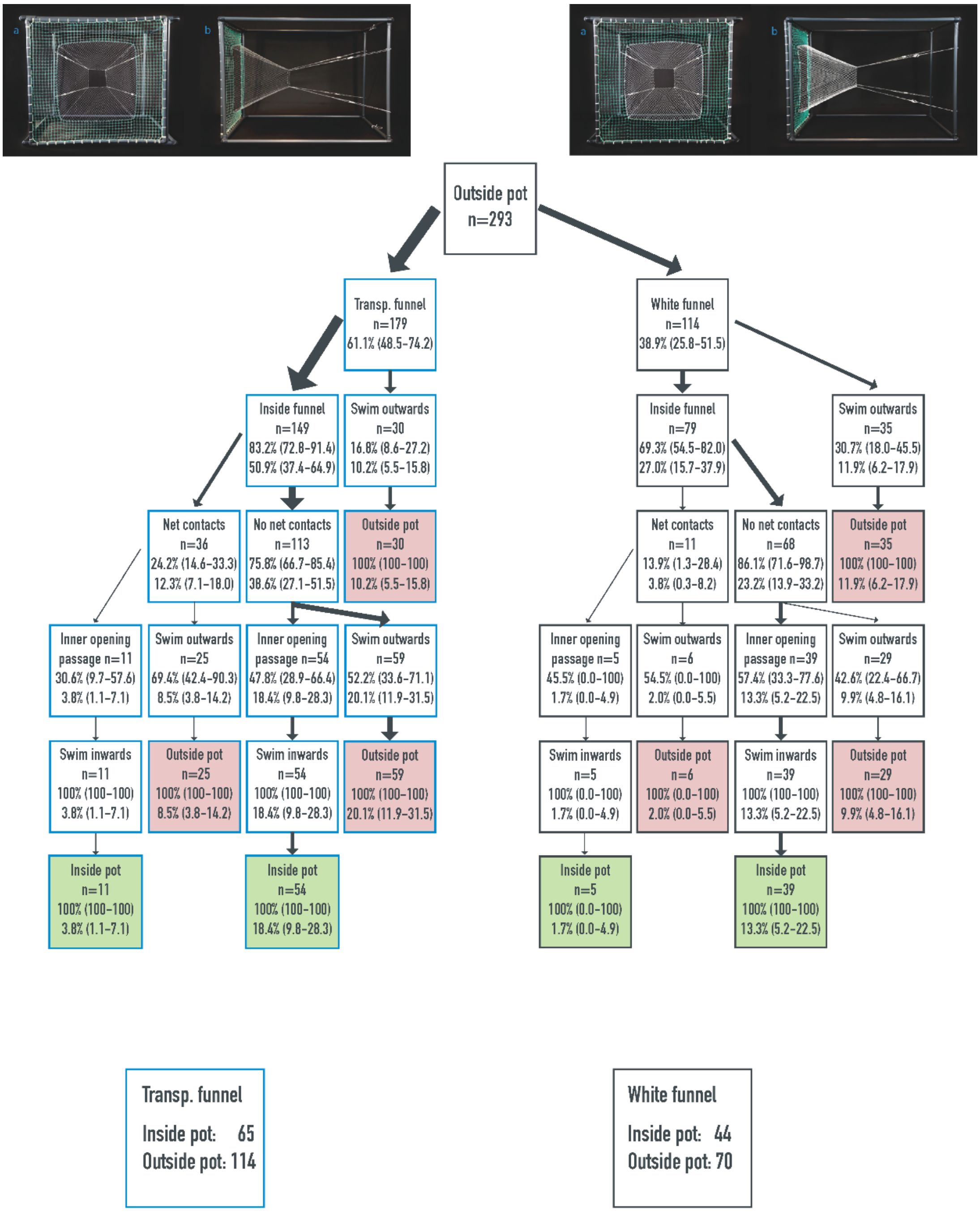


Fig. 9. **Behavioural event-chain tree comparing the ‘Transparent funnel’ (Test) with the ‘White funnel’ (Control) for interactions of cod with pot entrances starting outside. Each box represents an event type; the first line gives the event type name; the second line gives number of times this event was observed at this point in the event chain; the third line gives the marginal probabilities (MP), related to the total number of interactions; and the last line gives the conditional probabilities (CP), related to the number of interaction in the parent link (the link above a respective link). Confidence intervals are based on 1000 bootstrap iterations. The thickness of each arrow is representative of the MP the arrow is pointing to.**

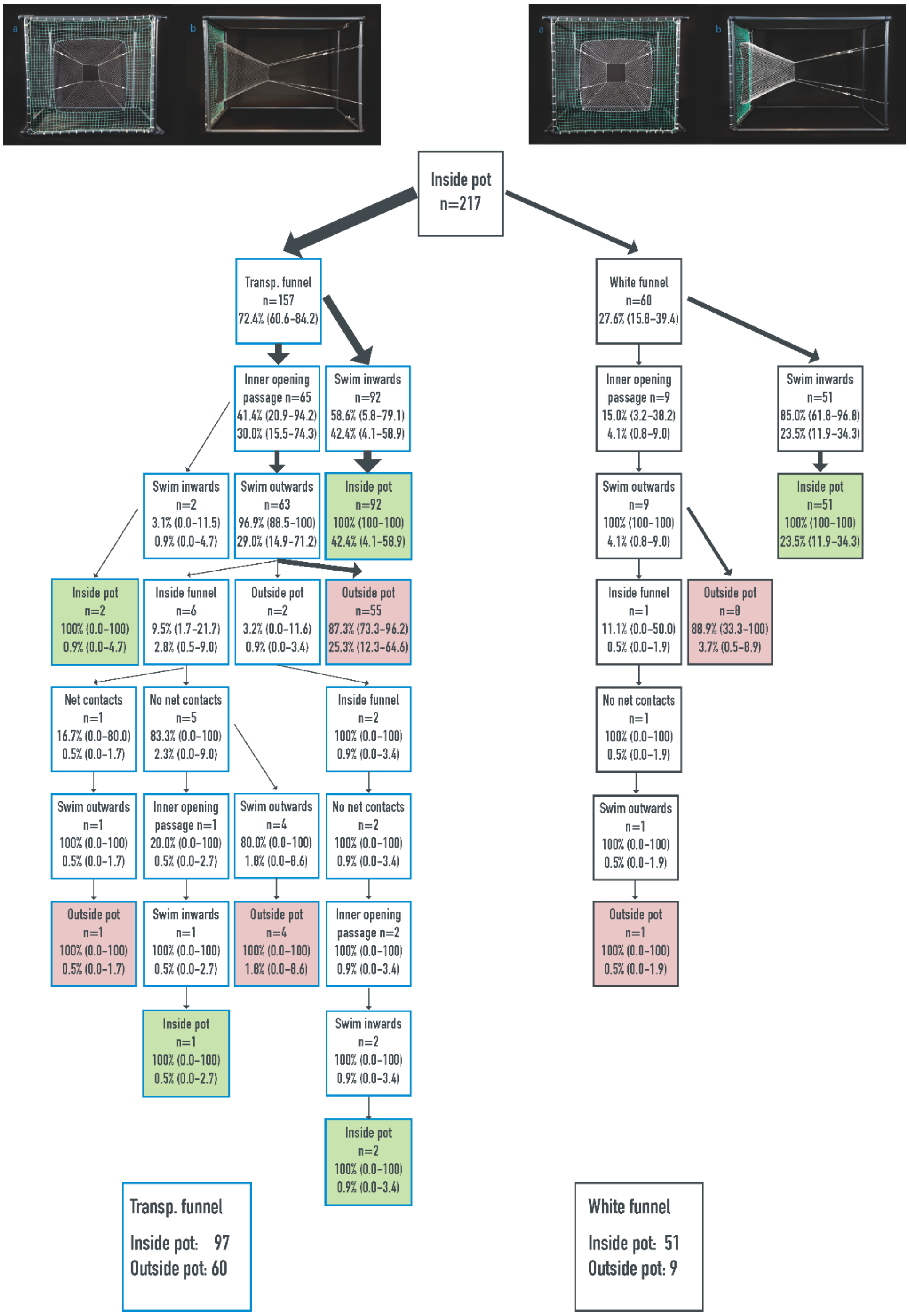


Fig. 10. **Behavioural event-chain tree comparing the 'Transparent funnel' (Test) with the 'White funnel' (Control) for interactions of cod with pot entrances starting inside. Each box represents an event type; the first line gives the event type name; the second line gives number of times this event was observed at this point in the event chain; the third line gives the marginal probabilities (MP), related to the total number of interactions; and the last line gives the conditional probabilities (CP), related to the number of interaction in the parent link (the link above a respective link). Confidence intervals are based on 1000 bootstrap iterations. The thickness of each arrow is representative of the MP the arrow is pointing to.**

Funnel length

No funnel

Three replicates of the comparison between ‘No funnel’ and ‘White funnel’ (control) entrance were conducted (Table 4). Both selected models included the side covariate (Table 5). The probability of entering through the ‘No funnel’ entrance was only 0.41 $p(I = 1)$, whereas exits occurred almost exclusively through the ‘No funnel’ $(p(O = 1) = 0.95)$. The behavioural event-chain tree for cod interactions starting outside the pot demonstrates that cod interacted significantly more often with the ‘White funnel’ control than with the ‘No funnel’ entrance (first level nodes in Fig. 11). However, of the cod approaching either entrance, the proportions aborting the entry attempt were similar (event chains ‘Swim outwards’ in Fig. 11). Nonetheless, a portion of the cod entering the control funnel aborted their entry attempt inside the funnel, reducing the entry efficiency of the control entrance at this point. Therefore, the lower entrance probability of the ‘No funnel’ entrance found by the GLM is caused by fewer cod encountering the ‘No funnel’ entrance. Inside the pot, significantly more cod interacted with the ‘No funnel’ than with the control entrance (Fig. 12). Only 13.3% of the interactions were observed at the control entrance. Furthermore, significantly more cod interacting with the ‘No funnel’ entrance exited through it (66.9%), whereas only 23.1% of cod interacting with the control entrance passed it to the outside. Therefore, the ‘No funnel’ entrance has a significantly lower cod retention capability.

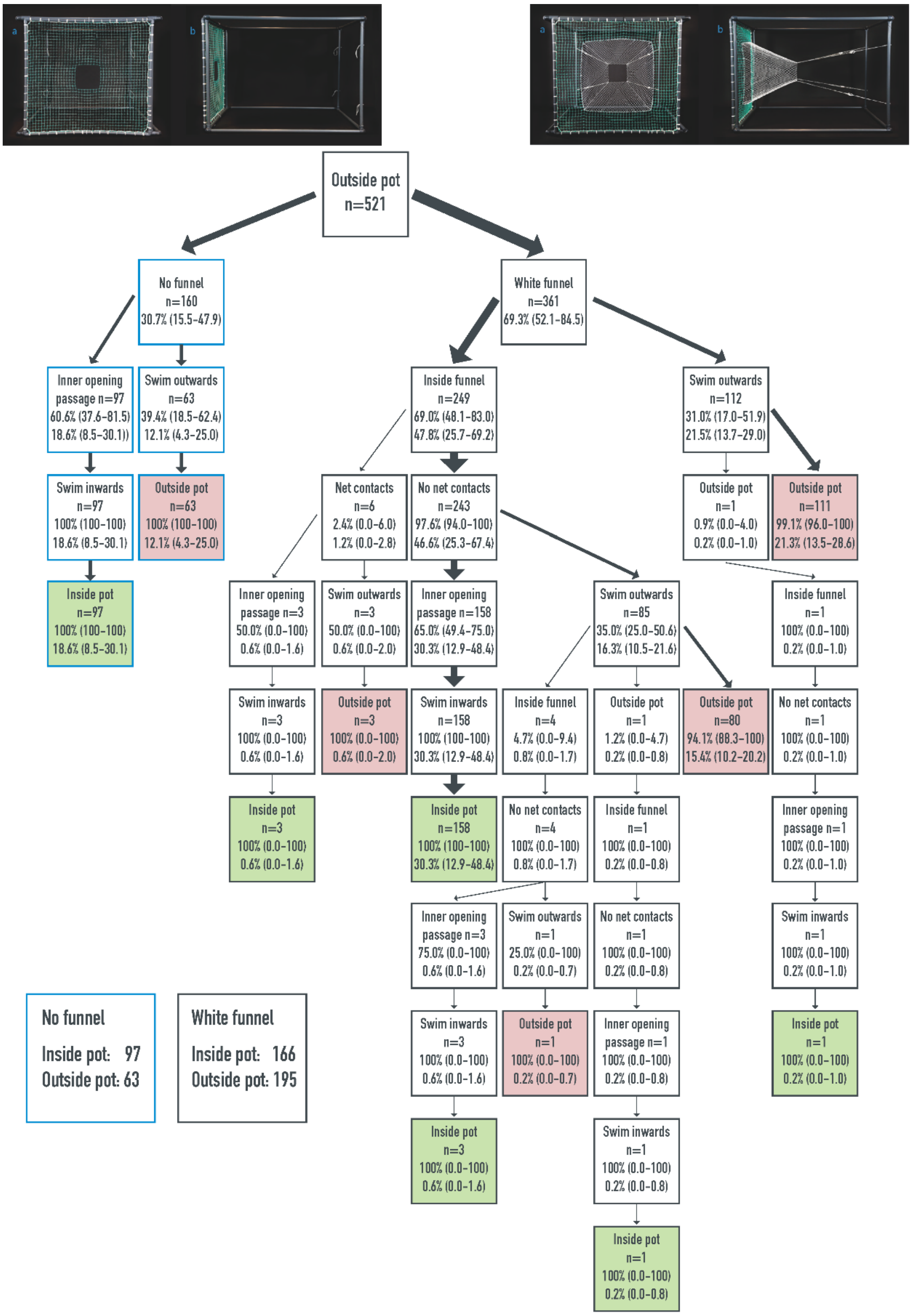


Fig. 11. Behavioural event-chain tree comparing the 'No funnel' (Test) with the 'White funnel' (Control) for interactions of cod with pot entrances starting outside. Each box represents an event type; the first line gives the event type name; the second line gives number of times this event was observed at this point in the event chain; the third line gives the marginal probabilities (MP), related to the total number of interactions; and the last line gives the conditional probabilities (CP), related to the number of interaction in the parent link (the link above a respective link). Confidence intervals are based on 1000 bootstrap iterations. The thickness of each arrow is representative of the MP the arrow is pointing to.

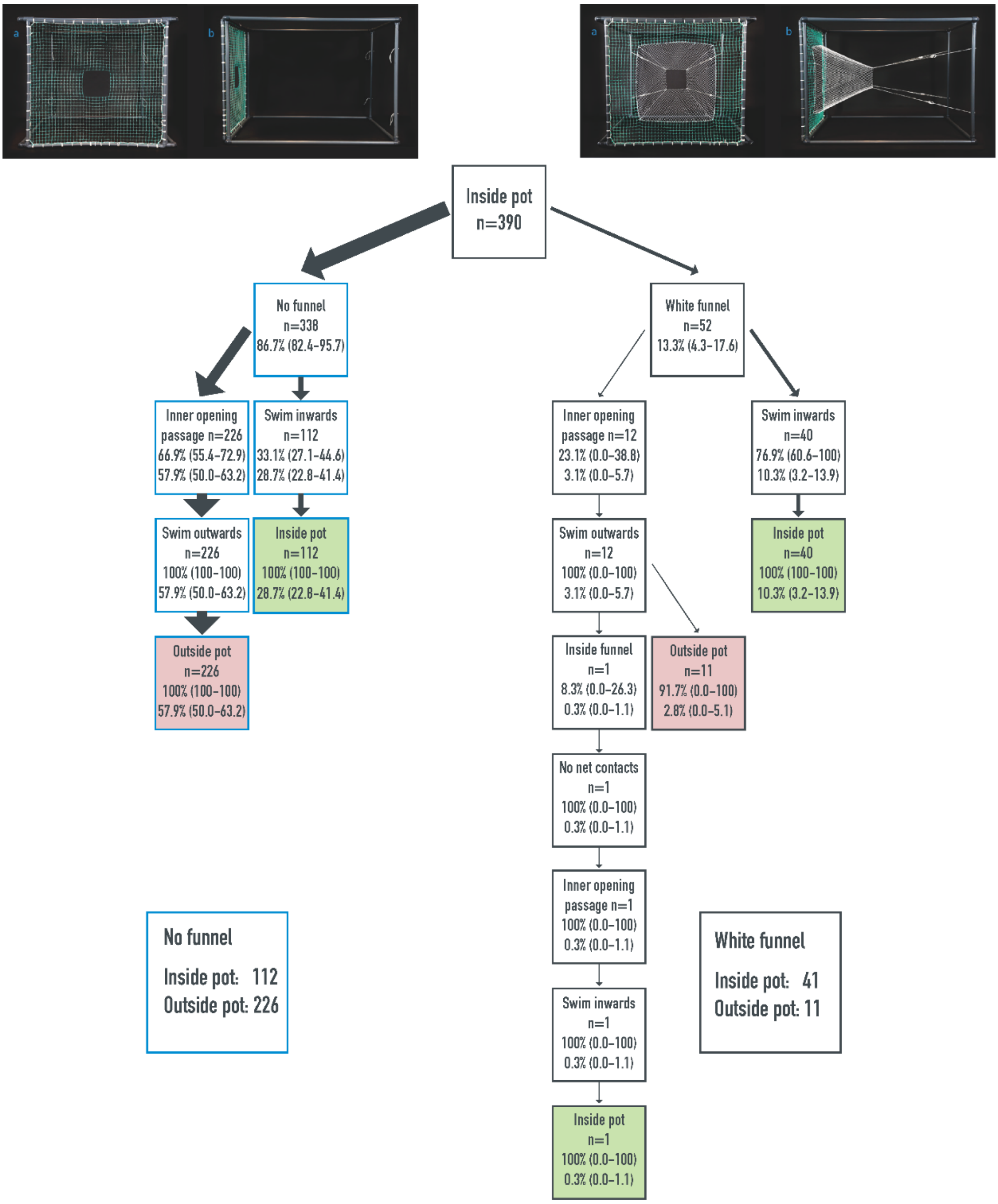


Fig. 12. Behavioural event-chain tree comparing the 'No funnel' (Test) with the 'White funnel' (Control) for interactions of cod with pot entrances starting inside. Each box represents an event type; the first line gives the event type name; the second line gives number of times this event was observed at this point in the event chain; the third line gives the marginal probabilities (MP), related to the total number of interactions; and the last line gives the conditional probabilities (CP), related to the number of interaction in the parent link (the link above a respective link). Confidence intervals are based on 1000 bootstrap iterations. The thickness of each arrow is representative of the MP the arrow is pointing to.

Long funnel

Two replicates of the comparison between the ‘Long funnel’ (75 cm) and ‘White funnel’ (50 cm; control) entrances were conducted (Table 4). No significant differences in the entry probabilities were observed ($p(I = 1) = 0.51$; Table 5). The almost identical behavioural event-chain tree branches support this observation (Fig. 13). In contrast, cod exited only through the control entrance, indicating that escapement through the ‘Long funnel’ is not the choice preferred by cod. This is also apparent in the behavioural event-chain tree for inside interactions: Cod strongly preferred interacting with the control entrance; only 15.0% of all inside pot interactions occurred at the ‘Long funnel’ entrance, with no CI overlap (Fig. 14). Furthermore, all interactions at the ‘Long funnel’ inner opening were aborted exit attempts, whereas 46.9% of cod interactions at the control entrance ended with a successful passage towards the pot outside.

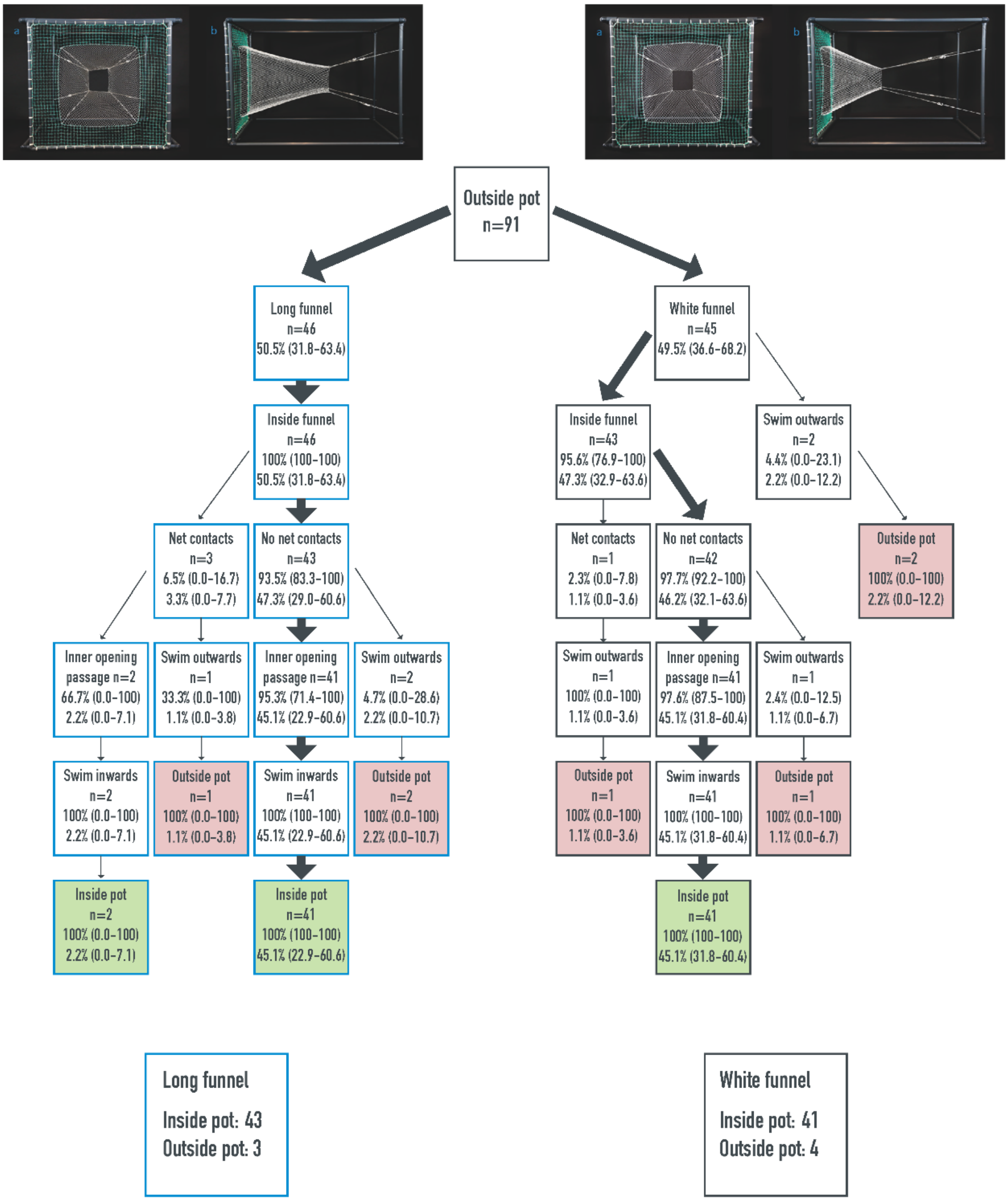


Fig. 13. **Behavioural event-chain tree comparing the ‘Long funnel’ (Test) with the ‘White funnel’ (Control) for interactions of cod with pot entrances starting outside. Each box represents an event type; the first line gives the event type name; the second line gives number of times this event was observed at this point in the event chain; the third line gives the marginal probabilities (MP), related to the total number of interactions; and the last line gives the conditional probabilities (CP), related to the number of interaction in the parent link (the link above a respective link). Confidence intervals are based on 1000 bootstrap iterations. The thickness of each arrow is representative of the MP the arrow is pointing to.**

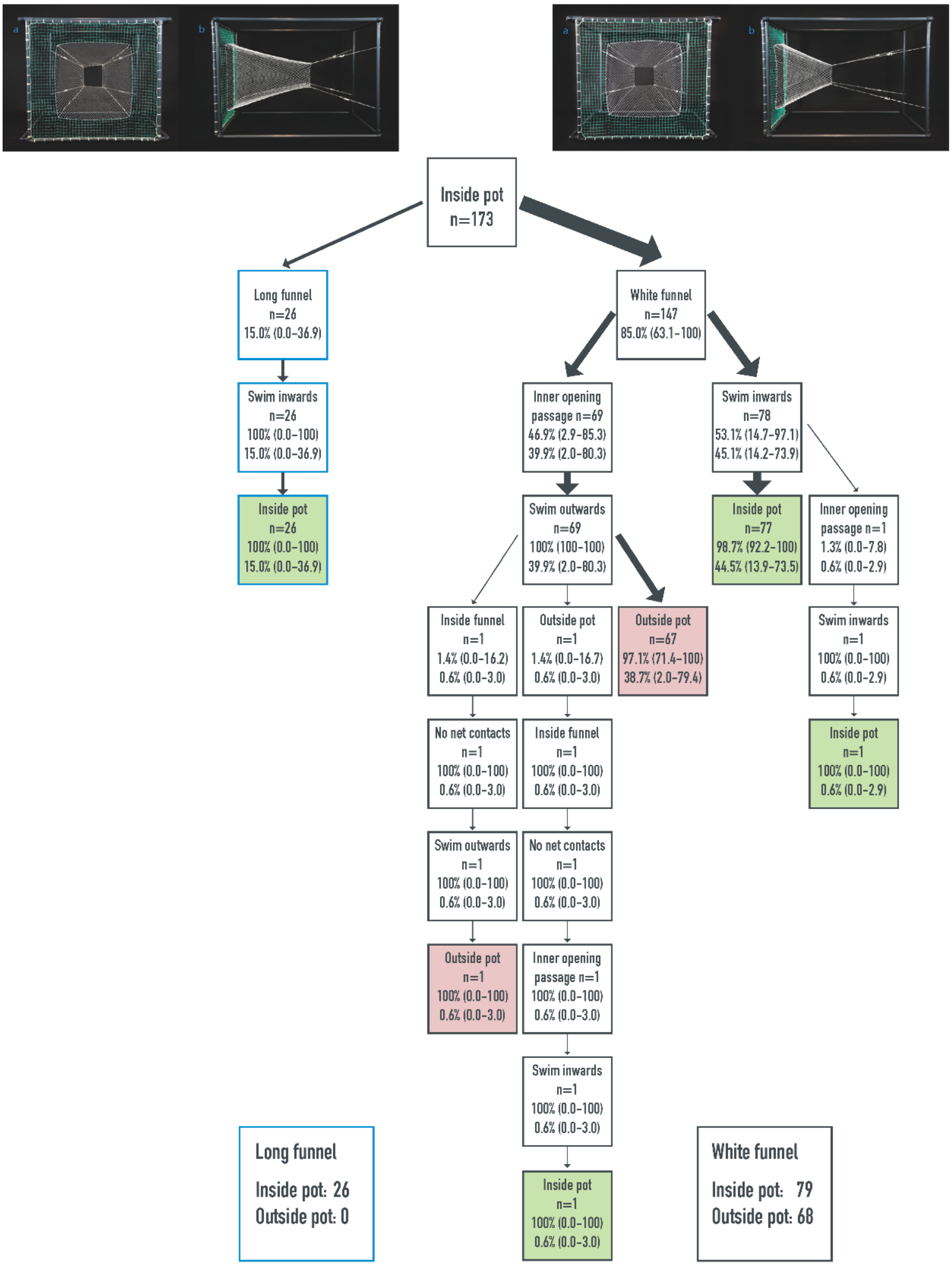


Fig. 14. **Behavioural event-chain tree comparing the 'Long funnel' (Test) with the 'White funnel' (Control) for interactions of cod with pot entrances starting inside. Each box represents an event type; the first line gives the event type name; the second line gives number of times this event was observed at this point in the event chain; the third line gives the marginal probabilities (MP), related to the total number of interactions; and the last line gives the conditional probabilities (CP), related to the number of interaction in the parent link (the link above a respective link). Confidence intervals are based on 1000 bootstrap iterations. The thickness of each arrow is representative of the MP the arrow is pointing to.**

Funnel shape: Narrow

Two replicates of the ‘Narrow funnel’ control entrance comparison were conducted (Table 4). Cod entered significantly more often through the control entrance and did not exit through the ‘Narrow funnel’. The final model for entries includes neither side nor day period (Table 5). The low entry probability through the ‘Narrow funnel’ $p(I = 1) = 0.14$, and the fact that no cod exited through it, reveal a clear preference for the control entrance for entering as well exiting. The behavioural tree (Fig. 15) reveals that the significantly lower entry rate through the ‘Narrow funnel’ is not because fewer cod interacted with it, but because most cod turn around inside the funnel, just before the narrow inner opening. Although there were no exits through the ‘Narrow funnel’ entrance – vs. six exits through the control entrance (Table 4) – the number of interactions at the ‘Narrow funnel’ entrance was considerably larger (62.2%) than at the control entrance, with little CI overlap (Fig. 16).

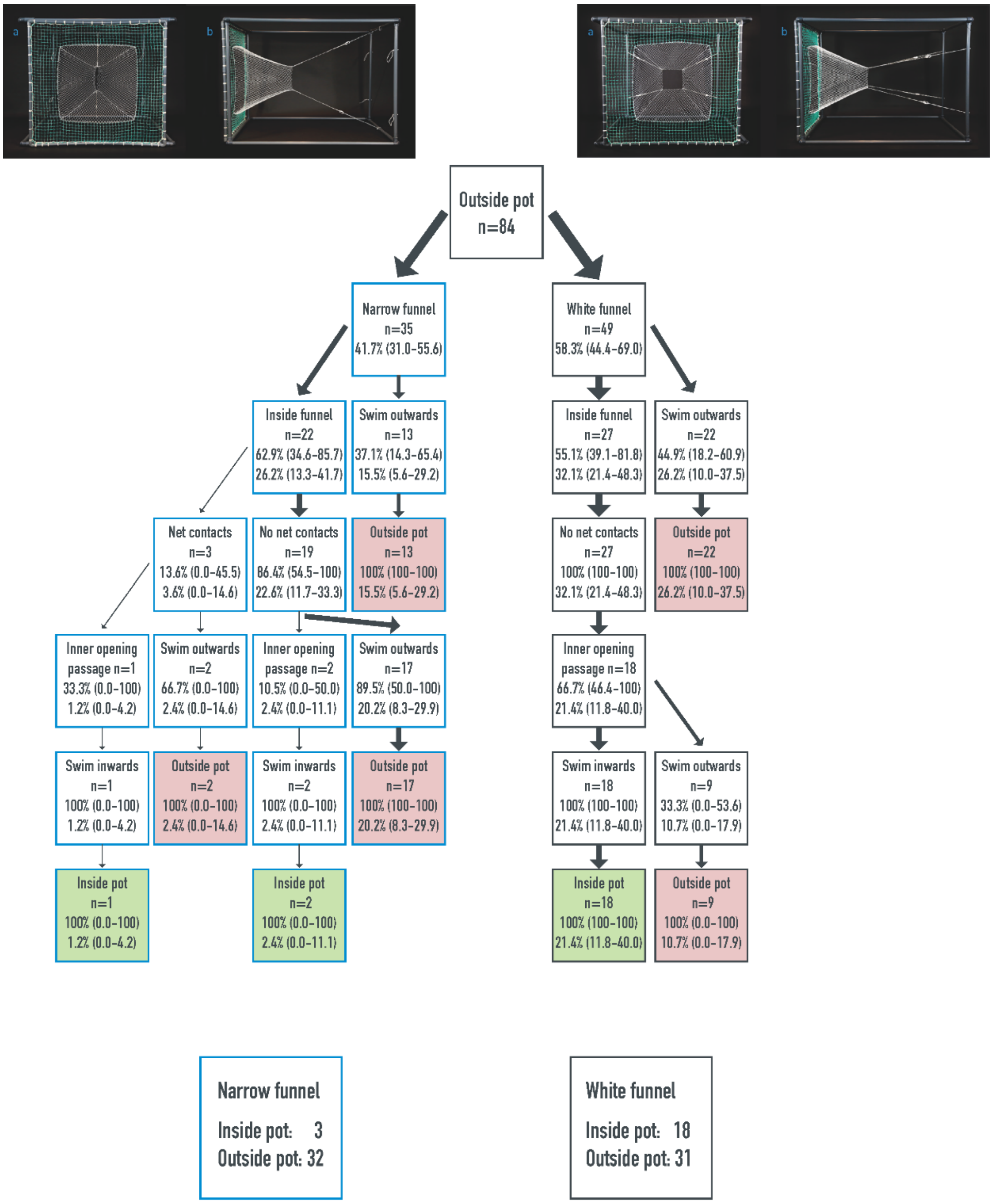


Fig. 15. **Behavioural event-chain tree comparing the 'Narrow funnel' (Test) with the 'White funnel' (Control) for interactions of cod with pot entrances starting outside. Each box represents an event type; the first line gives the event type name; the second line gives number of times this event was observed at this point in the event chain; the third line gives the marginal probabilities (MP), related to the total number of interactions; and the last line gives the conditional probabilities (CP), related to the number of interaction in the parent link (the link above a respective link). Confidence intervals are based on 1000 bootstrap iterations. The thickness of each arrow is representative of the MP the arrow is pointing to.**

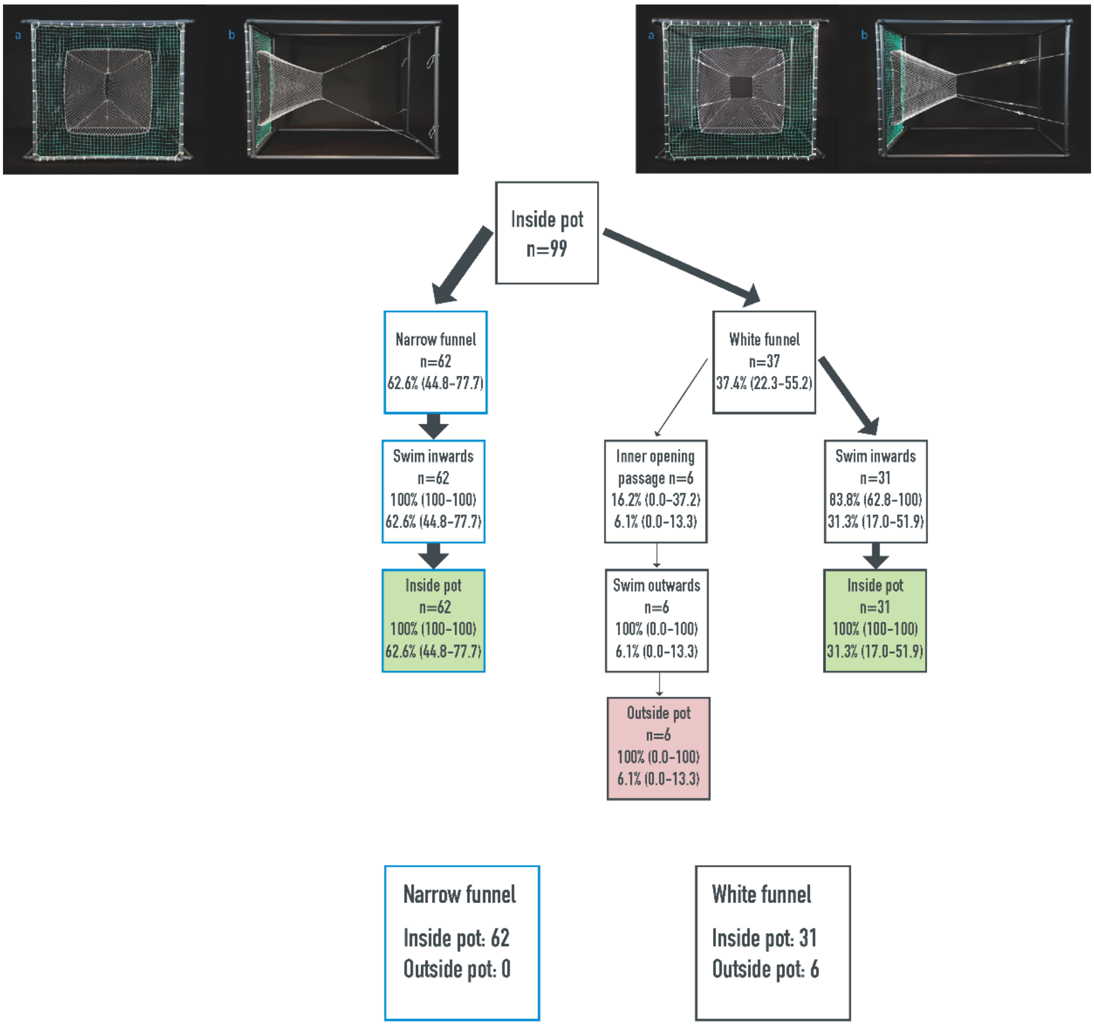


Fig. 16. **Behavioural event-chain tree comparing the 'Narrow funnel' (Test) with the 'White funnel' (Control) for interactions of cod with pot entrances starting inside. Each box represents an event type; the first line gives the event type name; the second line gives number of times this event was observed at this point in the event chain; the third line gives the marginal probabilities (MP), related to the total number of interactions; and the last line gives the conditional probabilities (CP), related to the number of interaction in the parent link (the link above a respective link). Confidence intervals are based on 1000 bootstrap iterations. The thickness of each arrow is representative of the MP the arrow is pointing to.**

Comparison of all entrances

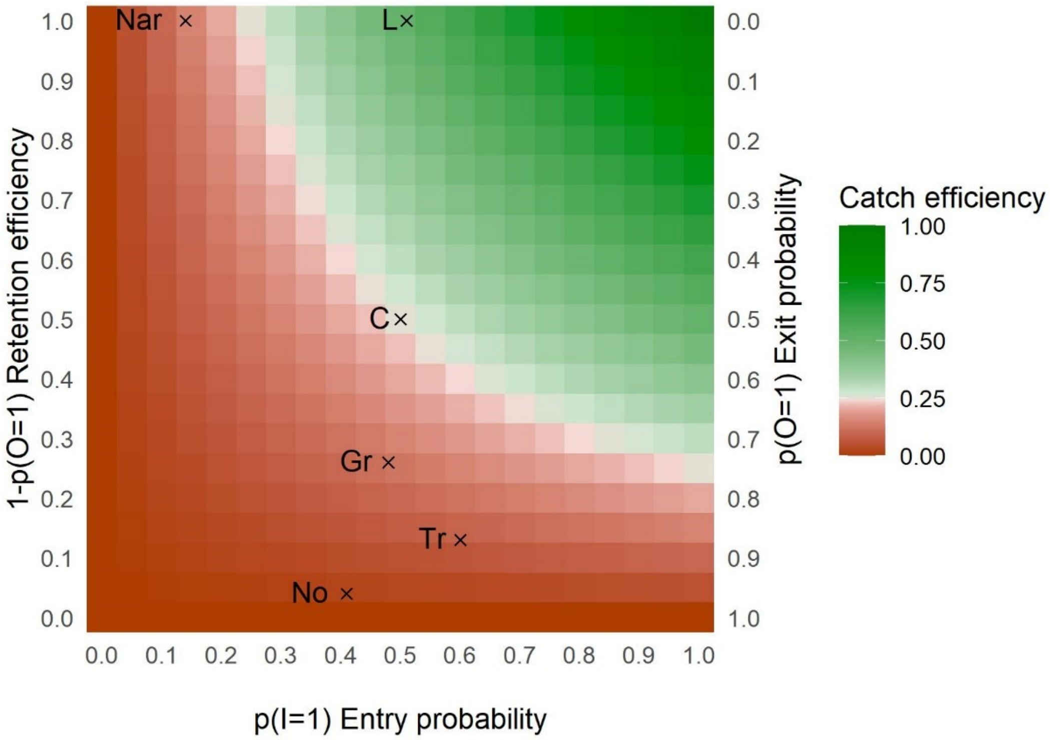


Fig. 17. **Comparison of catch efficiency for pot-entrance types in catch efficiency matrix. 'C' = the control entrance; 'Gr' = 'Green funnel'; 'Tr' = 'Transparent funnel'; 'No' = 'No funnel'; 'L' = 'Long funnel'; 'Nar' = 'Narrow funnel'.**

Because the final catch efficiency of pots is determined by the relationship between pot entry and exit rates, we directly compare all entrance types in a two-dimensional graph (Fig. 17), based on the expected probability of either entry $p(I = 1)$ and exit $p(O = 1)$ or retention $(1 - p(O = 1))$ in the test entrance. A catch efficiency of 0.25 indicates no difference between a test entrance and the reference control entrance, while a higher value indicates a higher catch efficiency than the control entrance and vice-versa (see chapter 2.6 "Statistical analysis"). The 'Green funnel' entrance performed worse than the control entrance because of a higher exit probability. Although the 'Transparent funnel' performed better for entries than the 'White funnel' entrance did, the overall catch efficiency was lower owing to the low retention capacity of this entrance. The 'No funnel' entrance is considerably less efficient than the control entrance, because it had fewer entries and more exits. Crucially, the exits were almost all exclusively through the 'No funnel' entrance. The 'Long funnel' entrance is considerably more efficient than the control entrance, because it does not differ in entry rate, whereas no exits occurred through the long funnel entrance. Although no cod exited the 'Narrow funnel' entrance, it was less efficient than the control entrance because significantly fewer cod entered through it.

Entrance inspections and herding

Entrance inspections

Cod inspected the entrances in 96.8% of all interactions, revealing that cod are attentive to the structural entrance elements and pass entrances with caution. Event duration of all successful and unsuccessful passages by not-inspecting cod (8.7± 4.0 sec), was significantly shorter than for inspecting cod (15.4 ± 16.3 sec; Shapiro–Wilk test for normality of all event durations W= 0.543, $p < 0.001$; Wilcoxon test W= 2312, $p < 0.001$).

Herding

Herding events were rare, with only 8.4% of (attempted) entries (n = 1464) and 4.5% of (attempted) exits (n = 1156). Event duration of cod in herding events (7.8 ± 7.4 sec) was significantly shorter than cod interacting alone with the entrances (15.7 ± 16.4; Wilcoxon test W = 16658, $p < 0.001$), indicating that cod in herding events moved faster, and so the speed of the lead cod triggered movements of the following cod.

Discussion

In this study, we successfully developed and applied a novel method to study the interaction between cod and pot entrances. The crucial relationship between pot entry and exit rates (Furevik and Løkkeborg, 1994; Hedgärde et al., 2016) was investigated for different funnel designs and allowed us to describe *how* and infer *why* cod interact differently with various entrances, which could not have been carried out with traditional catch comparison experiments. This study reveals that different entrances have strong effects on cod behaviour and so on the pot's catch efficiency. This understanding of behaviour is essential to improving pot design. In addition, it is the first study where cod–pot interactions were observed at night without strong lighting in the visible spectral range of cod, thus avoiding influencing behaviour.

Diurnal entrance interactions are primarily vision-based

The activity pattern of cod follows a diurnal rhythm with reduced activity at night (e.g., Løkkeborg and Fernö, 1999), regulated by ambient light levels (Meager et al., 2005, 2010, 2018; Meager and Batty, 2007; Monk et al 2006). The present study revealed that this also applies to interactions with pots, including slow movements of cod and almost no entrance passages at night. The rapid onset of entries and exits around dawn indicates that cod primarily use vision to locate and navigate through funnel entrances. This is corroborated by the fact that, in 96.8% of all observed entrance interactions, cod visually inspected the entrances, whereas only 3.4% of the interactions were accompanied by tactile probing. This tactile probing seems to be more relevant to the net-wall-guided search pattern during low light conditions, which results in more escapements through the 'No funnel' entrance than through funnel entrances, because funnels deflect fish away from the exit. Based on these findings, the increased nightly catch and entrance rates of illuminated cod pots (Bryhn et al., 2014; Hedgärde et al., 2016; Humborstad et al., 2018) could thus not only be the result of light attraction, but also the result of the illumination of the entrances, which allow cod to visually perceive and navigate through them into the pot. In contrast, the low-intensity lights might limit the visual dark adaptation of cod inside the pot without compensating with sufficient illumination to perceive the entrance netting clearly. Low-intensity lights could thus reduce their ability to exit the pot through the entrances. This could represent additional mechanisms explaining how lights increase pot-catch success.

Funnel colour

Funnel colour influenced cod passage through pot entrances. The results of the 'Transparent funnel' and the 'Green funnel' experiments underline the importance of colour and thus of cod vision in cod–pot entrance interactions. The white funnel of the control entrance resulted in a visibly strong contrast between the funnel, the background, and the green netting of the pot housing. For entries, the 'Green funnel' entrance performed similarly to the white control entrance with no differences found. However, the GLM model revealed a higher, but not significantly different, exit rate through the 'Green funnel', mostly the result of more exits during dusk and dawn, when some light was still available for orientation. Because the coastal waters at the site of the experiment had a green hue, the contrast between ambient light and green funnel netting seemed to appear lower than the white control funnel netting. Cod searching for an exit during twilight could thus have been drawn more towards the green funnel, which possibly appeared less conspicuous against the background, creating the appearance of an unobstructed passage. This would fit with previous findings that the visual stimulus of different netting colours against the background influences fish–gear interactions (summarised by Arimoto et al., 2010). The contrast between the ‘Transparent funnel’ and the background appears even more reduced. There were more passages through the ‘Transparent funnel’, indicating that cod searching for passage were attracted to it. Furthermore, many cod accidentally swam into the transparent funnel netting, indicating that they had problems perceiving it. Therefore, we propose that for cod to approach an entrance, they need to perceive it as an open passage into or out of the pot. This aligns well with the observation that cod and other fish species often fail to enter pots because they fail to locate pot entrances (e.g., Anders et al., 2016; Meintzer et al., 2017; Rose et al., 2005). Because the ’Transparent funnel’ exit probability was higher than the entry probability, the control entrance (and by transposition also the ‘Green funnel’ entrance) had better catch efficiency (Fig. 17). Nevertheless, the increased entry probability through the ‘Transparent funnel’, and the larger number of behavioural interactions with it, indicate development potential. For example, equipping transparent funnels with fish retention devices (FRD; Carlile et al., 1997; High and Ellis, 1973), which allow entry but not exit, could improve catch efficiency, provided the FRD does not disproportionally decrease the entry rate. Therefore, FRDs should also be transparent. Alternatively, the high exit rates of transparent funnels could be countered by including a second catch chamber situated above the first catch chamber as in the widely used Norwegian floated pot (Furevik et al., 2008). Lastly, these results also align with a recent two-year cod pot catch comparison study in Newfoundland and Labrador waters where the pots with transparent funnel netting outperformed the pot types with white funnel netting (Meintzer et al. 2018).

Funnel length

The results of the ‘No funnel’ and the ‘Long funnel’ entrance experiments highlight the importance of funnels for catch efficiency. The lower entry and higher exit rates through the ‘No funnel’ entrance, resulting in relatively poor catch efficiency of all tested entrance types, demonstrate that funnels are crucial to cod pots, congruent with a previous field-pot-entrance video study (Ljungberg et al., 2016). Significantly fewer cod approached the ‘No funnel’ entrance from the outside. Therefore, cod searching for a way into the pot had a greater chance of encountering the control entrance, probably because its outer opening area is nine times larger than the ‘No funnel’ entrance. The funnel colour experiments indicate that a clear unobstructed view of the pot outside is important for enticing cod inside the pot to approach the entrance. Although the view of the pot’s outside is limited in most positions inside the pots with funnel entrances, it is mostly unobstructed for the ‘No funnel’ entrance (Fig. 18), thus attracting cod to it. Additionally, this is reinforced by the observed net-wall-guided search behaviour at twilight. The increase in funnel length resulted in greater catch efficiency, because significantly fewer cod approached the ‘Long funnel’ from inside and none exited through it. This could also be because the pot area, from which the pot exterior is visible through the ‘Long funnel’, is smaller than the control entrance with shorter funnel length (Fig. 18). Nevertheless, there were 26 aborted inside approaches to the ‘Long funnel’ inner opening. This indicates that the funnel length itself also has an exit-impeding effect. These findings may further explain the larger catch taken in larger pots (e.g., Bagdonas et al., 2012; Furevik and Løkkeborg, 1994; Hedgärde et al., 2016; Munro, 1974), because larger pots can accommodate longer funnels and have more space in the pot without unobstructed view of the outside through the funnels. The positive effect, however, can be expected to have a tipping point when the funnel is so long that cod searching along the back net wall find the funnel inner opening in their nearfield and exit through it, and when the pot inside is too far away for cod outside the pot to be enticed to enter.

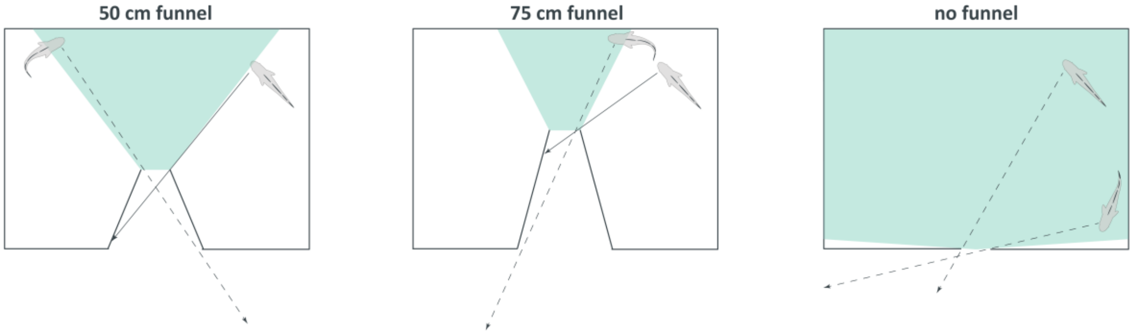


Fig. 18. **Schematic illustration of area inside a fish pot with outside view through the funnel, depending on funnel length.**

Funnel shape: Narrow funnel

Although no cod exited through the ‘Narrow funnel’ entrance, its catch efficiency was relatively poor, because it had almost no entries. The low entry rate was caused by more cod aborting entry attempts inside the funnel, which supports previous findings that cod do not like to pass through narrow entrances (Pol et al., 2010). Narrow funnel entrances for cod potting are thus not advisable.

The influence of social behaviour on entrance interactions

In addition to basic design parameters of the entrances, social behaviour influenced entrance interactions. The significantly higher speed of cod in leader–follower events indicates that the speed of the leader cod cues other cod to follow the leader. This fits with a previous study that reveals that leaders of cod shoals arriving at a feeding station have the highest arrival speed and are able to train naïve cod (Björnsson et al., 2018). Also, the decision of cod to enter a pot is often socially mediated (Anders et al., 2017; Hedgärde et al., 2016) and generally, cod rely on social cues when foraging (Meager et al., 2018).

Conclusion and outlook

The findings presented here lead to the following recommendations on entrance design and cod-pot fishing strategy: Increasing funnel length may reduce exit rates (but bearing in mind a potential turnaround point). Funnels should be set into the pot to minimise the area inside the pot from which the pot outside can be seen through the inner funnel opening. Transparent funnel netting allows for higher entry rates, but is recommended mainly when FRDs are attached to an entrance (Carlile et al., 1997; Furevik, 1994; High and Ellis, 1973; Munro, 1974), or a second catch chamber (Furevik, 1994; Furevik et al., 2008) is added to the pot design to mitigate the increased exit probability through the transparent funnel. Ideal setting time of the day of pots equipped with olfactory bait is at dawn, because olfactory bait rapidly loses its attractive capacity after only 1.5 h soak time (Løkkeborg, 1990; Westerberg and Westerberg, 2011). This assures a strong attraction at the time of the day with highest cod-pot entry rates. Furthermore, the strong effects of entrances observed in this study and the detailed insights gained demonstrate the efficiency of the net-pen-based approach to studying cod–pot interactions. Furthermore, the bootstrap-based, behavioural-tree method allows the interaction process to be ‘dissected’ and the cause of the observed differences to be identified. In this study, we used this approach to investigate the effect of different entrance designs on the entry and exit behaviour of cod. Other pot design parameters, such as FRDs, pot size and shape (e.g., Hedgärde et al., 2016), or entrance opening size and shape (e.g., Königson et al., 2015b; Ljungberg et al., 2016) can also influence the catch efficiency of pots, and should be investigated using this method. Based on such experiments, optimised pot designs can be efficiently developed, and their ultimate catch efficiency can be subsequently tested in field trials.

Funding

This work was funded by the German Federal Agency for Nature Conservation (Bundesamt für Naturschutz, project no. 3516821300, Entwicklung von alternativen Managementansätzen und Fangtechniken zur Minimierung der Konflikte zwischen Stellnetzfischerei und Naturschutzzielen in der deutschen AWZ der Ostsee - STELLA).

Acknowledgements

This study benefitted from the help of many dedicated people, who assisted during development of the experiments, running the experiments and/or analysing the data. Therefore, we thank Lily Bovim, Ulf Böttcher, Bodo Dolk, Johanna Ferretti, Ina Hennings, Aurélien Keller and Rainer Stechert for dedicated support developing, setting up and running the experiments. For the detailed video analysis, we thank Ashkan Daneshpour, Rainer Stechert, Ulf Böttcher and Wanda Witte. For figure illustrations, we thank Anne Schütz. Lastly, we thank three anonymous reviewers for helpful and constructive comments and suggestions that improved the final version of the manuscript.

References

Akaike, H., 1973. Information theory and an extension of the maximum-likelihood principle. In: Petrov, BN and Csaki, F. (eds), 2nd Int. Symp. on Information Theory. Akademiai Kiado, pp. 267-281.

Anders, N., Fernö, A., Humborstad, O.-B., Løkkeborg, S., Rieucau, G., Utne-Palm, A.C., 2017. Size-dependent social attraction and repulsion explains the decision of Atlantic cod *Gadus morhua* to enter baited pots. J. Fish Biol. 91, 1569–1581. https://doi:10.1111/jfb.13453

Anders, N., Fernö, A., Humborstad, O.-B., Løkkeborg, S., Utne-Palm, A.C., 2016. Species specific behaviour and catchability of gadoid fish to floated and bottom set pots. ICES J. Mar. Sci. J. Cons. 74, 769–779. https://doi.org/10.1093/icesjms/fsw200

Arimoto, T., Glass, C.W., Xiumei, Z., 2010. Fish Vison and its Role in Fish Capture, in: He, P. (Ed.), Behavior of Marine Fishes: Capture Processes and Conservation Challenges. Blackwell Publishing Ltd, Ames, USA, pp. 25–43.

ASCOBANS, 2016. ASCOBANS Recovery Plan for Baltic Harbour Porpoises | JASTARNIA PLAN (2016 REVISION) [WWW Document]. URL http://www.ascobans.org/en/document/ascobans-recovery-plan-baltic-harbour-porpoises (accessed 1.10.17).

Bagdonas, K., Humborstad, O.-B., Løkkeborg, S., 2012. Capture of wild saithe (*Pollachius virens*) and cod (*Gadus morhua*) in the vicinity of salmon farms: Three pot types compared. Fish. Res. 134–136, 1–5. https://doi.org/10.1016/j.fishres.2012.06.020

Bjordal, Asmund, Furevik, D.M., 1988. Full scale fishing trials for tusk (*Brosme brosme*) and cod (*Gadus morhua*) with a collapsible fish trap. C.M. 1988/B:33. ICES Fish capture Committee.

Björnsson, B., Karlsson, H., Macrander, A., 2018. Food searching behaviour in adult Atlantic cod *Gadus morhua* during acoustic training: social learning and leadership within a school. J. Fish Biol. 93, 814–829. https://doi.org/10.1111/jfb.13783

Bowmaker, J.K., 1990. Visual pigments of fishes, in: Douglas, R., Djamgoz M. (Eds.), The Visual System of Fish. Chapman and Hall, London ISBN 978-0-412-33050-6.

Bryhn, A.C., Königson, S., Lunneryd, S.-G., Bergenius, M.A.J., 2014. Green lamps as visual stimuli affect the catch efficiency of floating cod (*Gadus morhua*) pots in the Baltic Sea. Fish. Res. 157, 187–192. https://doi.org/10.1016/j.fishres.2014.04.012

Buscaino, G., Buffa, G., Sarà, G., Bellante, A., Tonello, A.J., Hardt, F.A.S., Cremer, M.J., Bonanno, A., Cuttitta, A., Mazzola, S., 2009. Pinger affects fish catch efficiency and damage to bottom gill nets related to bottlenose dolphins. Fish. Sci. 75, 537–544. https://doi.org/10.1007/s12562-009-0059-3

Carlile, D.W., Dinnocenzo, T.A., Watson, L.J., 1997. Evaluation of modified crab pots to increase catch of Pacific cod and decrease bycatch of Pacific halibut. North Am. J. Fish. Manag. 17, 910–928. https://doi.org/10.1577/1548-8675(1997)017%3C0910:EOMCPT%3E2.3.CO;2

CEC (Council of the European Communities), 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Brussels. Off. J. Eur. Communities L 206 /7, Brussels.

Friard, O., Gamba, M., 2016. BORIS: a free, versatile open-source event-logging software for video/audio coding and live observations. Methods Ecol. Evol. 7, 1325–1330. https://doi.org/10.1111/2041-210X.12584

Furevik, D.M., 1994. Behaviour of fish in relation to pots, in: Fernö, A., Olsen, S. (Eds.), Marine Fish Behaviour in Capture and Abundance Estimation. Fishing News Books, Oxford ISBN 978-0852382110, pp. 22–44.

Furevik, D.M., Humborstad, O.-B., Jørgensen, T., Løkkeborg, S., 2008. Floated fish pot eliminates bycatch of red king crab and maintains target catch of cod. Fish. Res. 92, 23–27. https://doi.org/10.1016/j.fishres.2007.12.017

Furevik, D.M., Løkkeborg, S., 1994. Fishing trials in Norway for torsk (*Brosme brosme*) and cod (*Gadus morhua*) using baited commercial pots. Fish. Res. 19, 219–229.

Geraci, M., Falsone, F., Scannella, D., Sardo, G., Vitale, S., 2019. Dolphin–Fisheries Interactions: An Increasing Problem for Mediterranean Small-Scale Fisheries. Politics 18, 1–8.

Gilman, E., 2015. Status of international monitoring and management of abandoned, lost and discarded fishing gear and ghost fishing. Mar. Policy 60, 225–239. https://doi.org/10.1016/j.marpol.2015.06.016

Grabowski, J.H., Bachman, M., Demarest, C., Eayrs, S., Harris, B.P., Malkoski, V., Packer, D., Stevenson, D., 2014. Assessing the Vulnerability of Marine Benthos to Fishing Gear Impacts. Rev. Fish. Sci. Aquac. 22, 142–155. https://doi.org/10.1080/10641262.2013.846292

Hardie, D.C., Hutchings, J.A., 2011. The Ecology of Atlantic Cod (*Gadus morhua*) in Canadian Arctic Lakes. ARCTIC 64, 137–150.

He, P. (Ed.), 2010. Behavior of marine fishes: capture processes and conservation challenges. Wiley-Blackwell, Ames, USA ISBN 978-0-8138-1536-7.

Hedgärde, M., Berg, C.W., Kindt-Larsen, L., Lunneryd, S.-G., Königson, S., 2016. Explaining the catch efficiency of different cod pots using underwater video to observe cod entry and exit behaviour. J. Ocean Technol. 11, 67–90.

Hermann, A., Chladek, J., Stepputtis, D., 2020. iFO (infrared Fish Observation)–An open source low-cost infrared underwater video system. HardwareX 8, e00149.

High, W.L., Ellis, I.E., 1973. Underwater observations of fish behavior in traps. Helgoländer Wiss. Meeresunters. 24, 341.

Humborstad, O.-B., Breen, M., Davis, M.W., Løkkeborg, S., Mangor-Jensen, A., Midling, K.Ø., Olsen, R.E., 2016. Survival and recovery of longline- and pot-caught cod (*Gadus morhua*) for use in capture-based aquaculture (CBA). Fish. Res. 174, 103–108. https://doi.org/10.1016/j.fishres.2015.09.001

Humborstad, O.-B., Utne-Palm, A.C., Breen, M., Løkkeborg, S., 2018. Artificial light in baited pots substantially increases the catch of cod (*Gadus morhua*) by attracting active bait, krill (*Thysanoessa inermis*). ICES J. Mar. Sci. 75, 2257–2264. https://doi.org/10.1093/icesjms/fsy099

Jørgensen, T., Løkkeborg, S., Furevik, D., Humborstad, O.-B., De Carlo, F., 2017. Floated cod pots with one entrance reduce probability of escape and increase catch rates compared with pots with two entrances. Fish. Res. 187, 41–46. https://doi.org/10.1016/j.fishres.2016.10.016

Königson, S., Fredriksson, R.E., Lunneryd, S.-G., Strömberg, P., Bergström, U.M., 2015a. Cod pots in a Baltic fishery: are they efficient and what affects their efficiency? ICES J. Mar. Sci. J. Cons. 72, 1545–1554. https://doi.org/10.1093/icesjms/fsu230

Königson, S., Lövgren, J., Hjelm, J., Ovegård, M., Ljunghager, F., Lunneryd, S.-G., 2015b. Seal exclusion devices in cod pots prevent seal bycatch and affect their catchability of cod. Fish. Res. 167, 114–122. https://doi.org/10.1016/j.fishres.2015.01.013

Lewison, R.L., Crowder, L.B., Wallace, B.P., Moore, J.E., Cox, T., Zydelis, R., McDonald, S., DiMatteo, A., Dunn, D.C., Kot, C.Y., Bjorkland, R., Kelez, S., Soykan, C., Stewart, K.R., Sims, M., Boustany, A., Read, A.J., Halpin, P., Nichols, W.J., Safina, C., 2014. Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. Proc. Natl. Acad. Sci. 111, 5271–5276. https://doi.org/10.1073/pnas.1318960111

Li, Y., Yamamoto, K., Hiraishi, T., Nashimoto, K., Yoshino, H., 2006a. Behavioral responses of arabesque greenling to trap entrance design. Fish. Sci. 72, 821–828. https://doi.org/10.1111/j.1444-2906.2006.01223.x

Li, Y., Yamamoto, K., Hiraishi, T., Nashimoto, K., Yoshino, H., 2006b. Effects of entrance design on catch efficiency of arabesque greenling traps: a field experiment in Matsumae, Hokkaido. Fish. Sci. 72, 1147–1152.

Ljungberg, P., Ovegård, M., Öhman, K., Königson, S., 2020. Correlation between catch method, condition, and diet patterns in Atlantic cod (Gadus morhua). ICES J Mar Sci 77, 267–277. https://doi.org/10.1093/icesjms/fsz167

Ljungberg, P., Ovegård, M., Öhman, K., Königson, S., 2019. Correlation between catch method, condition, and diet patterns in Atlantic cod (*Gadus morhua*). ICES J. Mar. Sci. https://doi.org/10.1093/icesjms/fsz167

Ljungberg, P., Ovegård, M., Öhman, K., Königson, S., 2020. Correlation between catch method, condition, and diet patterns in Atlantic cod (*Gadus morhua*). ICES J Mar Sci 77, 267–277. https://doi.org/10.1093/icesjms/fsz167

Løkkeborg, S., 1990. Rate of release of potential feeding attractants from natural and artificial bait. Fish. Res. 8, 253–261. https://doi.org/10.1016/0165-7836(90)90026-R

Løkkeborg, S., 1998. Feeding behaviour of cod, *Gadus morhua*: activity rhythm and chemically mediated food search. Animal Behaviour 56, 371–378. https://doi.org/10.1006/anbe.1998.0772

Løkkeborg, S., Fernö, A., 1999. Diel activity pattern and food search behaviour in cod, *Gadus morhua*. Environ. Biol. Fishes 54, 345–353. https://doi.org/10.1023/A:1007504712163

Martin, G.R., Crawford, R., 2015. Reducing bycatch in gillnets: A sensory ecology perspective. Glob. Ecol. Conserv. 3, 28–50. https://doi.org/10.1016/j.gecco.2014.11.004

Meager JJ, Solbakken T, Utne-Palm AC, Oen T (2005) Effects of turbidity on the reaction distance, search time, and foraging success of juvenile Atlantic cod (*Gadus morhua*). Can. J. Fish. Aquat. Sci., 62, 1978–1984. https://doi:10.1242/jeb.02489

Meager, J.J., Domenici, P., Shingles, A., Utne-Palm, A.C., 2006. Escape responses in juvenile Atlantic cod *Gadus morhua* L.: the effects of turbidity and predator speed. J. Exp. Biol. 209, 4174–4184. https://doi.org/10.1242/jeb.02489

Meager JJ, Batty RS (2007) Effects of turbidity on the spontaneous and prey-searching activity of juvenile Atlantic cod (*Gadus morhua*). Philos. Trans. R. Soc. B 362:2123–2130. https://doi.org/10.1098/rstb.2007.2104.

Meager JJ, Moberg O, Strand E, Utne-Palm AC (2010) Effects of light intensity on visual prey detection by juvenile Atlantic cod (*Gadus morhua* L). Mar. Freshw. Behav. Physiol. 43:99–108. http://dx.doi.org/10.1080/10236241003798910

Meager, J.J., Fernö, A., Skjæraasen, J.E., 2018. The behavioural diversity of Atlantic cod: insights into variability within and between individuals. Rev. Fish Biol. Fish. 28, 153–176. https://doi.org/10.1007/s11160-017-9505-y

Meintzer, P., Walsh, P., Favaro, B., 2017. Will you swim into my parlour? In situ observations of Atlantic cod (*Gadus morhua*) interactions with baited pots, with implications for gear design. PeerJ 5, e2953. https://doi.org/10.7717/peerj.2953

Mieske, B., 1998. Zerlegbare Netzkäfig-Pontonrahmen Technische Entwicklung des Instituts für Ostseefischerei. Inf Fisch. 45, 10.

Millar, R.B., 1993. Incorporation of between-haul variation using bootstrapping and nonparametric estimation of selection curves. Fish. Bull. 91, 564–572.

Millot, S., Nilsson, J., Fosseidengen, J.E., Bégout, M.-L., Kristiansen, T., 2012. Evaluation of self-feeders as a tool to study diet preferences in groups of Atlantic cod (*Gadus morhua*). Aquat. Living Resour. 25, 251–258. https://doi.org/10.1051/alr/2012020

Monk J, Puvanendran V, Brown JA (2006) Do different light regimes affect the foraging behaviour, growth and survival of larval cod (*Gadus morhua* L.)? Aquaculture 257, 287–293. https://doi.org/10.1016/j.aquaculture.2006.02.071

Munro, J.L., 1974. The mode of operation of Antillean fish traps and the relationships between ingress, escapement, catch and soak. ICES J. Mar. Sci. 35, 337–350. https://doi.org/10.1093/icesjms/35.3.337

Northridge, S., Coram, A., Kingston, A., Crawford, R., 2016. Disentangling the causes of protected-species bycatch in gillnet fisheries. Conserv. Biol. J. Soc. Conserv. Biol. 31, 686-695 https://doi.org/10.1111/cobi.12741

Olsen, L., 2014. Baited pots as an alternative fishing gear in the Norwegian fishery for Atlantic cod (*Gadus morhua*). UiT The Arctic University of Norway, 108p.

Ovegård, M., Berndt, K., Lunneryd, S.-G., 2012. Condition indices of Atlantic cod (*Gadus morhua*) biased by capturing method. ICES J. Mar. Sci. J. Cons. 69, 1781–1788. https://doi:10.1093/icesjms/fss145

Ovegård, M., Königson, S., Persson, A., Lunneryd, S.-G., 2011. Size selective capture of Atlantic cod (*Gadus morhua*) in floating pots. Fish. Res. 107, 239–244. https://doi.org/10.1016/j.fishres.2010.10.023

Pol, M., He, P., Winger, P., 2010. Proceedings of the International Technical Workshop on Gadoid Capture by Pots (GACAPOT) (Massachusetts Division of Marine Fisheries Technical Report No. TR-40). Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs Department of Fish and Game Massachusetts Division of Marine Fisheries.

R Core Team, 2020. R: A language and environment for statistical computing. Version 3.6.3. R Foundation for Statistical Computing, Vienna, Austria.

Read, A.J., Drinker, P., Northridge, S., 2006. Bycatch of marine mammals in US and global fisheries. Conserv. Biol. 20, 163–169. https://doi.org/10.1111/j.1523-1739.2006.00338.x

Renchen, G.F., Pittman, S.J., Brandt, M.E., 2012. Investigating the behavioural responses of trapped fishes using underwater video surveillance. J. Fish Biol. 81, 1611–1625. https://doi.org/10.1111/j.1095-8649.2012.03418.x

Rose, C.S., Stoner, A.W., Matteson, K., 2005. Use of high-frequency imaging sonar to observe fish behaviour near baited fishing gears. Fish. Res. 76, 291–304. https://doi.org/10.1016/j.fishres.2005.07.015

Santos, J., Herrmann, B., Mieske, B., Stepputtis, D., Krumme, U., Nilsson, H., 2016. Reducing flatfish bycatch in roundfish fisheries. Fisheries Research 184, 64–73. https://doi.org/10.1016/j.fishres.2015.08.025

Santos, J., Herrmann, B., Stepputis, D., Gökçe, G., Mieske, B., *in press*. Quantifying the performance of selective devices by combining analysis of catch data and fish behaviour observations: Methodology and case study on a flatfish excluder. Submitted to ICES J. Mar. Sci. 02-Dec.-2019.

Shester, G.G., Micheli, F., 2011. Conservation challenges for small-scale fisheries: Bycatch and habitat impacts of traps and gillnets. Biol. Conserv. 144, 1673–1681. https://doi.org/10.1016/j.biocon.2011.02.023

Stepputtis, D., Santos, J., Herrmann, B., Mieske, B., 2016. Broadening the horizon of size selectivity in trawl gears. Fish. Res., Fishing gear selectivity, selective fishing and balanced fishing: means, methods and implications 184, 18–25. https://doi.org/10.1016/j.fishres.2015.08.030

Stoner, A.W., 2003. Hunger and light level alter response to bait by Pacific halibut: laboratory analysis of detection, location and attack. J. Fish Biol. 62, 1176–1193. https://doi.org/10.1046/j.1095-8649.2003.00117.x

Stoner, A.W., 2004. Effects of environmental variables on fish feeding ecology: implications for the performance of baited fishing gear and stock assessment. J. Fish Biol. 65, 1445–1471. https://doi.org/10.1111/j.0022-1112.2004.00593.x

Stoner, A.W., Ottmar, M.L., 2004. Fish density and size alter Pacific halibut feeding: implications for stock assessment. J. Fish Biol. 64, 1712–1724. https://doi.org/10.1111/j.0022-1112.2004.00434.x

Stoner, A.W., Sturm, E.A., 2004. Temperature and hunger mediate sablefish (*Anoplopoma fimbria*) feeding motivation: implications for stock assessment. Can. J. Fish. Aquat. Sci. 61, 238–246. https://doi.org/10.1139/f03-170

Suuronen, P., Chopin, F., Glass, C., Løkkeborg, S., Matsushita, Y., Queirolo, D., Rihan, D., 2012. Low impact and fuel efficient fishing—looking beyond the horizon. Fish. Res. 119, 135–146. https://doi.org/10.1016/j.fishres.2011.12.009

Thieurmel, B., Elmarhraoui, A., 2019. Suncalc: compute sunposition, sunlight phases, moon position and lunar phase. R Package version 050. https://CRAN.R-project.org/package=suncalc

Thomsen, B., Humborstad, O.-B., Furevik, D.M., 2010. Fish Pots: Fish Behavior, Capture Processes, and Conservation Issues, in: Behavior of Marine Fishes. Wiley-Blackwell, pp. 143–158. https://doi.org/10.1002/9780813810966.ch6

Utne-Palm, A.C., Breen, M., Løkkeborg, S., Humborstad, O.B., 2018. Behavioural responses of krill and cod to artificial light in laboratory experiments. PloS One 13, e0190918. https://doi.org/10.1371/journal.pone.0190918

Vabø, R., Huse, G., Fernö, A., Jørgensen, T., Løkkeborg, S., Skaret, G., 2004. Simulating search behaviour of fish towards bait. ICES Journal of Marine Science: Journal du Conseil 61, 1224–1232. https://doi.org/10.1016/j.icesjms.2004.06.001

Valdemarsen, J.W., Fernö, A., Johannessen, A., 1977. Studies on the behaviour of some gadoid species in relation to traps. C.M. 1977/B:42. ICES Gear and Behaviour Committee Ref. Demersal Fish (N) Committee.

Walsh, P.J., Hiscock, W., 2005. Fishing For Atlantic Cod (*Gadus morhua*) Using Experimental Baited Pots Results from Trials Placentia Bay& Fortune Bay December 2003 & 2004 Newfoundland and Labrador Canada. Centre for Sustainable Aquatic Resources Fisheries & Marine Institute of Memorial University of Newfoundland, St. John's, NL, Canada.

Westerberg, H., Westerberg, K., 2011. Properties of odour plumes from natural baits. Fish. Res. 110, 459–464. https://doi.org/10.1016/j.fishres.2011.06.002

Wiedenfeld, D.A., Crawford, R., Pott, C., 2015. Results of a Workshop on Reduction of Bycatch of Seabirds, Sea Turtles and Marine Mammals in Gillnets, 21-23 January 2015. American Bird Conservancy and BirdLife International, Shepherdstown, USA.

Žydelis, R., Bellebaum, J., Österblom, H., Vetemaa, M., Schirmeister, B., Stipniece, A., Dagys, M., van Eerden, M., Garthe, S., 2009. Bycatch in gillnet fisheries – An overlooked threat to waterbird populations. Biol. Conserv. 142, 1269–1281. https://doi.org/10.1016/j.biocon.2009.02.025

Žydelis, R., Small, C., French, G., 2013. The incidental catch of seabirds in gillnet fisheries: A global review. Biol. Conserv. 162, 76–88. https://doi.org/10.1016/j.biocon.2013.04.002

Appendix

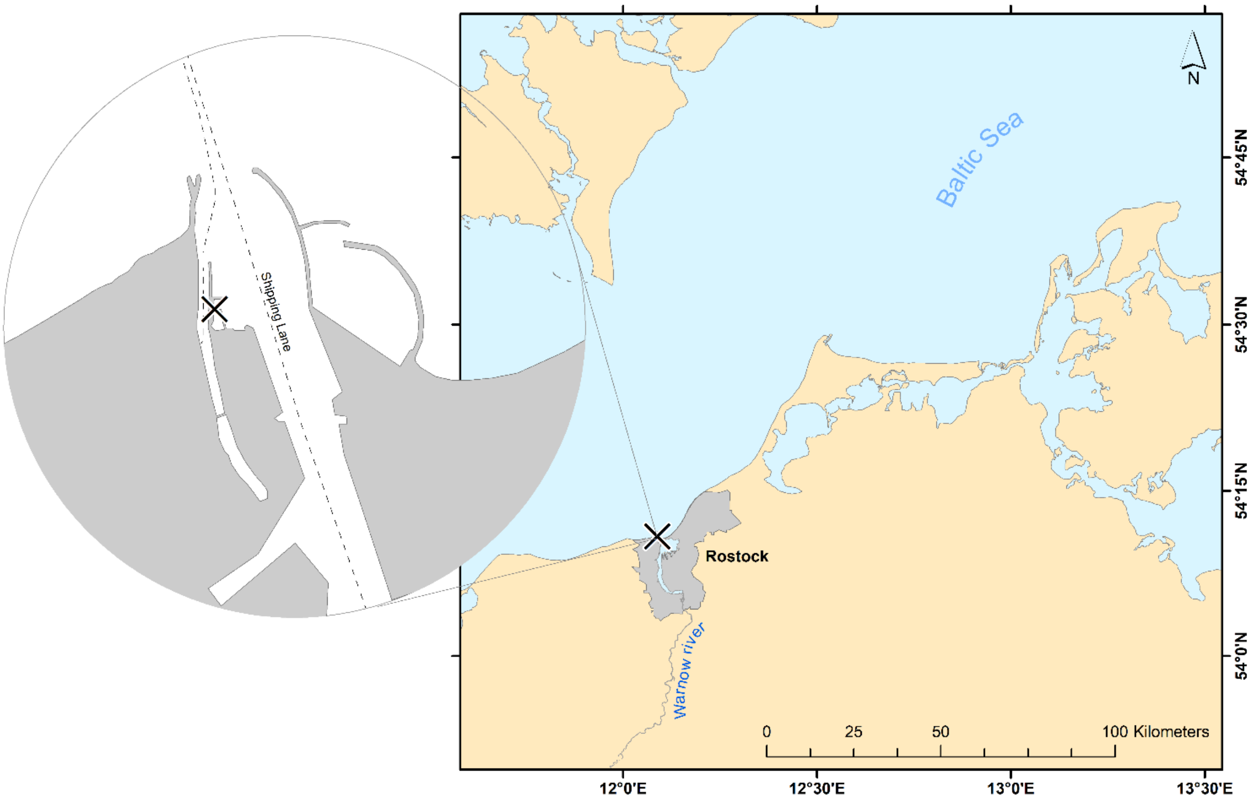


Fig. A1. **The experiment's location in sporting marina Rostock-Warnemünde, Germany.**

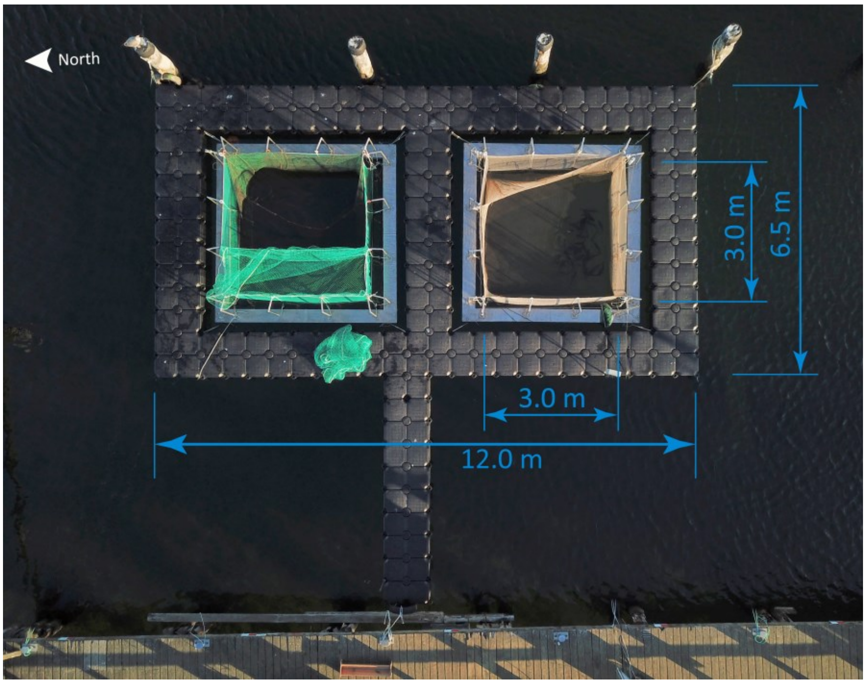


Fig. A2. Net-pen facility in Rostock-Warnemünde, Germany. Aerial view. The right net pen (south) is the experimental net pen; on the left (north) is the holding pen.

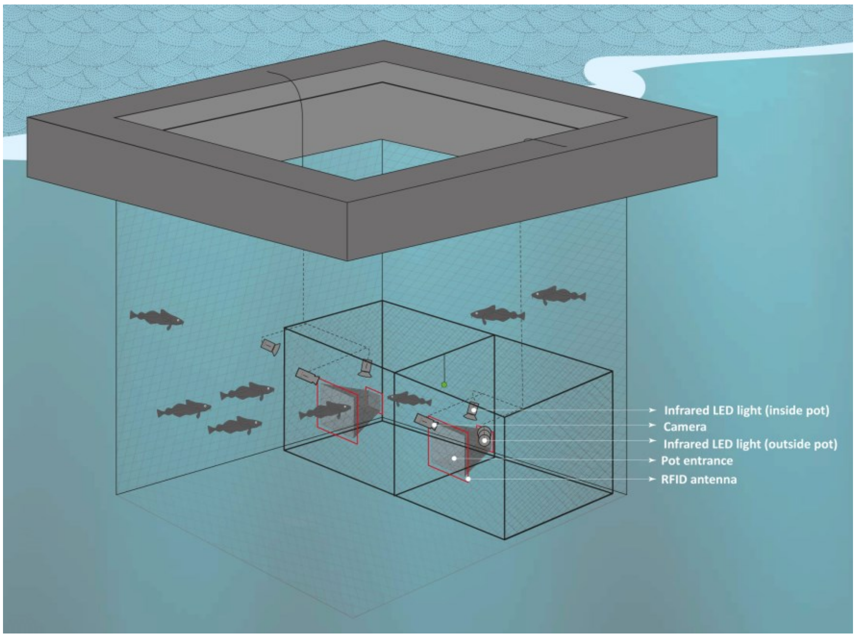
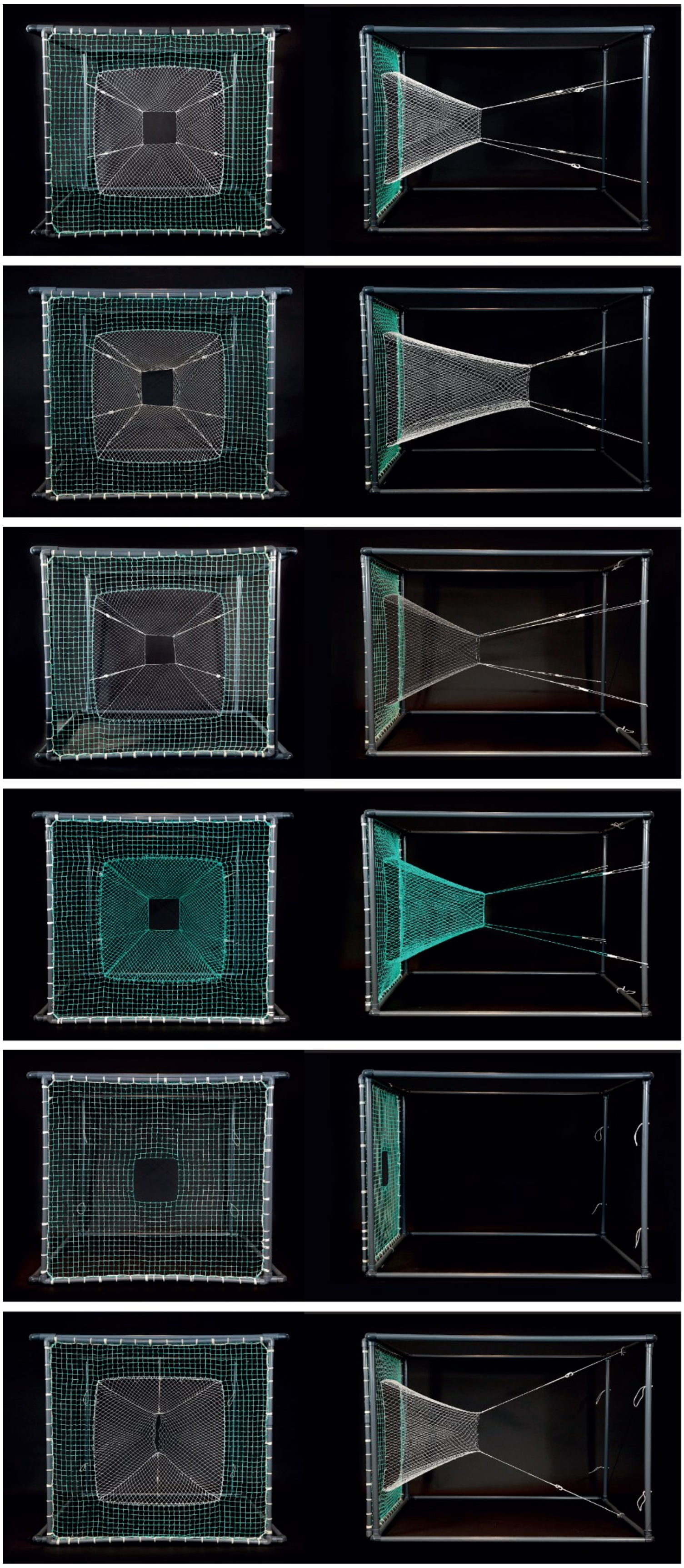


Fig. A3. Schematic representation of the experimental setup. An experimental pot with two exchangeable entrances is lowered into a 3 × 3 × 3 m net pen. Cod inside the pot are free to swim from one entrance to the other. For observation, an IR-camera system (one camera and one IR light before the entrance, one IR light inside the pot above the inner opening of the funnel), and two RFID antennae are mounted at each entrance. Note: Owing to technical difficulties, RFID data could not be used in the data analysis.

Fig. A4. **Experimental pot with two exchangeable entrances. Two IR cameras (1) in front of each funnel entrance and two IR lights (2) on each entrance side (one inside above the funnel inner opening, the other outside next to the IR cameras). Black frames around funnels are RFID antennae (3). Note: Owing to technical difficulties, RFID data could not be used in the data analysis.**



White funnel (50cm long)

Long funnel (75cm long)

Transparent funnel (50cm long)

Green funnel (50cm long)

No funnel

Narrow funnel (50cm long)

Fig. A5. **Front and side views of all experimental entrances.**

Table A1: **Overview of all trials conducted for different entrance types (Test) compared with 'White funnel' entrance (Control): Start, end times and total duration of all entrance experiments. Time gaps equals the total duration of gaps in video recordings. End time is the time when the experimental pot was lifted.**

Tested entrance	Start time	End time (pot lifted)	Duration [hh:mm]	Time gaps [hh:mm]
Green funnel	14.03.2019 15:27	15.03.2019 13:28	22:01	00:16
Green funnel	15.03.2019 14:27	16.03.2019 13:42	23:15	00:10
Green funnel	16.03.2019 14:11	17.03.2019 13:32	23:21	00:14
Green funnel	17.03.2019 14:02	18.03.2019 13:28	23:26	00:32
Green funnel	03.04.2019 14:15	04.04.2019 13:29	23:14	00:20
Green funnel	04.04.2019 14:15	05.04.2019 13:30	23:13	00:24
Transparent funnel	14.12.2018 15:57	15.12.2018 13:56	21:58	00:15
Transparent funnel	18.03.2019 15:04	19.03.2019 13:29	22:26	00:13
Transparent funnel	19.03.2019 15:28	20.03.2019 13:29	22:01	00:18
Transparent funnel	20.03.2019 14:10	21.03.2019 13:31	23:21	00:24
Transparent funnel	05.04.2019 14:24	06.04.2019 13:29	23:05	00:09
Transparent funnel	07.04.2019 14:03	08.04.2019 13:30	23:27	00:38
No funnel	19.12.2018 14:52	20.12.2018 13:15	22:23	00:15
No funnel	20.04.2019 14:07	21.04.2019 13:30	23:22	00:07
No funnel	21.04.2019 14:28	22.04.2019 13:29	23:01	02:15
Long funnel	16.04.2019 14:34	17.04.2019 13:32	22:58	00:56
Long funnel	17.04.2019 14:43	18.04.2019 13:11	22:28	00:13
Narrow funnel	26.04.2019 14:21	27.04.2019 13:27	23:06	00:14
Narrow funnel	28.04.2019 14:22	29.04.2019 13:27	23:04	00:30

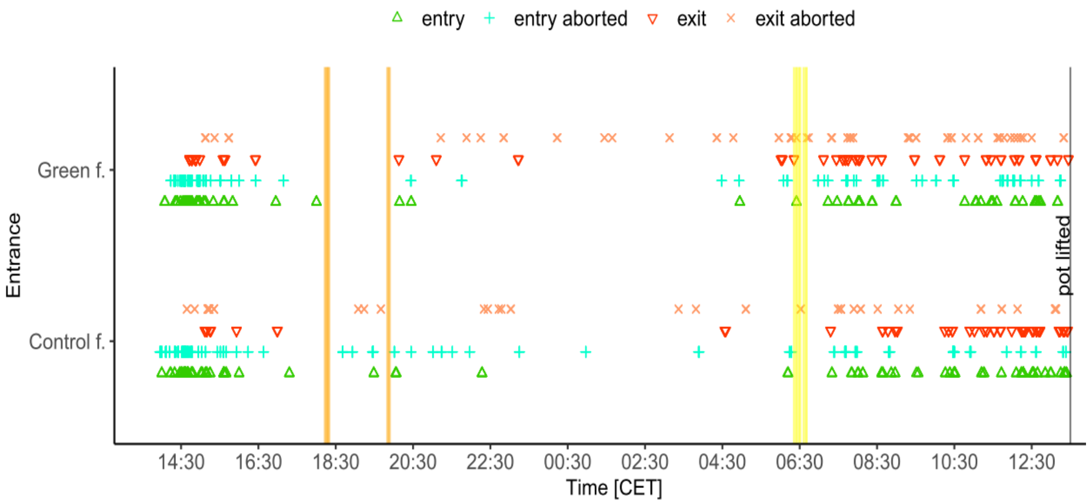


Fig. A6. **Gant chart of entry, aborted entry, exit and aborted exit events of all 'Green funnel' experiments with entrances including funnels (six trials). Vertical lines indicate sunset, sunrise times, and time pot lifted respectively.**

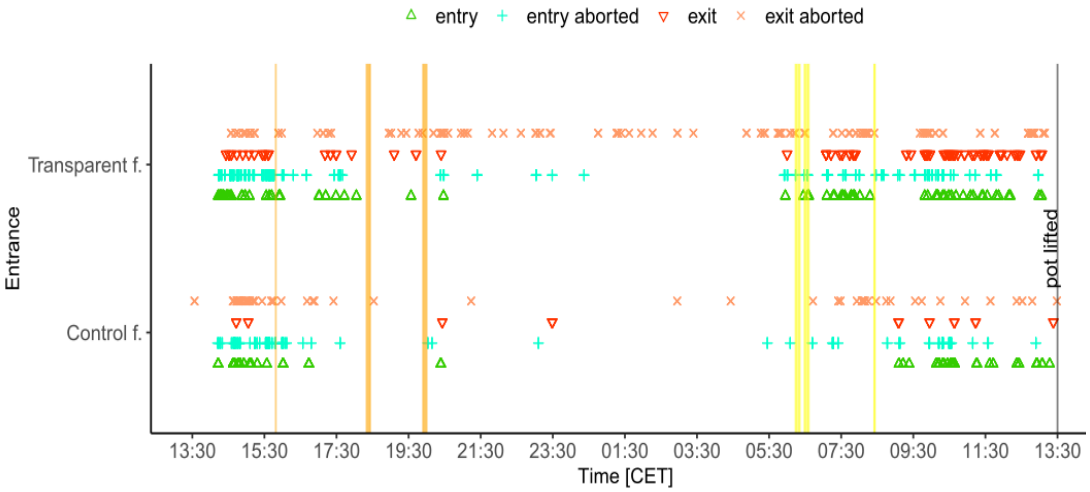


Fig. A7. **Gant chart of entry, aborted entry, exit and aborted exit events of all 'Transparent funnel' experiments with entrances including funnels (six trials). Vertical lines indicate sunset, sunrise times, and time pot lifted, respectively.**

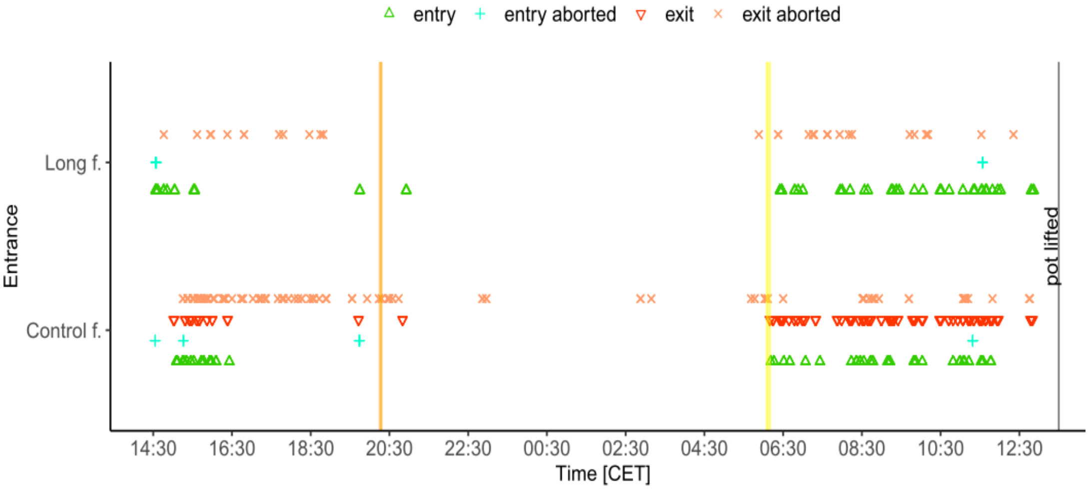


Fig. A8. **Gant chart of entry, aborted entry, exit and aborted exit events of all 'Long funnel' experiments with entrances including funnels (two trials). Vertical lines indicate sunset, sunrise times, and time pot lifted, respectively.**

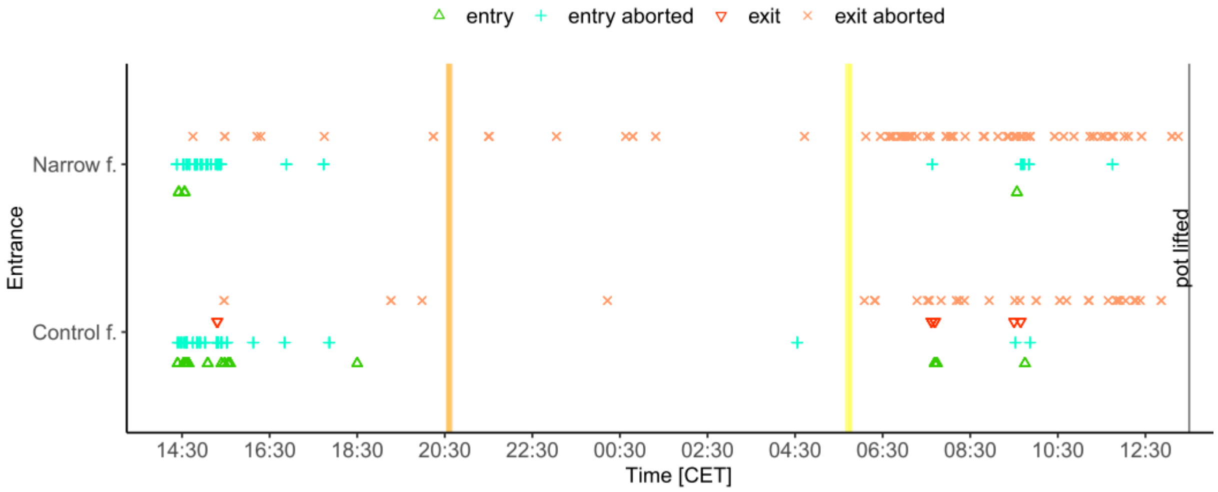


Fig. A9. **Gant chart of entry, aborted entry, exit and aborted exit events of all 'Narrow funnel' experiments with entrances including funnels (two trials). Vertical lines indicate sunset, sunrise times, and time pot lifted, respectively.**

Table A2: **GLM entries and exit GLM AICs of all tested entrance experiments. Models in bold selected by lowest AIC.**

Test entrance	Direction	Model	AIC
Green funnel	Entries	$\boldsymbol{\eta X = \beta_0}$	170.83
		$\eta X = \beta_0 + \beta_1 * side$	172.82
		$\eta X = \beta_0 + \beta_2 * dayperiod$	172.77
		$\eta X = \beta_0 + \beta_1 * side + \beta_2 * dayperiod$	174.75
	Exits	$\eta X = \beta_0$	113.98
		$\eta X = \beta_0 + \beta_1 * side$	113.58
		$\eta X = \beta_0 + \beta_2 * dayperiod$	113.37
		$\boldsymbol{\eta X = \beta_0 + \beta_1 * side + \beta_2 * dayperiod}$	113.20
Transparent funnel	Entries	$\boldsymbol{\eta X = \beta_0}$	149.03
		$\eta X = \beta_0 + \beta_1 * side$	151.03
		$\eta X = \beta_0 + \beta_2 * dayperiod$	151.01
		$\eta X = \beta_0 + \beta_1 * side + \beta_2 * dayperiod$	153.01
	Exits	$\boldsymbol{\eta X = \beta_0}$	55.44
		$\eta X = \beta_0 + \beta_1 * side$	57.40
		$\eta X = \beta_0 + \beta_2 * dayperiod$	55.59
		$\eta X = \beta_0 + \beta_1 * side + \beta_2 * dayperiod$	57.48
No funnel	Entries	$\eta X = \beta_0$	348.28
		$\boldsymbol{\eta X = \beta_0 + \beta_1 * side}$	293.26
		$\eta X = \beta_0 + \beta_2 * dayperiod$	349.42
		$\eta X = \beta_0 + \beta_1 * side + \beta_2 * dayperiod$	293.80
	Exits	$\eta X = \beta_0$	91.02
		$\boldsymbol{\eta X = \beta_0 + \beta_1 * side}$	90.65
		$\eta X = \beta_0 + \beta_2 * dayperiod$	92.99
		$\eta X = \beta_0 + \beta_1 * side + \beta_2 * dayperiod$	92.57
Long funnel	Entries	$\boldsymbol{\eta X = \beta_0}$	118.4
		$\eta X = \beta_0 + \beta_1 * side$	120.05
		$\eta X = \beta_0 + \beta_2 * dayperiod$	119.05
		$\eta X = \beta_0 + \beta_1 * side + \beta_2 * dayperiod$	120.65
	Exits	No exits through ‘Long funnel’	–
Narrow funnel	Entries	$\boldsymbol{\eta X = \beta_0}$	19.22
		$\eta X = \beta_0 + \beta_1 * side$	21.19
		$\eta X = \beta_0 + \beta_2 * dayperiod$	no entries at night
		$\eta X = \beta_0 + \beta_1 * side + \beta_2 * dayperiod$	no entries at night
	Exits	No exits through ‘Narrow funnel’	–

Arbeitspaket 3 – Veröffentlichung 2 “Development and testing of fish-retention devices for pots: transparent triggers significantly increase catch efficiency for Atlantic cod (*Gadus morhua*).”

Chladek, J.C., Stepputtis, D., Hermann, A., Kratzer, I.M.F., Ljungberg, P., Rodriguez-Tress, P., Santos, J., Svendsen, J.C. 2020. Development and testing of fish-retention devices for pots: transparent triggers significantly increase catch efficiency for Atlantic cod (*Gadus morhua*). ICES Journal of Marine Science 78 (1): 199-219, doi:10.1093/icesjms/fsaa214

Abstract

Fish pots have lower catch efficiency than gillnets and trawls and, therefore, are rarely used for catching Atlantic cod (*Gadus morhua*) and similar species. Fish-retention devices (FRDs), non-return devices that permit fish to enter the pot while impeding exit, reduce the pot exit rate and therefore can increase catches. Conventional FRDs, however, also reduce entry rate and may not improve catches. To increase pot-catch efficiency, we developed and tested a new trigger-type FRD, made of transparent acrylic glass, which we named acrylic fingers (AFs). AFs are almost invisible underwater and offer little resistance to entering cod. We compared AFs with Neptune fingers (NFs), a conventional trigger-type FRD with a distinct visual outline, by observing cod entry and exit rates through both trigger types rigged to a pot in a net pen. Both trigger types significantly reduced exit rates compared with a funnel without triggers; however, NFs also reduced entry rates by visually deterring cod. Specifically, AFs have higher entry-to-exit ratios and therefore improve catch efficiency. Combining AFs with funnels further increased catch efficiency. Thus, transparent acrylic triggers present a promising new approach to increasing pot-catch efficiency and may increase the uptake of the cod pot, an environmentally low-impact gear.

Vollständige Veröffentlichung (Open Access)

https://academic.oup.com/icesjms/article/78/1/199/6032366

Arbeitspaket 3 – Veröffentlichung 3 “iFO (infrared Fish Observation) - An open source low-cost infrared underwater video system.”

Hermann, A., Chladek, J.C., Stepputtis, D. 2020. iFO (infrared Fish Observation) - An open source low-cost infrared underwater video system. HardwareX 8:e00149, https://doi.org/10.1016/j.ohx.2020.e00149

Abstract

Underwater video surveillance is an important data source in marine science, e.g. for behaviour studies. Scientists commonly use water resistant ruggedized monitoring equipment, which is cost-intensive and usually limited to visible light. This has two disadvantages: the observation is limited to space and time where visible light is available or, under artificial illumination, behaviour of marine life is potentially biased. Infrared (IR) video surveillance have been used before to overcome these. It records videos at visible light and under IR-illumination. With today’s efficiency of IR-LED and video technology even low-cost systems reach visibility ranges suited for many application scenarios. We describe a low-cost open-source based hardware/software system (iFO). It consists of a single-board computer controlling the camera and lamps (with high power IR-LEDs), printed circuit boards (PCB), the underwater housings and 3D-printable models to mount PCBs in the housings and the housings to standard GoPro mounts. The Linux based software includes webserver, remote control, motion detection, scheduler, video transfer, storage at external hard disk and more. A ready-to-use SD-card image is included. We use rugged underwater housings with 100 m (optional 400 m) depth ratings. Finally, we describe a typical application observing the behaviour of cod in fish pots.

Vollständige Veröffentlichung (Open Access)

https://doi.org/10.1016/j.ohx.2020.e00149

Arbeitspaket 3 – Dissertation “Fishing gear technology to mitigate harbour porpoise and seabird bycatch in the Baltic Sea: Gillnet modifications and alternative fishing gear fish pot.”

Chladek, J.C. 2022. Fishing gear technology to mitigate harbour porpoise and seabird bycatch in the Baltic Sea: Gillnet modifications and alternative fishing gear fish pot. Dissertation, University of Hamburg, Hamburg. 153 pp. (submitted)

Zusammenfassung

Stellnetze sind das weltweit wichtigste Fanggerät der kleinen Küstenfischerei („small scale fisheries“ (SSF)). Sie sind kostengünstig und einfach einzusetzen, ihre hohe Größenselektivität ist gut einstellbar und vor allem weisen sie eine hohe Fangeffizienz für ihre Zielarten auf. In jüngster Zeit wird ihre Verwendung zunehmend kritisiert, denn sie führen zu einem erheblichen Beifang von Meeressäugern, tauchenden Seevögeln sowie marinen Schildkröten, den Fortbestand vieler dieser Megafaunaarten bedrohend. Stellnetze haben die höchste Beifangintensität aller fischereilichen Fanggeräte für diese Taxa. In der Ostsee werden Stellnetze u. a. zum Fang von Dorsch (*Gadus morhua*), Hering (*Clupea harengus*), Steinbutt (*Scophthalmus maximus*) und Scholle (*Pleuronecta platessa*) verwendet. Die Stellnetzfischerei führt dort zu einem erheblichen Beifang von Schweinswalen (*Phocoena phocoena*) sowie zu einer der höchsten Stellnetzbeifangraten für tauchende Seevögel weltweit. Mehrere dieser Seevogelarten sowie eine der beiden dortigen Schweinswalunterpopulationen gelten als gefährdet und werden als besonders durch Stellnetzbeifang bedroht angesehen. Die baltischen EU-Mitgliedsstaaten sind rechtlich dazu verpflichtet, die Beifänge dieser Arten zu begrenzen.

Ziel dieser Dissertation ist die Entwicklung neuer Ansätze zur Beifangverringerung. Ausgangspunkt ist die Annahme, dass Stellnetzbeifang nicht durch einen einzelnen technischen Lösungsansatz ausreichend vermindert werden kann. Zielführend ist vielmehr die Entwicklung eines Werkzeugkastens unterschiedlicher Maßnahmen.

In Teil A dieser Dissertation (Paper I) wurde der “Porpoise ALert” (jetzt vom Hersteller F3 Maritime Technology unter dem Namen “porpoise-PAL” vertrieben; “PAL” hiernach) als eine Weiterentwicklung der sog. „Pinger“-Technologie getestet. Pinger sind an Stellnetze zu befestigende Geräte zur akustischen Vergrämung von Walen, Delfinen und Schweinswalen. Dazu senden herkömmliche Pinger künstliche Geräusche ohne biologische Bedeutung aus. Es bestehen wissenschaftliche Bedenken im Hinblick auf ihre Wirksamkeit und andere unbeabsichtigte Auswirkungen auf die damit zu schützenden Meeressäuger, wie zum Beispiel weiträumige Habitatvertreibung. Ziel der Pinger-Weiterentwicklung PAL war die Vermeidung dieser negativen Pingereffekte. Dazu sendet der PAL natürliche, aversive Kommunikationssignale von Schweinswalen der westlichen Ostsee aus.

Leitfrage von Teil A war, ob der PAL den Beifang von Schweinswalen der westlichen Ostsee in der kommerziellen Stellnetzfischerei wirksam reduziert. Dazu wurde ein Fischereiversuch mit drei Fahrzeugen der kommerziellen Stellnetzfangflotte durchgeführt, die von 2014 bis 2016 insgesamt 778 Tages-Fangreisen im Rahmen ihrer üblichen Fischereiaktivität durchführten. Die Beifangwahrscheinlichkeit von insgesamt 1.120 PAL-ausgestatteten Stellnetzfleeten sowie 1.529 Kontrollfleeten ohne PAL wurde verglichen.

Über die gesamte Versuchsdauer wurden insgesamt 18 Schweinswale in Kontrollfleeten sowie fünf Schweinswale in PAL-Fleeten beigefangen. Mittels eines „generalised linear mixed model“ (GLMM) wurde nachgewiesen, dass PAL den Beifang von Schweinswalen der westlichen Ostsee um 79,7% signifikant verringern, wenn der Abstand zwischen an den Fleeten aufeinanderfolgenden PAL nicht mehr als 200 m beträgt.

Die Studie von Teil A zeigt des Weiteren, dass eine Erhöhung der Distanz zwischen aufeinanderfolgenden PAL auf 210 m den Beifang-verringernden Effekt auf 64.9% verringert. Diese Erkenntnis unterstützt die Ergebnisse früherer Pingerstudien, die zeigten, dass die Distanz zwischen aufeinanderfolgenden Pingern ein wichtiger Einflussfaktor auf deren Beifang-verringernden Effekt ist.

In der Teil-A Studie wurden keine Hinweise darauf gefunden, dass PAL die Stellnetzfängigkeit auf die Zielarten verringert – ein wichtiges Ergebnis für den Einsatz von PAL in der Stellnetzfischerei. Die xi Tatsache, dass über 100 deutsche Stellnetzfahrzeuge in der westlichen Ostsee die PAL mittlerweile schon seit mehreren Jahren einsetzen, belegt dies. Somit kann geschlussfolgert werden, dass der PAL Stellnetz-Schweinswalbeifang in der westlichen Ostsee signifikant verringert. Der PAL kann für effektive Schweinswalbeifangvermeidung in dieser Region genutzt werden, mit vergleichbarer Effektivität zu konventionellen Pingern.

Der PAL ist das erste akustische Gerät, dass den Beifang von Schweinswalen mittels ihrer eigenen kommunikativen Lautäußerungen verringert. Er stellt somit ein wichtiges „proof-of-concept” dar und eröffnet damit einen neuen Ansatz zur Beifangvermeidung von Walen, Delfinen und Schweinswalen.

Obwohl PAL und konventionelle Pinger in der Studie von Teil A nicht direkt verglichen wurde, wird argumentativ erörtert, ob der PAL vergleichbare oder sogar gleichartige schädliche Effekte bewirken könnte. Bei einer Before-After-Control-Impact (BACI) Studie von Schweinswalverbreitung in dem Gebiet, in dem der PAL seit mehreren Jahren eingesetzt wird, wurden keine Belege für Habitatsvertreibung gefunden. Die Belege der BACI-Studie sind jedoch nicht stark aussagekräftig und eine potentiell schädliche Habituation der Schweinswale an das PAL-Signal konnte nicht untersucht werden. Somit bedürfen mögliche Habitatsvertreibung und Habituation weiterer Untersuchungen, um ausgeschlossen werden zu können.

In Teil B der Dissertation lag der Fokus auf möglichen Fanggerätealternativen mit geringerem Beifangpotential im Vergleich zu Stellnetzen. Die meisten bekannten Fanggerätealternativen werden von der kleinen Küstenfischerei der Ostsee nicht genutzt, da sie für den Einsatz von kleinen Fischereifahrzeugen weniger geeignet sind. Auch haben sie meistens eine geringere Fangeffizienz und ihr Einsatz ist somit ökonomisch weniger rentabel. Des Weiteren weisen sie oft eine geringere Einsatzvielseitigkeit auf: Manche Fanggerätealternativen können nur in bestimmten Gebieten eingesetzt werden, zum Beispiel nur in flachen Küstengewässern.

Im ersten Schritt wurde zur Identifikation des als Stellnetzalternative am besten geeigneten Fanggeräts, Fanggerätealternativen systematisch nach operativen, wirtschaftlichen und ökologischen Kriterien bewertet. Grundlage für die Bewertung war eine Literaturrecherche sowie Diskussionen mit Fischereifangtechnikern und professionellen Fischern. Die folgenden Fanggeräte wurden analysiert: pneumatisch-hebbare Großreusen, sog. „Ponton-Fallen“, Fanggeräte mit Haken wie Langleinen und sog. „Jigging-Maschinen“, das aktive Fanggerät Snurrewade oder „Danish seine“ sowie Fischfallen. Letztere wurden als beste Stellnetzalternative für die kleine Küstenfischerei der Ostsee identifiziert. Sie sind ebenso vielseitig einsetzbar, liefern den hochwertigsten Fang und können selbst von kleinsten Fischereifahrzeugen eingesetzt werden. Und im Kontext dieser Dissertation entscheidend: Fischfallen haben ein geringes Risiko für Beifang von Schweinswalen sowie tauchender Seevögel.

Wichtigstes Ziel der im zweiten Schritt in Teil B unternommenen Studien war, die Fangeffizienz von Fischfallen bei der Dorschfischerei zu erhöhen. Denn damit würde ihre Wirtschaftlichkeit verbessert werden und somit auch ihre Aufnahmewahrscheinlichkeit durch die Stellnetzfischerei. Mittels einer Literaturstudie von Fischfallen-Fangeffizienzstudien wurden Einflussfaktoren identifiziert und bewertet. Fischfalleneingänge wurden dabei als zentraler Einflussfaktor herausgearbeitet. Fischfalleneingänge sollen idealerweise den Eintritt von sich der Fischfalle nähernden Fischen in die Fischfalle möglichst erleichtern und einen darauffolgenden Austritt verhindern. Diese zentrale Eigenschaft wird bei der Fischfallenfischerei jedoch meist nicht erreicht.

Weiterhin zeigte die Literaturstudie, dass die meisten Fischfallen-Fangeffizienzstudien Fischereifangvergleiche im Feld sind. Bei solchen Studien werden unterschiedliche Fischfallentypen unter gleichen Bedingungen in einer Fischerei parallel gefischt. Ihr Fangertrag (catch-per-unit-effort xii (CPUE)), also die Anzahl gefangener Fische pro eingesetzter Fischfalle eines bestimmten Fischfallentyps, ist dabei der Hauptmesswert, mit dem die Fangeffizienz der Fischfallen verglichen wird. Dieser Messwert erlaubt jedoch keine Rückschlüsse darauf, wie die Zielart mit den Fischfallen interagiert. Dabei ist diese Information essenziell für effiziente Fanggeräteentwicklung, einschließlich Studien zur Steigerung der Fangeffizienz. Fischereifangvergleiche im Feld haben mehrere weitere Nachteile, zum Beispiel die so nicht zu erfassende, variierenden Zielartabundanzen um die getesteten Fischfallen, oder die nicht zu erfassende Größe und Kondition sich den Fallen nähernder Fische.

Zur Vermeidung dieser Nachteile von Fischereifangvergleichen, wurde in Teil B eine neue, effektivere Methode entwickelt: Die netzkäfigbasierte Beobachtungsmethode („net pen-based observation method“). Sie erlaubt den direkten Vergleich des Verhaltens von Fischen in Relation zu Fischfallencharakteristika. Die Methode umfasst physische und statistische Elemente. Der physische Aufbau umfasst eine speziell für den Versuchsaufbau angefertigte Fischfalle, derer zwei Eingänge leicht austauschbar sind und an der ein Unterwasser-Videosystem mit Langzeitaufnahmekapazitäten angebracht ist. Das Videosystem hat Infrarotlicht (IR)-Aufnahmefähigkeiten und erlaubt so eine Fische nicht beeinflussende Tag- und Nachtbeobachtung (Paper II). Damit können alle Interaktionen von Fischen mit den Eingängen während der Versuche aufgezeichnet werden, also erfolgreiche wie nicht-erfolgreiche Durchtrittsversuche. Fischfalle samt Videosystem werden in einen Netzkäfig platziert, in denen ausgesuchte Fische eingesetzt werden können.

Das erste statistische Element der Methode ist ein Ethogramm für die Interaktion von Fischen mit Fischfalleneingängen, mit dem diese beschrieben und bewertet werden können. Die beobachtete Fischfalleneingangseffizienz – eine Funktion aus Eintritts- und Austrittswahrscheinlichkeit durch einen Eingang – wird mit einem Bündel aus zwei statistischen Methoden quantifiziert und verglichen. Diese statistischen Elemente erlauben die Ereignisketten von Fisch-Eingangsinteraktionen zu „sezieren“. Die Ursachen für die zwischen den getesteten Eingängen beobachteten Unterschiede können so präzise bestimmt werden. Bei jedem Versuchsdurchgang wird die gleiche Anzahl an Fischen in den Netzkäfig gesetzt, und so eine gleichbleibende Fischabundanz um die Fischfalle gewährleistet.

Die Zielart für die Effizienzsteigerung der Fischfallen war Dorsch, derzeit eine der Haupt-Zielarten für die kleine Küstenfischerei der Ostsee zu dieser Zeit. Um das Verständnis der Interaktion von Dorschen mit Fischfalleneingängen zu erhöhen, wurden mittels der entwickelten Methode zweier Fischfallenstudien durchgeführt. In der ersten Studie (Paper III) wurde der Einfluss von grundlegenden Parametern von Fischfalleneingängen untersucht. Analysierte Parameter waren Präsenz von angebrachten Netz-Kehlen, Kehlenlänge, Kehlenfarbe sowie Kehlentyp. Wichtige, grundlegende Erkenntnisse für das Verständnis der Interaktion von Dorschen mit Fischfalleneingängen wurden erzielt: Zum einen wurden ausgeprägte Tag/Nacht Unterschiede aufgezeigt, mit sehr wenigen nächtlichen Eingangsdurchtritten. Zum anderen wurde eine unbehinderte Durchsicht durch die Eingänge des Falleninneren oder -äußeren für von außen oder innen mit den Eingängen interagierenden Dorschen als Schlüsselfaktor für eine erfolgreiche Eingangspassage identifiziert. Bezüglich Einfluss der Eingangsparameter wurde gezeigt, dass eine angebrachte Kehle die Wahrscheinlichkeit erhöht, dass sich nährende Dorsche den Eingang finden, weil sie die äußere Eingangsöffnung vergrößert und so Dorsche auf den Eingang hinleiten. Des Weiteren verringern Kehlen die Austrittsrate, mutmaßlich indem Dorsche von der inneren Eingangsöffnung abgelenkt werden und indem sie den Bereich in der Falle verringern, von dem die Ausgangsöffnung unversperrt sichtbar ist. Kehlen sind somit entscheidend, um die Fischfallenfängigkeit zu maximieren. Durch Verlängerung der Kehlenlänge wird der Bereich in der Falle, von der die Ausgangsöffnung unversperrt sichtbar ist, weiter verringert. Auch wird mutmaßlich die Austrittswahrscheinlichkeit durch die längere xiii Distanz, die Dorsche beim Austritt wieder zurückschwimmen müssen, reduziert. Kehlenfarbe (getestete Netzfarben: weiß, grün sowie transparentes Netzmaterial) beeinflusst Kehlendurchtrittsraten, mit signifikant höherer Durchtrittsrate bei transparenten Kehlen.

Ziel der zweiten Fischfallenstudie (Paper IV) war, Fischfallenfängigkeit durch Reduktion der Austrittswahrscheinlichkeit, bei gleichzeitiger Vermeidung einer Reduzierung der Eintrittswahrscheinlichkeit, zu erhöhen. Aufbauend auf der Erkenntnis der ersten Studie, dass Dorsche vor allem ihr Sehvermögen zum Durchtritt von Fischfalleneingängen nutzen, wurden die sog. „Acrylic fingers" (AF) entwickelt. AF sind ein neuartiger Typ von fingerförmigen Fischrückhaltevorrichtungen, sog. „Trigger". Im Gegensatz zu Vorgänger-Trigger, bestehen AF aus transparentem Acrylglas und sind unter Wasser daher fast durchsichtig.

AF wurden mittels der netzkäfigbasierten Beobachtungsmethode mit einem konventionellen, kommerziell erhältlichen und unter Wasser deutlich sichtbaren Triggertyp, den „Neptune fingers" (NF), verglichen. Beide Typen verringerten signifikant die Austrittsrate aus der Fischfalle im Vergleich zu Eingängen ohne Trigger. Die rigiden NF reduzierten jedoch auch die Eintrittsrate, indem sie Dorsche visuell abschreckten. Die AF hingegen bewirkten keine Änderung der Eintrittsrate im Vergleich zu Eingängen ohne Trigger. AF haben somit ein höheres Eintritt-zu-Austrittverhältnis als Eingänge ohne AF und verdoppeln somit fast die Fangeffizienz.

Diese transparenten Acrylglastrigger stellen insgesamt einen vielversprechenden Ansatz zur Erhöhung der Fischfallen-Fangeffizienz und erlauben die Entwicklung neuer, innovativer Eingänge für Fischfallen zur gleichzeitigen Befischung mehrerer Zielarten (Mehrartenfischfalle). Damit könnte die Aufnahme von Fischfallen als alternatives Fanggerät mit geringen Umweltauswirkungen für die kleine Küstenfischerei der Ostsee vorangebracht werden.

Die in Teil B der Dissertation gewonnenen Erkenntnisse zeigen die Vorteile der netzkäfigbasierten Beobachtungsmethode im Vergleich zu den üblichen Fischerei-Fangvergleichen auf. Die Methode erlaubt ein tiefgehendes Verständnis für den Einfluss verschiedener Eingangsparameter auf die Interaktion von Dorschen mit Fischfalleneingängen zu gewinnen. Sie ermöglicht somit eine zielgerichtete Entwicklung und Evaluation verbesserter Eingänge. In dieser Dissertation wurde sie genutzt, um entscheidende Erkenntnisse zur Interaktion von Dorschen mit Fischfallen zu gewinnen und so eine Grundlage für weitere Eingangsverbesserungen zu legen. Darüber hinaus wurde mit ihr ein verbesserter Trigger-Typ entwickelt, der die Rückhaltekapazität von Eingängen erhöht, ohne die Eintrittswahrscheinlichkeit zu verringern. Weitere Fischfallenstudien werden von dieser Methode und den so gewonnenen Erkenntnissen profitieren können.

Die Erkenntnisse von Teil B haben darüber hinaus auch direkt Fischerei-Managementrelevanz. Denn aufgrund des kritischen Erhaltungszustands der Schweinswal-Population der zentralen Ostsee werden in Zukunft Stellnetze in bestimmten Schutzgebieten der zentralen Ostsee verboten sein. Diese Verbote stellen eine erhebliche Einschränkung für die kleine Küstenfischerei dar. Fischer werden auf alternative Fanggeräte (wie zum Beispiel Fischfallen) umstellen müssen, wenn sie in den Schutzgebieten weiter fischen wollen. Die Erkenntnisse bezüglich Tag/Nacht-Unterschieden bei Eingangspassagen sowie das verbesserte Verständnis der Interaktion von Dorschen mit Fischfalleneingängen können den Fischern beim erfolgreichen Umstieg auf Fischfallen nützlich sein.

Die vorliegende Dissertation bestückt den Beifangverringerungs-Werkzeugkasten für die Ostsee mit neuen, innovativen und effizienten Werkzeugen. Sie kann so dazu beitragen, den Dissens zwischen Fischerei- und Arterhaltungsinteressen zu verringern. Das PAL-Konzept sowie die netzkäfigbasierte Beobachtungsmethode und die damit gewonnenen Erkenntnisse können zudem teils direkt, teils perspektivisch auf andere marine Regionen übertragen werden.

Arbeitspaket 3 – Bericht “Ponton-Hebereuse”

1. Einleitung

Das Hauptziel der fangtechnischen Arbeiten im Projekt STELLA war die Entwicklung und Erprobung von Fanggeräten, die den Beifang geschützter Arten reduzieren. Die Arbeiten zu Stellnetzmodifikationen und zu Fischfallen folgten vor allem diesem Ziel. In den letzten Jahren kam noch ein weiteres Themenfeld hinzu: Die Robbenpopulation in den deutschen Gewässern nahm in den letzten Jahren stark zu. Daraus resultiert ein zunehmender Konflikt zwischen den Interessen der Fischer und dem Naturschutz, da die Robben sowohl die Fische aus den Stellnetzen fressen (Abbildung 19), die Stellnetze beschädigen, aber auch die Wahrscheinlichkeit steigt, dass Robben in Fanggeräten mitgefangen werden. Aus diesem Grund ist es notwendig, auch an Fanggeräten zu arbeiten, die „Robbensicher“ im doppelten Sinne sind: Die Fanggeräte müssen den Fang vor den Robben schützen, aber auch die Robben davor schützen, mitgefangen zu werden.

Im Rahmen der Arbeiten zu alternativen Fanggeräten wurde u.a. untersucht, wie sich das Design von Fischfallen optimieren lässt. Es wurde aber auch ein an der deutschen Küste noch nie eingesetztes Fanggerät – die Ponton-Hebereuse – untersucht und weiterentwickelt.

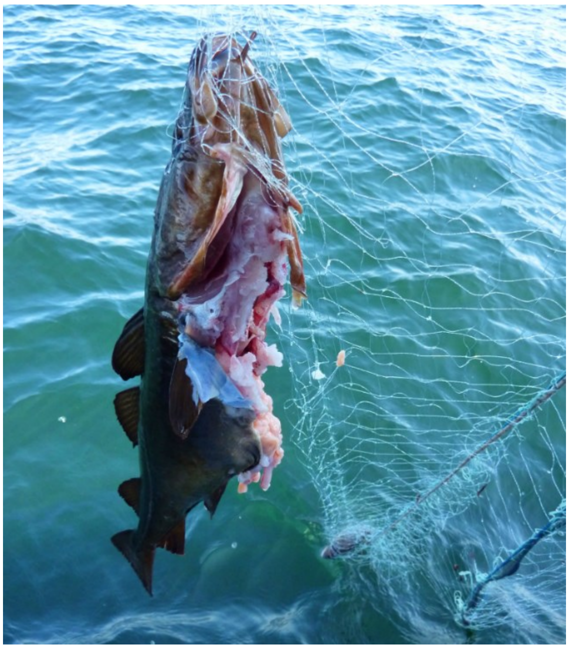


Abbildung 19: Fraßschäden durch Robben an Fisch im Stellnetz (Bild: Peter Ljungberg, SLU)

2. Beschreibung Ponton-Hebereuse

Die Ponton-Hebereuse ist ein *passives Fanggerät*, das im Grunde eine *modifizierte Großreuse* ist.

Die Verwendung von Großreusen hat in der Ostsee eine lange Tradition. In Dänemark wird seit Beginn des 20. Jahrhunderts mit nach oben offenen Reusenanlagen („Bundgarn“) aus an gerammten Holzpfählen aufgespannten Netzen gefischt.

Vor der Wiedervereinigung war die Heringsfischerei mit Kummreusen in der Region Rügen weit verbreitet. In Ufernähe findet man heute nur noch an einigen ausgewählten Standorten Kummreusen oder Schwimmreusen. Reusen erfüllen die höchsten Nachhaltigkeitsansprüche (z.B. in Bezug auf Habitateinfluss, Treibstoffverbrauch, Qualität der Ware (in der Regel lebt der Fisch in der Reuse), Beifangfreiheit) und sind deshalb als alternative Fanggeräte sehr attraktiv. Das Betreiben einer Großreuse ist in der Regel allerdings vergleichsweise aufwendig. Neben dem Auf- und Abbau der Reuse ist auch das ‚Besehen‘ der Reuse aufwendig und erfordert die Mitarbeit mehrerer Fischer.

In Schweden und Finnland wurde vor einigen Jahren eine weitere Variante der Großreuse entwickelt. Bei diesen so genannten Ponton-Hebereusen wird beim ‚Besehen‘ der Reuse die Fangkammer der Reuse mittels Druckluft an die Oberfläche geholt und der Fang kann einfach durch einen Fischer entnommen werden. Dazu ist die stabile Fangkammer mit Luftkammern versehen (aus dem engl. Pontoon resultiert der Name Pontoon-trap = Ponton-Hebereuse), die mittels Schläuchen an der Oberfläche und eines mobilen Kompressors aufgepumpt werden.

Abbildung 20: ‚Besehen‘/Heben einer originalen skandinavischen Ponton-Hebereuse. Bild aus der skandinavischen Lachsfischerei: Bild: SLU Schweden

Abbildung 21: STELLA-Untersuchungen zur Ponton-Hebereuse in deutschen Gewässern: Luftaufnahme der Schwimmreuse mit Ponton-Hebereuse-Fangkammer (Standort: Prohner Wiek). Zu sehen ist: a) Leitwehr der Schwimmreuse; b) Rückfang der Schwimmreuse (Netz als dunkler Schatten unter Wasser zu erkennen); c) Fangkammer der Ponton-Hebereuse (altes Design), d) eine Kufe mit Auftriebskörper/Luftkammer

Abbildung 22: Nahansicht der Ponton-Hebereuse (Fangkammer, altes Design aus 2018)

3. Ziel der Versuche

Die Ponton-Hebereuse wurde für die Fischerei in Skandinavien entwickelt und dort auch eingesetzt. Die Gegebenheiten der Fischerei in Skandinavien unterscheiden sich jedoch stark von den Verhältnissen in deutschen Gewässern. Unterschiede sind zum Beispiel

- die Küstenmorphologie: Während in Skandinavien die Ponton-Hebereuse entweder oberflächennah oder als Bodenreuse in den oft tieferen und geschützten Bereichen der Schären eingesetzt werden, ist die deutsche Küste (einschließlich der Bodden) relativ flach und oft ungeschützt. Dadurch ergeben sich z.B. große Herausforderungen in Bezug auf Stabilität und Verankerung
- die Zielarten: In Skandinavien werden die Ponton-Hebereusen vor allem zum Lachsfang (oberflächennah) oder zum Fang von Dorschen eingesetzt. An der deutschen Küste sollen mittelfristig auch die bei uns typischen Ostsee-Meeresfischarten (Dorsch, Flunder, Scholle, Steinbutt, Hering) gefangen werden, aber auch verschiedene Süßwasserfischarten (Zander, Hecht, Flussbarsch).

Aus diesem Grund hatten die Versuche im Rahmen des Projektes STELLA zur Ponton-Hebereuse folgende Ziele:

- Test der Handhabung der Ponton-Hebereuse unter Praxisbedingungen
- Anpassung des Handlings und der Konstruktion der Ponton-Hebereuse an die Gegebenheiten der deutschen Küstenfischerei
- Untersuchung und Verbesserung der Fangeffizien

4. Durchgeführte Arbeiten

4. 1 Durchgeführte Einsätze

Im Frühjahr 2018 wurde eine Ponton-Hebereuse vom Hersteller Maskin Marine aus Schweden beschafft. Diese Reuse (mit entsprechenden Modifikationen, s.u.) wurde bisher in folgenden Zeiträumen eingesetzt:

- Frühjahr 2018
- August-Oktober 2018
- Juni-Juli 2019
- September-November 2019
- Juni-Juli 2020

4. 2 Einsatzgebiet der Reusen

Die Ponton-Hebereuse wurde in den Jahren 2018 und 2019 in den Boddengewässern nördlich von Stralsund (Prohner Wiek) eingesetzt. Im Jahr 2020 wurde die Ponton-Hebereuse zunächst südlich der Insel Ummanz eingesetzt (Abbildung 23). Im weiteren Jahresverlauf sollte versucht werden, die Reuse auch ‚mobil' einzusetzen, d.h. den Standort auch zu wechseln, um diese Möglichkeit und die damit verbundenen Vorteile demonstrieren zu können.

Abbildung 23: **Standort der Ponton-Hebereuse während der Fangsaison 2018 und 2019 in der Prohner Wiek nördlich von Stralsund und 2020 südlich von Ummanz. Oben: Übersichtskarte; unten: Detailkarte mit Position der Standorte der Ponton-Hebereuse in den entsprechenden Jahren (Positionen und Längen der Leitwehre sind indikativ).**

5. Weiterentwicklung der Konstruktion (Teil 1)

Wie bereits beschrieben, wurde die ursprüngliche Konstruktion für andere Fanggebiete und andere Fischarten entwickelt. Bereits bei den Fangeinsätzen im Jahr 2018 wurde klar, dass es notwendig ist, die ursprüngliche Konstruktion der Ponton-Hebereuse (Abbildung 24) anzupassen. Neben einer ganzen Reihe kleinerer Änderungen wurde aus diesem Grund in den ersten Monaten 2019 die gesamte Konstruktion umgebaut (Fangkammer und Rückfang; Abbildung 25 - Abbildung 28).

Hauptziele bei den Umbauten im Winter 2018/2019 waren

- Verbesserte Fangkammer um die Ponton-Hebereuse auch in den flachen, relativ ungeschützten Küstengewässern einsetzen zu können
- Verbessertes Handling
- Vergrößerung der Fangkammer, um den Fischen möglichst viel Raum zu geben, und somit das Wohlbefinden der Fische in der Reuse zu erhöhen
- Erhöhung der Fängigkeit für ein breiteres Spektrum von Fischarten
- Pelagische Fischarten: Hering, Hornhecht, usw.
- Demersale Fischarten: Zander
- Bodenfische: Flunder (die beim ursprünglichen Design gar nicht gefangen wurden)
- Einbau eines neuen Robben-Excluders (Rechteck-Rahmen mit 17cm Breite)

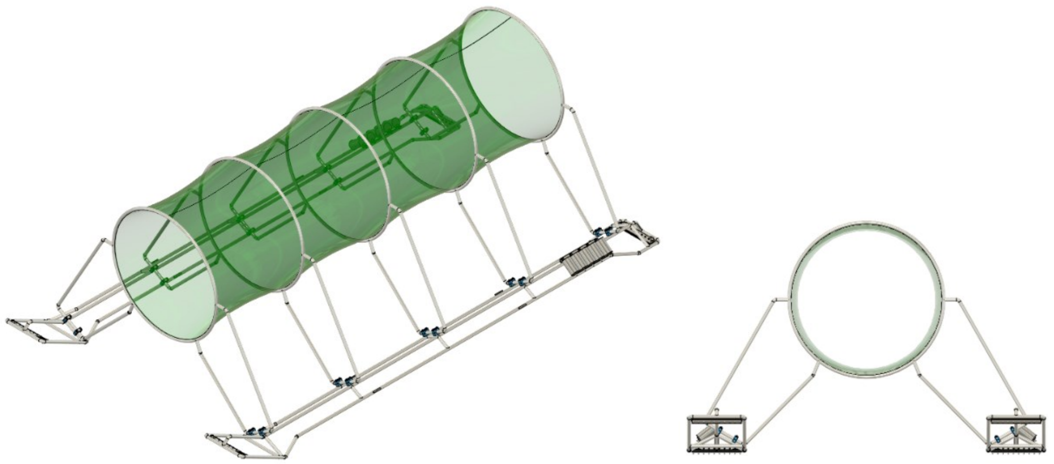


Abbildung 24: **Ponton-Hebereuse: Originales Design der Fangkammer**

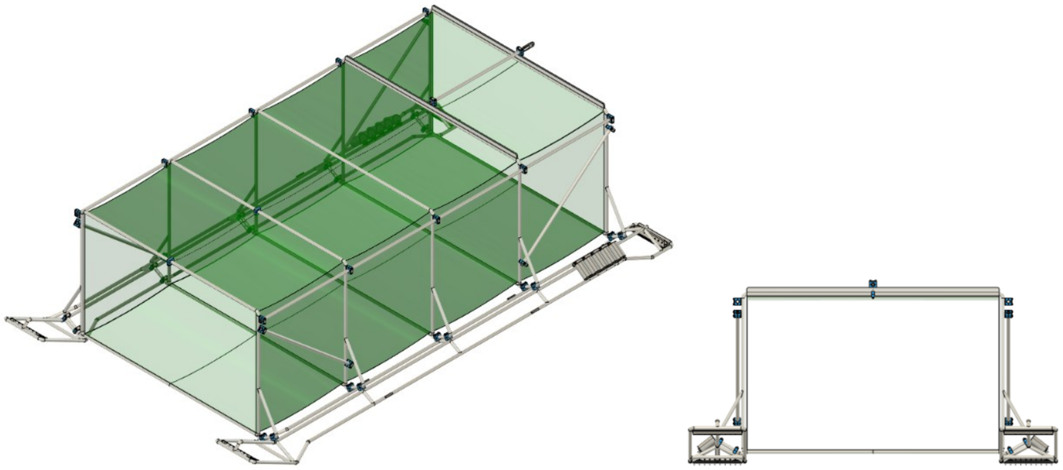


Abbildung 25: **Ponton-Hebereuse: Konstruktion der Fangkammer nach Umbauten Anfang 2019**

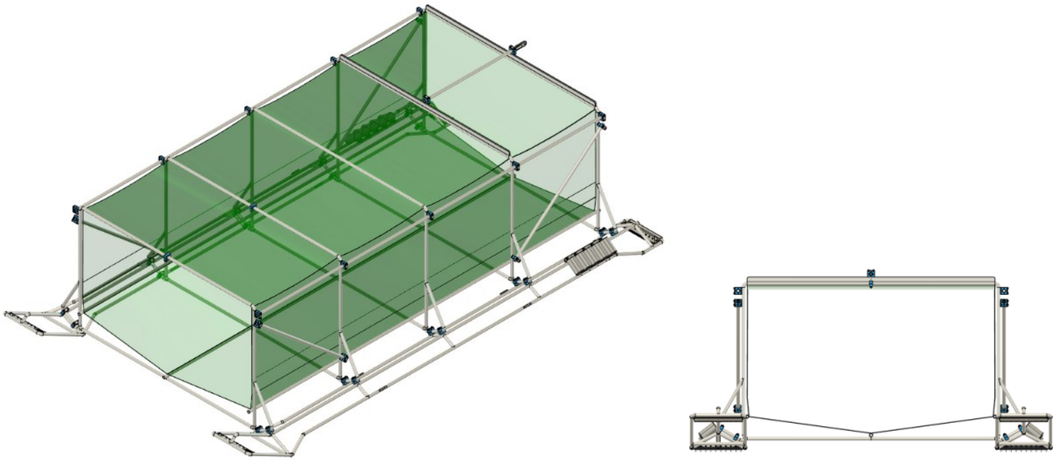


Abbildung 26: **Ponton-Hebereuse: Konstruktion der Fangkammer nach Umbauten Anfang 2020 mit Modifikation zur leichteren Entleerung (vergl. Unterseite der Fangkammer)**

Abbildung 27: Ponton-Hebereuse: Konstruktion der Fangkammer nach Umbauten Anfang 2019; oben links: Rahmen-Konstruktion ohne Netztuch; oben rechts Rahmen-Konstruktion mit Netztuch und Rahmen der originalen Konstruktion zum Vergleich; unten links: Rahmen mit Netztuch und montiertem Rückfang (oben auf Fangkammer liegend, optimal für Transport); unten rechts: Fangkammer mit Rückfang wie er auf dem Fangplatz steht.

Abbildung 28: Ponton-Hebereuse. Fangkammer mit Einlass und Robben-Excluder (vertikaler Rahmen). Blick von innen.

6. Weiterentwicklung der Konstruktion (Teil 2)

Nach den sehr positiven Erfahrungen mit der neuen Konstruktion (Abbildung 25) im Jahr 2019 wurden im Winter 2019/2020 weitere Anpassungen vorgenommen, um die Reuse weiter zu optimieren (Abbildung 26).

Die Modifikationen der Reuse (Abbildung 26) betreffen vor allem

- die Unterseite der Fangkammer, die nun zur Mitte hin geneigt ist, damit die Fische besser in den Steert rutschen können;
- den Steert, der nun wesentlich schmaler im Umfang ist und dementsprechend auch leichter beim Leeren der Reuse gehandhabt werden kann.

Ursprünglich sollte die modifizierte Reuse bereits im Frühjahr 2020 zur Heringssaison eingesetzt werden. Durch die einschränkenden Maßnahmen zur Bekämpfung der Corona-Krise war das jedoch nicht möglich. Die erneut modifizierte Reuse wurde erstmals im Juni 2020 eingesetzt und es zeigte sich, dass die vorgenommenen Änderungen zu einer weiteren Verbesserung der Fangeigenschaften der Reuse führten.

7. Fangdaten

Auf allen Fangfahrten wurde der Fang (Anlandungen) durch den Fischer dokumentiert. Darüber hinaus benutzte der beteiligte Fischer die Mofi-App, um seine Fangfahrten zu dokumentieren.

Zusätzlich zur Aufnahme der normalen Fänge (und damit den Aufgaben im STELLA-Projekt) wurden im Herbst 2019 auch Versuche zum möglichen Einsatz von Fluchtfenstern durchgeführt. Obwohl die Ponton-Hebereuse durch die große Fangkammer den gefangenen Fischen optimale Bedingungen bietet und untermassige Fische sehr schonend wieder zurückgesetzt werden können, sollte evaluiert werden, inwieweit es möglich ist, diese zeitnah aus dem Netz zu entlassen. Die Auswertung der Daten steht noch aus.

Abbildung 29: Ponton-Hebereuse: Links: schonendes Entleeren der Fangkammer (hier vor allem Hornhecht); Rechts: ein guter Fang.

Tabelle 1: **Ponton-Hebereuse. Übersicht über die Fangeinsätze und Fänge**

			Fang [kg]												
Setzen	Hieven	Standzeit	Gesamtfang	Hering	Barsch	Flunder	Hecht	Zander	Hornfisch	Dorsch	Aal	Blei	Quallen	untermaßig	Kormoran (Stück)
16.05.2018 10:30	21.05.2018 07:20	4.87	85.00	30			50		5					30	
21.05.2018 08:30	24.05.2018 07:15	2.95	82.80				49		17		1.8	15		25	
24.05.2018 07:50	29.05.2018 06:50	4.96	51.50				50				1.5			20	
29.05.2018 07:20	02.06.2018 08:15	4.04	76.00			8	32	2	4			30		20	
02.06.2018 09:00	08.06.2018 07:30	5.94	74.00			3	34	5	8		4	20		15	
08.06.2018 08:10	15.06.2018 08:00	6.99	42.00				20	5			2	15		28	
15.06.2018 08:30	18.06.2018 07:20	2.95	14.00		2		9		3						
18.06.2018 07:40	20.06.2018 07:30	1.99	2.00				2								
10.09.2018 11:45	14.09.2018 08:40	3.87	5.00				2				3			25	
14.09.2018 09:00	18.09.2018 14:00	4.21												10	
18.09.2018 14:00	29.09.2018 08:20	10.76	12.00				3	8		1	1			33	
24.09.2018 08:50	04.10.2018 08:30	9.99	5.00				2	1		3				10	
04.10.2018 08:50	13.10.2018 08:50	9.00	1.50								1.5			25	
17.10.2018 09:00	21.10.2018 09:00	4.00	0.40		0.4										
21.10.2018 09:30	01.11.2018 09:50	11.01	0.00											5	

			Fang [kg]												
Setzen	Hieven	Standzeit	Gesamtfang	Hering	Barsch	Flunder	Hecht	Zander	Hornfisch	Dorsch	Aal	Blei	Quallen	untermaßig	Kormoran (Stück)
21.06.2019 11:00	24.06.2019 07:10	2.84	40.00						40					125	
24.06.2019 07:30	25.06.2019 07:50	1.01	34.25						33		1.25			11	
25.06.2019 08:50	28.06.2019 08:30	2.99	21.00				2	2	17					55	
28.06.2019 09:15	11.07.2019 07:30	12.93					11	6	7						
11.07.2019 08:30	19.07.2019 08:30	8.00												150	
22.09.2019 09:30	24.09.2019 09:00	1.98	221.00	212		2		3	0.4	0.4	3.5			10	
24.09.2019 11:30	27.09.2019 08:50	2.89	89.50	54	5	4		10			16.5			Protokoll	
27.09.2019 10:50	06.10.2019 08:45	8.91	48.00	7	2	4		24			11			Protokoll	9
06.10.2019 10:45	11.10.2019 07:40	4.87	3.00				2.5				0.5			25	5
11.10.2019 09:10	13.10.2019 12:00	2.12	11.00	4		1.5		3			2.5			Protokoll	5
13.10.2019 14:30	17.10.2019 08:00	3.73	11.00	5		2		4					400	Protokoll	1
17.10.2019 10:40	20.10.2019 09:50	2.97	18.50	2.5		1	3.5				11.5		150	Protokoll	1
20.10.2019 11:00	23.10.2019 09:30	2.94	5.00	3							2		1000	Protokoll	
23.10.2019 12:00	30.10.2019 08:30	6.85	16.00	5							11			Protokoll	2
30.10.2019 10:50	03.11.2019 08:50	3.92	9.00	7		2							NA	90	1
03.11.2019 10:00	08.11.2019 11:00	5.04	7.00	5		2									1

8. Weitere Schritte

Auch nach dem Ende des STELLA-Projektes sollen die Versuche zur Ponton-Hebereuse fortgeführt werden, um weiter an der Lösung der Probleme des Meeressäugerbeifanges und des Robbenkonflikts zu arbeiten – insbesondere, da die bisherigen Tests zeigten, dass die Ponton-Hebereuse Potential hat.

Zu den nächsten Schritten gehören

- weitere Optimierungen der Reuse
- der Einsatz der Reuse während der Heringsfangzeit
- der Einsatz der Reuse zu anderen Zeiten, um auch anderen Zielarten befischen zu können
- der ‚mobile' Einsatz der Reuse an wechselnden Fangplätzen, um in den jeweiligen Fangzeiten den optimalen Standort auszuwählen und um zu demonstrieren, dass die Reuse mit vertretbarem Aufwand eingesetzt werden kann.

Die bisherigen Tests der Ponton-Hebereuse und der entsprechenden Modifikationen fanden in den Boddengewässern südwestlich von Rügen statt. Dabei hat es sich gezeigt, dass die 2019 (Abbildung 25) und die 2020 (Abbildung 26) modifizierten Fangkammern auch bei starken Wellen und starker Strömung sehr stabil waren. Damit ist ein sinnvoller und logischer nächster Schritt der Einsatz in den Küstengewässern der Ostsee. Hierzu gibt es bereits Gespräche mit einem Fischer aus Schleswig-Holstein.

Für den Einsatz in der Ostsee wäre es sinnvoll, eine weitere Ponton-Hebereuse zu beschaffen. In diesem Zusammenhang werden bereits weitere Optimierungsmöglichkeiten diskutiert, die die Stabilität der Konstruktion weiter erhöhen (Abbildung 30).

Nachdem bisher vor allem die Konstruktion und deren Optimierung im Mittelpunkt stand, sollen möglichst zeitnah auch Untersuchungen zur Optimierung der Fängigkeit durchgeführt werden. Da ein Fangvergleich aus verschiedenen Gründen nicht möglich ist, sollten Untersuchungen zum Verhalten der Fische im Bereich der Reuse mittels optischer und akustischer Kameras durchgeführt werden.

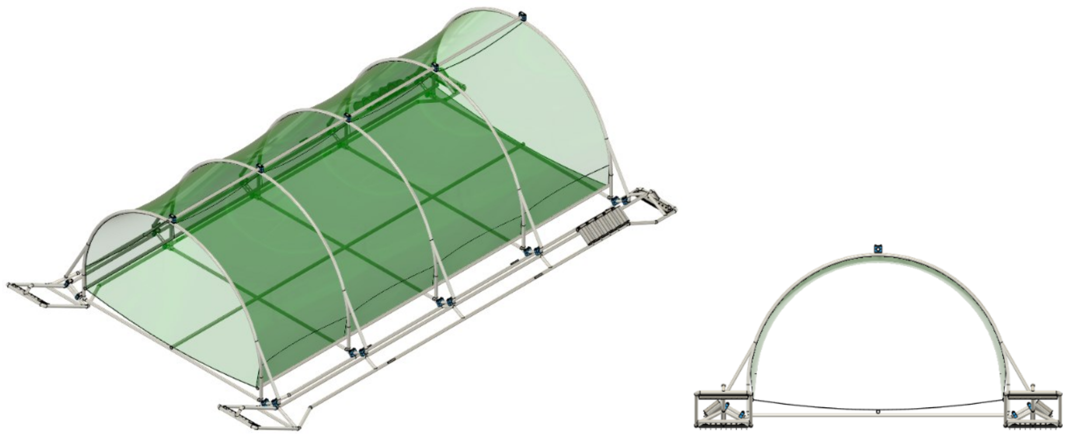


Abbildung 30: Ponton-Hebereuse: mögliche künftige Anpassung der Konstruktion zur Verbesserung der Stabilität in den flachen Küstengewässern (Rundbogen-Form)

Arbeitspaket 4 – Veröffentlichung 1 “A Literature Review on Stakeholder Participation in Coastal and Marine Fisheries.”

Schwermer, H., Barz, F., Zablotski, Y. 2020. A Literature Review on Stakeholder Participation in Coastal and Marine Fisheries. In: Simon Jungblut, Viola Liebich und Maya Bode-Dalby (Hg.): YOUMARES 9 - The Oceans: Our Research, Our Future, Bd. 19. Cham: Springer International Publishing, S. 21–43.

Abstract

Stakeholder participation is a fundamental component of many states’ and local agencies’ fisheries legislations worldwide. The European Common Fisheries Policy (CFP), as one example, increasingly adopted a holistic approach to managing marine living resources. An important component of such an ecosystem-based management approach is the consideration of knowledge, values, needs and social interactions of stakeholders in decision-making processes. However, despite that stakeholder participation is a widely used term, a great variety of definitions exist, which often cause misunderstanding. Stakeholder participation is often used as part of conducting research on stakeholders but not in the context of their participation in resource management. Here, we present the results of a comprehensive literature review on the topic stakeholder participation in coastal and marine fisheries. We identified 286 scientific publications in Web of Science of which 50 were relevant for our research questions. Publications were analysed regarding (i) definition of stakeholder participation, (ii) analysis of participating stakeholders, (iii) applied participatory methods and (iv) intention for participation. Stakeholder types addressed in the publications included, e.g. fishery (fishers and direct representatives, N = 48), politics (policymakers and managers, N = 31), science (N = 25) and environmental non-governmental organizations (eNGOs, N = 24). In total, 24 publications labelled their studies as stakeholder participation, while stakeholders were only used as a study object. We conclude that improving science and the practice of including stakeholders in the management of coastal and marine fisheries requires definitions of who is considered a stakeholder and the form of participation applied.

Vollständige Veröffentlichung (Open Access)

https://link.springer.com/chapter/10.1007/978-3-030-20389-4_2

Arbeitspaket 4 – Veröffentlichung 2 “Boats don’t fish, people do” - how fishers’ agency can inform fisheries-management on bycatch mitigation of marine mammals and sea birds

Barz, F., Eckardt, J., Meyer, S., Kraak, S. B. M., Strehlow, H. V. 2020. `Boats don't fish, people do’- how fishers’ agency can inform fisheries-management on bycatch mitigation of marine mammals and sea birds. Marine Policy 122: 104268, doi:10.1016/j.marpol.2020.104268

Vollständige Veröffentlichung (Pre-print Proof)

Abstract

Bycatch of seabirds and marine mammals in gillnet fisheries is a major hazard for conservation globally. Measures for bycatch mitigation in fisheries management mostly base on technological and ecological findings and they generally assume fishers as a homogenous group that is supposed to apply new technology or act according to the latest ecological insights. There is often a lack of knowledge about the heterogeneity of fishers’ actions and drivers, despite its importance for effective fisheries management. For the specific case of the German gillnet fleet in the Baltic Sea a qualitative social-science research approach was chosen to generate knowledge that can inform management. In applying the concept of agency, three types of fishers’ actions are distinguished: projective (future-oriented), evaluative (present-oriented) and iterational (past-oriented). Fishers’ attitude towards incidental bycatch differed between viewing bycatch as a normal part of the daily routine or as a disturbing event. These findings are discussed in the context of management instruments, such as closed fishing zones and seasons, brought up during an expert workshop. It is concluded that considering fishers’ agency may be an important contribution to design effective management instruments to mitigate bycatch of seabirds and marine mammals in gillnet fisheries.

Keywords: fishers´ agency; bycatch discourse; bycatch mitigation; documentary method; fisheries management instruments; social-science fisheries research

1. Introduction

Bycatch of marine mammals and seabirds is a major ecological hazard throughout the world´s seas and can negatively impact populations [1]. Some of the bycaught taxa are protected under different regulations, such as the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS [2]) and Flora-Fauna-Habitat Directive [3]. This makes them directly relevant for conservation management and obliges EU member states to develop management instruments for the purpose of conservation [4]. Since Germany has limited management in place for bycatch mitigation of seabirds and marine mammals, this case study presented the unique opportunity to apply interdisciplinary research to inform management instruments.

Bycatch mitigation of seabirds and sea mammals usually targets technical solutions and tactical measures [5–8] from a governance [9] and economic perspective [7, 10]. In gillnet fishing, technical suggestions include increasing acoustic visibility of gillnets [11, 12], attaching visual cues [13–15] or acoustic deterrence devices [16, 17] as well as the use of thinner twines in nets or ropes to facilitate escape [18]. Tactical measures focus inter alia on spatial and temporal closures [1, 19, 20] or change of operational factors, such as water depth, mesh size and net height [21]. Economic perspectives in bycatch mitigation evaluate inter alia these tactical measures in order to prioritize investments of fisheries management into inexpensive measures [10].

However, these technical and tactical measures alone often did not achieve their objectives, as seen e.g. in low uptake of newly developed mitigating fishing gear [22]. To overcome such a mismatch, incorporating the human dimension can positively affect management [23–26]. Research targeting the human dimension suggests that fishers are not a homogenous group and their heterogeneity can yield decision-relevant information to managers [24, 27, 28]. Different typologies establish the heterogeneity of mostly coastal fishers from a social-science perspective: some authors gave an overview of English fishers to inform management strategies [29]; other authors identified varying fishers´ tactics and strategies [30–32], yet others described divergent fishing styles [33] or studied implications of dissimilar types for recruitment of fishers [34]. There are also studies on different types of deep-sea fishers [35]. It has been proposed to address different forms of fishers´ actions for effective bycatch-reduction policies before [36]; however, to the best of our knowledge, no literature considering different types of fishers to mitigate bycatch of seabirds and sea mammals exists. Considering the different cultural and historical backgrounds in the mentioned studies and the German gillnet fishers, the results cannot simply be transferred [23], especially as the specific objective bycatch mitigation is not covered in these studies. Furthermore, to the best of our knowledge, none of the studies mentioned above choose a qualitative reconstructive approach, which allows for a deep insight into fishers´ actions. They have also not looked for heterogeneity among fishers who primarily apply the same gear type, namely gillnets.

Within the ecosystem approach to fisheries, sociocultural knowledge, among others, is needed to facilitate adoption of management [37]. The presented case study developed an approach to integrate human-dimension aspects of gillnet fishers into fisheries management to improve it and will therefore present different types of social fishing practices (hereinafter referred to as fishers´ agency). With the concept of fishers´ agency a deeper understanding of fishers´ historical, cultural and structural background [37] as well as personal skills, tacit knowledge [38] and motivation [39] to lead to implications for bycatch-mitigation management is proposed. As most of the bycatch events of marine mammals and seabirds occur within the gillnet fisheries [40] the case study focussed on gillnet fishers in the German Baltic Sea.

Research objectives were to (1) identify a typology of fishers, using reconstructive social-science methods for gathering data on narratives and attitudes of fishers on bycatch as well as their discretion to act; (2) study local fisheries-management experts´ opinions during a workshop and collect a suite of management instruments aimed to mitigate bycatch of seabirds and mammals and (3) evaluate identified management instruments against the background of the established typology.

2. Theoretical background

Applying theory of structuration [41] allows to take a certain perspective on research objectives and leads to studying actors (through fishers) as well as gain an insight into fisheries management structures (through local fisheries management experts). The theory of structuration is a praxeological theory. Praxeological approaches focus on social practices and are well applicable to discuss environmental problems from a sociological perspective. They allow for the dissolution of (apparent) contradictions such as micro- and macro perspectives as well as the integration of structure theory and action theory, moving away from separating these research units [42]. Giddens established that actors have agency: they are competent in their actions and act in continuity with the past, while at the same time each new action is a fresh act and has the potential to bring social change. Actors are knowledgeable and to a degree share mutual knowledge. It is mostly implicit as well as practical, discursive and unconscious knowledge, which is not necessarily separate but engages during social practices [43]. The structures that frame these actions are not conceptualized as barriers, but are involved in the production of actions, which in turn can transform or stabilize structures [41]. Giddens distinguishes three forms of circumstances, which undermine established practices: (i) external factors (e.g. ecological changes), (ii) diverging interpretation of existing norms (e.g. presenting in orientation frames) and (iii) transformation of social institutions (e.g. fisheries management). Communicative actions are understood as a realisation of structural patterns [41] and therefore it is argued that structural dimensions of social actions will present themselves while analysing interviews of the agents that are participating in these social actions. The documentary method allows to process information and also access implicit as well as discursive and action-guiding (practical as Giddens calls it) knowledge and therefore social practices, at the same time [44]. It reconstructs the relation between orientation frame and experience to identify a typology on a sense-genetic level (summary of different orientation frames) and multidimensional socio-genetic level (sense-genetic types put into social contexts) in order to, for our purpose, gain access to the social fishing practice [45]. Orientation is understood as a form of habitus, giving insight in how actions are constructed and topics are dealt with [45]. When generating the typology with the documentary method, ideal types [46] of fishers were derived, which can be understood as an abstract construct of groups of fishers, which can be used to inform management discussions and instruments. \`Ideal types\` as opposed to \`real types\` can be seen as a form of variable or category that is developed within research. They are theoretical constructs that do not mirror reality, but rather summarize characteristic of a group. Focusing on ideal types of social practices, findings were consistent with other authors [47], whose insights into agency concepts were valuable to describe fishers and their potential to induce change in a distinct way. [47] describe agency as \`the temporally constructed engagement by actors of different structural environments - the temporal-relational contexts of action - which, through the interplay of habit, imagination, and judgment, both reproduces and transforms those structures in interactive response to the problems posed by changing historical situations\`. As a result of the critical analysis of theoretical concepts, fisher´s social practices were therefore analysed and described as fishers´ agency. Looking at the engagement of fishers in their structural environment allowed drawing conclusions about their respective actions when confronted with changed structures, such as a voluntary agreement to mitigate bycatch. Conclusively the authors of this study argue that the chosen concepts and methods of structuration theory, documentary method and agency worked very fruitful together, because they root in the same epistemological understanding and enable directing research towards a complex understanding of German Baltic Sea gillnet fishers and fishery in the context of bycatch mitigation.

3. Material and Methods

The research design is based on the theory of structuration [41], focussing on fishers as well as the relevant structures they move in. To achieve the stated objectives, relevant agents (fishers) were interviewed, if they were found to be at high risk of having bycatch and a typology of agency as well different discourses on bycatch was deducted. To investigate structures, a workshop with experts and stakeholders from science, fisheries administration, federal and state administration as well as non-governmental organisations was held to assess possible bycatch mitigation instruments and their operationalisation. In a second step, the latter findings were evaluated, based on the typology and additional qualitative data emerging from the interviews.

3.1. Selection of relevant fishers

The selection of relevant fishers was based on an upstream study that separated the German Baltic gillnet fleet into groups of vessels with distinct annual landing sequences [48]. Groups with the highest potential risk of bycatch were selected based on two factors: First, their characteristic seasonal fishing patterns, that is their regular activity throughout the year. Only vessel groups with regular recorded landings were selected. Second, those remaining groups were ranked according to their number of fishing trips, which was used as a proxy for fishing effort [49]. In order to concentrate research efforts on the most relevant groups, the study focused on the three groups with the most fishing trips in 2016, assuming that a higher number of fishing trips increases the risk of incidental bycatch. These three groups of vessels with distinct annual landing sequences were the cod-group, the herring-cod-group and the herring-flounder-group, from which then fishers were selected for interviews. It was possible that fishers were part of more than one group if they operated more than one vessel [48]. Further narrowing down the pool of potential fishers within each group, the focus was set on ports with the most landings within or close to Natura 2000 sites, which are protected areas that aim amongst others to conserve certain bird species and harbour porpoises. In these ports, fishers were selected based on their descending amounts of landings and contacted by telephone. Additional fishers were selected opportunistically by meeting them in the relevant ports or by snowball sampling of fishers´ contacts.

3.2. Problem-focussed interviews and questionnaire

Problem-focussed, semi-structured interviews were conducted based on a guideline of questions (App. A) and complemented by a short questionnaire (App. B). During the interviews, the focus was set on narrative-generating questions supplemented by steering questions and ad-hoc questions [50]. The interviewees were regarded as experts of their orientations, values and doings and motivated to express and reflect these in narrative answers [50]. The interviews were audio recorded, complemented by an interview protocol, transcribed into a word-for-word transcript using an adapted GAT-strategy [51] and as part of the process of anonymization, all fishers were given German tree-names.

3.3. Analysis of the interviews applying the documentary method

To derive a typology of fishers´ agency, the interview analysis was based on the documentary method (Nohl 2010). In order to find out how fishers view certain situations and therefore create actions, analysis focussed on how they narrated these situations, e.g. entering the fishery could be described as a very active decision or as a more passive process. Different orientation frames were then abstracted, detaching them from the individual cases and summarized as sense-genetic types. Sense-genetic types were put into a social context and developed further into multidimensional socio-genetic types [45]. Working inductively, analysis focussed primarily on how fishers narrated their answers to reconstruct orientation frames, next to focussing on what they replied. For the analysis, 11 research workshops were held with varying groups of 3 to 9 (on average 5) scientists from different professional backgrounds, consisting of co-authors, colleagues and fellow PhD-students. These groups of researchers discussed interpretations of the anonymised transcripts to ensure that the interpretation was exhaustive and verified, modified or falsified. This group process, which interspersed the individual interpretation-processes by the first author, aimed at transparency and reproducibility of the analysis. As a result, the narratives of fishers´ actions were categorized as different sense-genetic types up to a point of theoretical saturation. To incorporate further dimensions and generate more complex ideal types, sense-genetic types were expanded to include sociocultural factors [45] of fishers within each sense-genetic type, e.g. family background, gear technology and associated group of vessels with distinct annual landing sequence. The information was collected during the interviews, in a separate questionnaire (App. B) and from the analysis of the gillnet fleet [48]. Combining sense-genetic types with common sociocultural factors resulted in socio-genetic types, which will be referred to from hereinafter as “fishers´ agency”.

3.4. Expert workshop

A workshop was held in which 19 experts discussed potential management options aimed to mitigate bycatch of seabirds and marine mammals and problems that might prevent the implementation of such, leading to a set of suggested management options. The experts originated from the scientific Thuenen-Institute for Baltic Sea Fisheries (9), the states´ fisheries administration (7), the Federal Agency for Nature Conservation (1), as well as environmental non-government organisations (2). The participants of the workshop were divided into subgroups and were asked to answer the same set of questions: (i) Which management instruments for mitigation of bycatch can you imagine for the gillnet fishery in the Baltic Sea? (ii) How do you judge these instruments? What can be advantages, disadvantages as well as administrative constraints? (iii) Which management options do you deem most effective for mitigating bycatch? (iv) What could be your specific contribution to realise successful mitigating instruments? The subgroups later discussed their respective results in a plenary session.

The results of the workshop were subsequently evaluated against the background of the characteristics of fishers´ agency to consider potential reactions of distinct fisher types towards different management instruments in order to assess their effectiveness.

4. Results

The interview analysis revealed three distinct types of fishers´ agency that can be applied to inform management: iterational, evaluative and projective (see section 4.2). In addition, interviewed fishers displayed different bycatch discourses: some fishers described bycatch as a normal event (normalizing), whilst other described it as a disturbing event (non-normalizing) (see section 4.3.). Management options assessed during the expert workshop were evaluated by the authors against the background of these findings, which suggested how different fisher types might assess management instruments (see section 4.4.).

4.1. Relevant fishers

Based on the selection criteria, the most relevant ports for the cod-group were situated close to the island of Fehmarn (Fig. 1) and the most relevant ports for both the herring-flounder-group and the herring-cod-group were located around Greifswald Bay (Fig. 1). Additional interviews where held with fishers located between Kiel and Flensburg. In total 22 valid interviews were achieved.

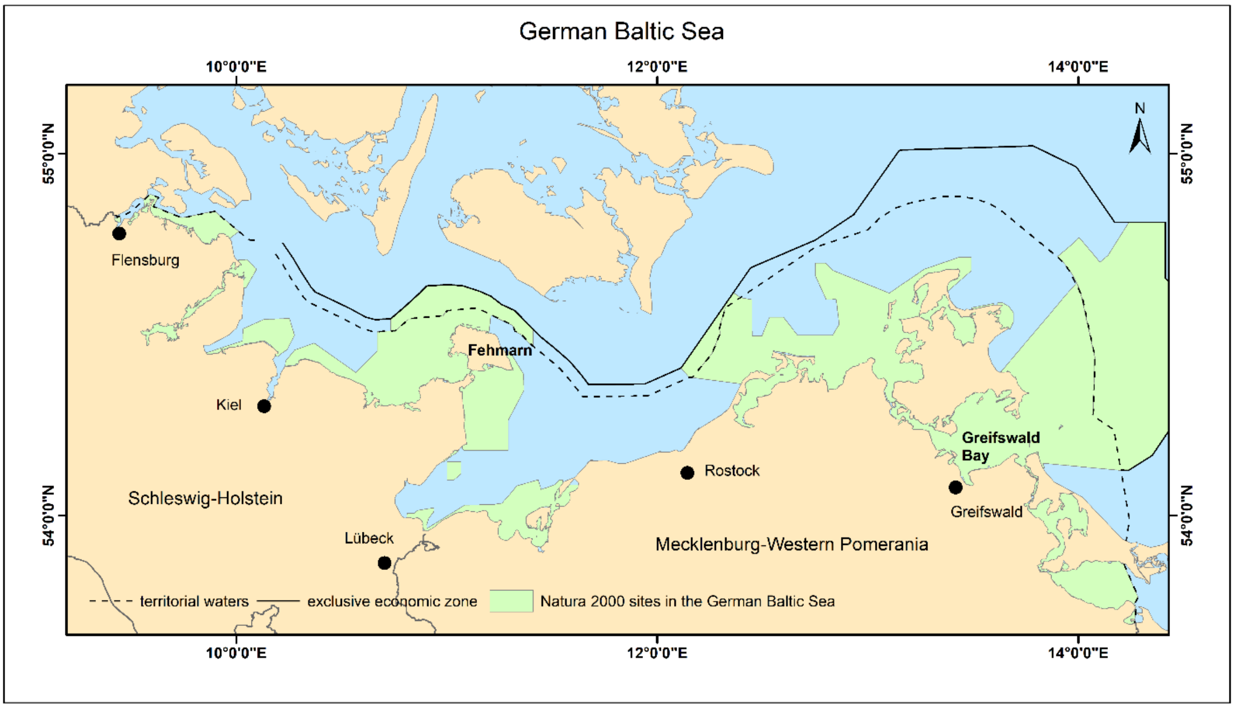


Fig. 1. **Map of the German Baltic Sea depicting the research regions. ©Thuenen / N. Plantener**

4.2. Typology of fishers´ agency

Common characteristics amongst all interviewed fishers were found, such as a strong tie to their respective homeports or a strong value for independence. Nevertheless, different groups of fishers were determined according to their social fishing practice within the group of German Baltic Sea gillnet fishers. Analysing the interviews and connecting them to the data derived from the questionnaire and the analysis of the gillnet fleet [48] resulted in three different ideal types of fishers´ agency: (i) projective agency, (ii) evaluative agency and (iii) iterational agency (Table 1).

Table 1: Short description of the characteristics of different fishers´ agencies

Type / Dimension	Projective	Evaluative	Iterational
Professional biography	Started fishing as a child, became a professional fisher immediately after school, as an active choice	Did another qualified job before becoming a fisher	Often became a fisher immediately after school, out of heritage due to the father being a fisher as well, more of a passive choice
Time-orientation of actions	Actions and narratives are oriented towards the future, sets goals for the future	Actions and narrative are oriented towards the present, sets goals in sight	Actions and narrative are oriented towards the past
Decision-making	Anticipative, sets goals in (medium-range) future	Evaluates present situations, finds quick and unproblematic solution	Relies on well-established schemes of action, that he retrieves according to the situation at hand
Openness towards new forms of fishing	Is interested in trying new ways of fishing, intrinsic motivation	If the opportunity presents with the right framework, will most likely try new gear, but not from entirely intrinsic motivation	Less likely to establish new routines or practices; relies on gillnets, which they have learned and established throughout their fishing experience
Plans for the future	Long time	Optimises current situation through new schemes of actions or plans to leave fishery	Wants to continue fishing in familiar ways, which sometimes means he has no concrete plan of how to make a living of fishing
target species	Diverse	Diverse	Specialised in mostly cod
Number of vessels	Likely owns and uses more than one vessel, invested in new vessels, gear and accessories needed for new ways of marketing e.g. direct marketing	Owns one vessel at the time, but has likely changed vessels before, when the opportunity presented itself	Fishes with only one vessel but might own more; does not invest in business, besides regular maintenance

Projective fishers: A Fisher with a dominating projective agency anticipates future developments in the context of fisheries and creates ambitious and long-term projects for his businesses. Since childhood, he went fishing on his own or with his father. Straight after finishing school, he became an apprentice as a fisher. Subsequently he owned his own vessel, completed training courses over the years. He owns at least one other vessel and new gear, which allows him to target different species and/or adapt to different weather conditions. Due to projection and a certain degree of flexibility, projective fishers are more likely to be amongst the higher earners in the study areas.

Different forms of projection are demonstrated in one example: The fisher, Mr. Kiefer, brought his fish to a big fish market two hours’ drive away, where it was sold directly to the customers achieving a better price. Nevertheless, in the future, he wanted to find a different way of selling his fish that will not involve a long drive. He applied for a permit to build a little hut on the pier, in order for his wife to sell fish directly from there. Although he has been active in trying to get the permit, he described the hut on the pier as a project for the medium term. Later during the interview, the fisher expands the project of a hut into a proper fish shop close to the harbour:

You have to have an idea, how the future will unfold, right. I can´t wait for something to happen. That’s why I… something has to be done. Somehow. It would be best to open up a fish-shop. There is no fish shop around here anymore. (Mr. Kiefer)

Evaluative fishers: A fisher whose dominating agency can be described as evaluative, acts present-oriented and sets goals in sight. He acts in order to change current situations after evaluating, so that whatever it is that needs adapting, can be solved quickly and in an unproblematic way. The evaluative fisher has most likely started in a different job after school. After some years, he became a fisher, because his current employment was not fulfilling his demands anymore. Reasons could be unemployment or missing joy at work. After trying out fisheries, he evaluated the current situation and concluded that becoming a fisher is going to be the next step in his professional biography:

Well and then, on day one it was clear to me – although I always said I would never become a fisher – on day one (in fishing – remark FB) it was clear to me, that´s what I have to do, because that´s what I want to do. (Mr. Buche)

The evaluative fisher is likely to buy a new vessel when the opportunity occurs, e.g. when a colleague retires or grant funds are available. He acts opportunistically and if need be finds a way to act around rules, which he perceives as constraining, mostly in terms of earning a living. The quota system and its rules is one example:

What do you think about five tons of cod? I don´t even have to have an education to know that that doesn´t work anymore [to earn a living- remark F.B.]. And that´s what I am angry about. That you always have to cheat somehow. […] It doesn´t work anymore if we don´t cheat. […] They make you do things that maybe you shouldn’t do, you know? Because it doesn’t work any other way.” (Mr. Buche)

An evaluative fisher is usually not as flexible in his target species and has no long-term plan for his business. He wants to either optimise the present situation within the fishery or leave the fishery.

Iterational fishers: Most fishers of this type have shown an iterational part of themselves when being asked to describe their last day of fishing. Although the question specifically referred to the last fishing trip, an iterational fisher describes an average fishing trip, suggesting that during this part of the work he relies on well-established schemes of action. His experiences shape his present actions, which are therefore past-oriented throughout his fishing life in general. The primary way of acting is to recall, select and apply patterns, which he has established in past interactions. This is not an automatic process, but asks for attention and engagement to the present context in order to retrieve said schemes [47]. Consequently, iterational fishers are less likely to establish new routines or practices. The example given below presents Mr. Laerche, who does not know how to keep on fishing with a diminishing quota, whereas an evaluative fisher can think of new practices to deal with the reduction of his targeted species (see. citation Mr. Buche above).

But today, when you don´t have quota – how are you supposed to compensate that? Then you are in debt. Like that. Debts mean your business will be destroyed, right? That´s just the way it is. (Mr. Laerche)

Like a projective fisher, an iterational fisher often became a fisher straight after school. This was more due to circumstance and upbringing than an active choice:

I became a fisher because of my parents you know? My grandpa and all of the family. Well, the choice wasn’t far off that you would do the same then, you know. Right. So I became a fisher as well. (Mr. Eiche)

The narratives often referred to past times or events:

There was more solidarity in the past, you know. Everyone was there when there was a storm, everyone was sitting together. But not today. It´s split up, you know. It´s not like it used to be. (Mr. Fichte)

A dominating iterational fisher ismainly using gillnets throughout his professional biography and does not invest in his business, besides regular maintenance. He is rather reluctant to try different gear and consequently diversify his target species, which leaves him very specialised:

I have been only fishing with gillnets, since 1982. Best gear there is. That’s right, you know? Quiet life, you are back home every day. That’s alright, isn´t it? (Mr. Laerche)

We found this type of fishers´ dominating agency only within the cod-group, a group targeting mainly one species, which supplements the description above.

4.3. Bycatch discourse and fishers´ inherent mitigation strategies

Because of the methodology of using narrative-generating questions during the interviews, valuable information about fishers´ views of and experience with bycatch were reconstructed. They displayed two different ways of bycatch discourse that manifested in their actions and narratives. On the one hand, fishers described bycatch of mostly sea birds as a part of their normal fishing routine and were therefore normalizing bycatch. On the other hand, fishers narrated bycatch of sea mammals as an event that they could not process as part of their daily routine, which was therefore non-normalized (also refer to Table 1).

4.3.1. Normalizing bycatch of seabirds

Fishers usually normalized bycatch of sea birds and during normalizing narratives saw no active role in mitigating bycatch beyond voluntarily avoiding certain areas where they assumed seabirds were present. In these statements, fishers considered bycaught seabirds as being unlucky or sick.

“The bird finds a net and then he runs of out luck. That´s the way it is." (Mr. Weide)

Most fishers presented bycatch mitigation of sea birds as a by-product of economically oriented fishing strategies, assuring that they do not want to have bycatch because that would mean that significantly less fish will be caught in the same net.

“You don´t set your nets where there are ducks. Because then you never finish. Everything is full of ducks. That´s stupid, bycatch of seabirds. […] You usually don´t set your nets in Duckburg, because getting them out of the net stops you from fishing. Doesn´t make sense. So you categorically avoid these areas.” (Mr. Linde)

Fishers recount that in the past sometimes fishers would set nets into a seabird area on purpose, because they were able to sell them as food.

4.3.2. Non-normalizing bycatch of sea mammals

Non-normalization was mostly present in narratives about marine mammals. During non-normalizing reports, fishers narrated bycatch as a disturbing incident in their daily fishing life, which concerned them:

“No fisher wants to have bycatch like this [harbour porpoise – remark FB], you know. You get sad about it.” (Mr. Tanne)

Consequently, they think of ways to mitigate bycatch of sea mammals actively, e.g. changing gears, working together with scientists to test porpoise alert devices (PALs). The narrative suggests a great appreciation towards nature:

“And you are happy, when you see a porpoise jump out of the water. That´s great. When I cut fish [on the vessel – remark F.B.] […] I turn off the engine, it´s quiet and you can hear the ducks chatter. That´s the experience of nature. Tourists would pay money for that, you know. ” (Mr. Tanne)

4.3.3. Fishers´ inherent mitigation strategies

In general, fishers´ personal bycatch mitigation strategies and motivations were diverse and mostly based on experience: (i) actively avoiding high-risk areas, seasons and depths for bycatch of seabirds prior to fishing; (ii) visual check for seabird gatherings during fishing; (iii) use of PALs or pingers to mitigate bycatch of harbour porpoises; (iv) reducing soaking time and net lengths. The last two strategies are mainly due to the participation in a voluntary agreement that will be elaborated on later.

4.4. Environmental instruments and its assessment by different fisher agency types

Environmental management instruments were identified for the German Baltic Sea during an expert workshop and evaluated by the authors according to the established fishers´ agency types (Table 2). During the workshop, the groups developed ideas on how to mitigate bycatch, which ranged from low degree of state intervention to high degree of state intervention: persuasive instruments, cooperative instruments, processual instruments, market instruments and regulatory instruments [52].

Persuasive Instruments can be education and information on bycatch of seabirds and mammals, on how bycatch is threatening the ecosystem and on the political discourse around endangered species. In order to start informing about bycatch, workshop participants suggested collecting reliable data about bycatch first. They hypothesised that collecting data can be difficult due to a distrusting relationship between fishers and other stakeholders. The narratives from the interviewed fishers supported this hypothesis; most iterational and evaluative fishers stated that they are sometimes afraid of talking to scientists or administrative people about sensitive topics such as bycatch, whereas projective fishers have participated in scientific projects before or are willing to do so. Experts discussed Marine Stewardship Counsel-labelling (MSC) as a persuasive instrument, where bycatch awareness could be included. Based on the interviews it was concluded that most fishers don´t see the incentive to gain an MSC label. Projective and evaluative fishers, who most likely sold fish directly to the customers, claimed they have a higher demand than they can supply, whereas iterational fishers who discussed MSC, did not see the benefit a certification, due to their small boats. Experts also suggested adapting the curriculum of fisheries training school in order to inform and educate early on about bycatch-related issues. Although they were not sure how big the impact might be, since there are only a few new gillnetters entering the Baltic Sea.

Cooperative instruments, characterized by negotiations between political and societal actors, aim at creating common ground for collective actions. Treating different stakeholders as equal partners facilitates informal agreements. Nonetheless, these cooperative instruments emerge under the threat of state intervention otherwise [52]. In Schleswig-Holstein, one of the two German federal states bordering the Baltic Sea, a voluntary agreement to mitigate bycatch has been negotiated and introduced in 2015 [53] . The agreement combines different aspects of cooperative instruments [52]: it provides social incentives (by letting fishers show their engagement in bycatch mitigating practices), participative management strategies (different stakeholder groups were involved in the negotiating process) and independent monitoring (through an environmental association). The interviewed fishers are ambivalent about the agreement. Some do not agree with closed areas or do not see the necessity of using PALs. Some of the interviewed evaluative fishers signed the agreement and use PALs because their cooperative asked them to do so and they see it as a sign of good will that fishers actively participate in mitigating bycatch.

Market-based instruments, such as EU-funding and subsidies, were discussed at length during the workshop. They appeared to be the first management options that came to mind. Market-based instruments focus on economic incentives to induce a change in behaviour and work on the assumption that fishers have mostly profit-maximising interests. However, most fishers were found to not want to spend their time or have the capacity to apply for grants in complex procedures.

Table 2 **Evaluating different environmental policy instruments and their assessment by experts against findings from the interviews and characteristics of fishers' agency.**

	Instruments based on literature	Concrete instruments based on expert workshop	Assessment of instruments during the expert workshop	Assessment of instruments, if they were mentioned during the interviews, according to fishers types
Persuasive instruments	Information on environmental topics	Bycatch data collection	Reliable bycatch data needs to be basis for bycatch management Distrust on different levels hinders data collection	Most *fishers of all types* do not view bycatch of seas birds as a problem Most *evaluative and iterational fishers* distrust the consequences of data collection. Most *projective fishers* participated in scientific data collection before and are therefore most likely to do it again. Another projective fisher offered to participate in bycatch mitigating research, without being asked about it.
	Eco-Labels	MSC - labelling	Can increase fishers´ income	*Projective and evaluative* fishers, who are most likely to engage in direct marketing, have a higher demand then they can supply, even without MSC. *Iterational fishers,* who discussed MSC, claimed it would not be worth it for their small boats.
	Education on environmental topics	Adapting curricular of fisheries training school	Experts were not sure about the impact, since numbers of new gillnetters entering the sector are very low	No discussion of the topic.
Cooperative instruments	Voluntary agreements	Voluntary Agreement of Schleswig Holstein	Does not need a strong legal framework, works in some parts Little control and no scientific monitoring, no concrete agreed objective	*Evaluative fishers* who knowingly participate view it as a sign of good will. Some *fishers of all types* do not know whether they are part of the agreement or how it works.
Procedural instruments	No discussion of the topic			

	Instruments based on literature	Concrete instruments based on expert workshop	Assessment of instruments during the expert workshop	Assessment of instruments, if they were mentioned during the interviews, according to fishers types
Market-based instruments	Financial support programs	EU (EMFF) funds for e.g. alternative gears	Perceived as overly bureaucratic Will not work under current EMFF regulations	No discussion of the topic.
	Subsidies	Subsidies	Fishers can receive manifold subsidies already	*Fishers of all types* prefer fishing over receiving subsidies for not fishing
Regulatory instruments	Requirements / prohibitions	Alternative gear	Fishers need to be able to handle alternative gears Regulations need to allow for alternative gear Mitigating gear can be a strong incentive in areas where seals are perceived as a strong competitor for fish	*Iterational fishers* are sceptical towards new gear and see no alternative to gillnets; *projective and evaluative fishers* have used different gear before. Catchability is the greatest concern about alternative gears for *projective* and *evaluative* fishers.
		Closed areas and/or seasons	Experts worry about fishers´ businesses and their livelihoods when constraining their areas and seasons further	Most *fishers of all types* avoid areas perceived as high risk for bycatch of seabirds, without any regulation in place
	Regulations	Reporting of bycatch	No discussion on topic	

Regulative instruments are the traditional and most common form of instruments in environmental politics. They are binding, hierarchical management options that restrict individual choices and express socially desirable behaviour, which can create conflicts between regulating institutions and regulated actors [52]. In this context, workshop participants discussed alternative gears. Whilst iterational fishers were sceptical towards alternative gears and emphasised that gillnets have no alternative, evaluative and projective fishers have used different gear, e.g. weirs before. Experts were concerned that fishers would need to be able to handle newly developed gear while fishers worried mainly about catchability. Since seals have resettled in the Greifswald Bay and interactions with gillnet fishers may cause significant operational and economic impacts [54, 55], experts discussed that bycatch- and seal-safe gears can be an incentive to use other gears than gillnets in the future.

5. Discussion

Using the documentary method, to our knowledge novel in fisheries research, the research captured the heterogeneity of gillnet fishers, identifying three fishers´ agency types and explaining how fishers deal with bycatch. Evaluating potential management measures against the background of the types, laid the foundation for more effective informed bycatch management. In the following section, the results are conceptualized, to make them applicable to other case studies and discuss fishers´ agency in general as well as bycatch mitigation specifically. Furthermore, the results are expanded with existing literature and further research questions that follow the results are pointed out before concluding this article.

5.1. Conceptualizing the results

The results were conceptualized and generalized into different points of interventions to address bycatch mitigation (Fig. 2): from the perspectives of (i) fishers´ agency, (ii) possible management measures they are confronted with and (iii) the bycatch discourse. The intervention points can be assessed and discussed for other case studies as well and/or expanded to other research fields. Different intervention points must be brought together to ensure efficiency and should not be considered separately, as utilized and presented below in the examples.

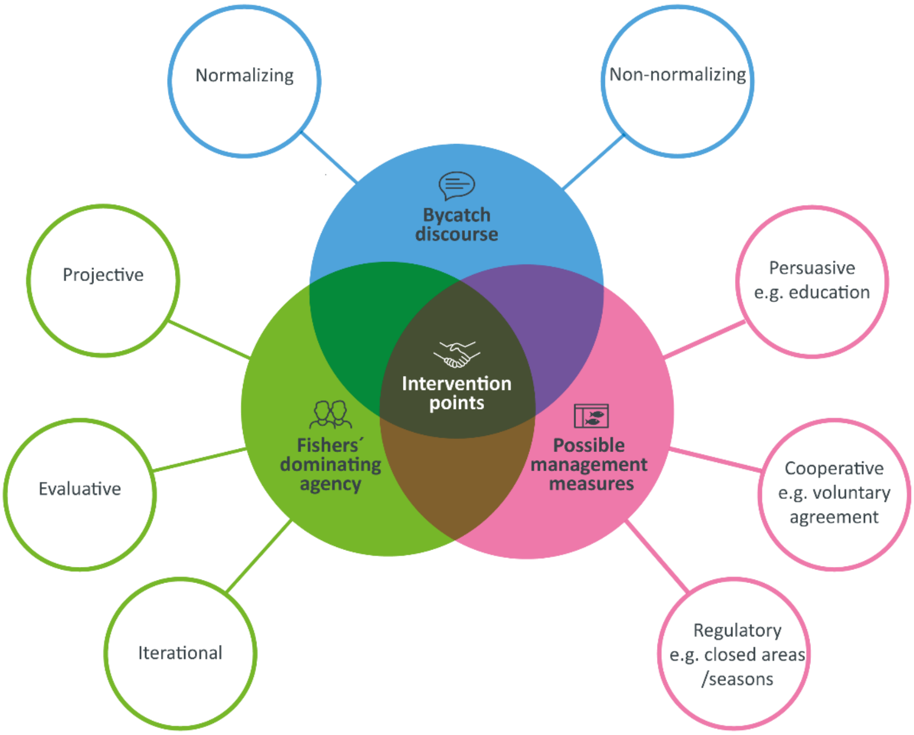


Fig. 2. **Conceptual intervention points for bycatch mitigation. ©Thuenen / A. Schuetz**

5.2. Fishers´ agency

It is important to collect knowledge about stakeholders and the way they act in their role as stakeholders [56], so that miscommunication between scientists, managers and fishers, based on different experiences and educations [57], can be reduced. Fishers´ agency can contribute to an understanding of fishers, allows finding common ground and meeting people where they are. Although agency is discussed in transition literature, it remains unclear how the concept can contribute towards a change to more sustainability [58].

Projective fishers are likely to be innovative and are therefore the most interesting partners for scientific projects. The findings support that a certain type of fisher, projective and with a stake, is more likely to be selected for and to participate in research, which can lead to a selection bias. This needs to be considered when interpreting results of stakeholder research projects and establishing relationships between science and fishing industry [59].

Fishers have been established as being short-term oriented and with inadequate coping strategies [60] or described as very traditional and reluctant to change their fishing activity voluntarily [61]. While this might be true for evaluative or iterational fishers, the results on projective fishers contradict these findings. Projective fishers can be addressed to strengthen management instruments in manifold ways: they can be a target group for new communication strategies where they are addressed as gatekeepers for their community [29]. In their role as intermediaries, gatekeepers can help understand fishers´ perspectives as well as make management rationale understandable to fishers and this way help manage expectations on all sides. Projective fishers can also be approached to be part of a co-management strategy or they can be part of post-implementation monitoring, suggested for evaluating management instruments for bycatch reduction [62]. These fishers have a rather diverse landing composition and can thus be assumed to be the most resilient group [60], which will adapt to political as well as ecological changes most easily.

Evaluative fishers are opportunists who are looking for pragmatic solutions. They will most likely find their way in manifold situations; even if it means breaking the law or exiting fishing. They are used to balance decision-making according to different situations and might not feel appealed by management instruments that do not allow for own decisions. In this case, they can resort to illegal fishing actions. It is suggested to create room for own decisions for evaluative fishers e.g. with results-based management approaches which focus on the outcome of fishing activities but leave implementation details to fisheries [63].

Iterational fishers need guiding to undertake a change of fishing practice, because they are most unlikely to pick up new schemes of actions. Managers need to communicate regulations and expectations comprehensibly. It is recommended to involve a clear communication strategy with all newly implemented management instruments. This will be useful for all stakeholders [29], but especially for iterational fishers. Iterational fishers were mainly specialised in cod fishing, therefore can be seen as the least resilient [60].

Alternatively to using interviews to identify fishers´ agency, logbook data can be used. Projective fishers have shown to have a more diverse landing composition as well as experience with different gears. Iterational fishers are mostly highly specialised in their target species, which can also be identified analysing logbook data. However, this method should rather be seen as a shortcut, when resources are limited. The shortcut might likely work for ecosystems with rather specialised fisheries with few target species involved, but might not work in a multispecies fishery.

5.3. Management instruments for bycatch mitigation

In the following, the management-instrument types listed in Table 2 (section 4.4.) are discussed in the context of the identified fisher types (section 4.2.) and discourse types regarding bycatch (section 4.3.).

Persuasive instruments: Expanding fishing education to focus on bycatch and its significance for the ecosystem of the Baltic Sea will be suitable for all types of fishers. These instruments are especially useful to address a change in bycatch discourse. Different discourses around bycatch were captured by asking well-framed questions to trigger narratives about bycatch (App. A): normalizing and non-normalizing. On the one hand, most fishers seem to normalize bycatch of seabirds, on the other hand a non-normalizing discourse was only observed in narratives about harbour porpoises. Perception of bycatch as a problem can vary when charismatic or endangered species of conservation interest are involved [64], which can explain the different discourses. The normalizing bycatch discourse appeared to be hegemonic, which means that existing circumstances are accepted and therefore consolidated. Opposed to that, protective international agreements such as ASCOBANS proclaim a non-normalizing discourse as a societal goal [2]. A change towards a non-normalizing discourse on bycatch can be considered to lead to more sustainable actions, such as active mitigation strategies from fishers or public problem-solving processes. Literature on discourse interventions inspires further bycatch mitigation measures, besides education. Tools for discursive change can be communication tools: from micro-level instruments such as taking possession of certain terms, framing or scandalising to macro-level strategies such as campaigns

Cooperative instruments in co-management processes create a framework, where projective and evaluative fishers can act future-oriented. Co-management is often recommended in fisheries management [62, 65] where it has been shown e.g. to generate a high uptake of bycatch reducing technology [66] or increase fishers´ efforts to mitigate bycatch [67]. One form of existing co-management is the voluntary agreement of Schleswig-Holstein. After considering the role of the agreement in Schleswig-Holstein, as well as its strengths and weaknesses, it is suggested to implement a similar form of voluntary agreement in Mecklenburg-Western Pomerania, the other German federal state at the Baltic Sea. It is important to learn from the experience of the agreement in Schleswig-Holstein, determine systematically which factors make it successful or unsuccessful and establish suitable structures in Mecklenburg-Western Pomerania before starting another agreement. It is argued that a voluntary agreement can reach all types of fishers: projective fishers might see it as a long-time strategy to avoid bycatch; evaluative fishers stated that participating could be a sign of good will. Some evaluative fishers as well as iterational fishers seem to participate because their cooperative tells them to and they usually follow their instructions.

Procedural instruments seem to be a gap in management, which could be filled in the future with e.g. an ecosystem assessment, where bycatch is included. Projective fishers are, again, most likely to participate in an assessment process, if it is voluntary. It might be necessary to link an assessment to a regulation, if management expects all types of fishers to participate.

Monetary incentives and other economic incentives are no panaceas and are likely to crowd out intrinsic motivations [68]. Projective fishers, with most likely the highest income within the gillnet fishery, do not base their business strategies on how to maximise subsidies, whereas evaluative fishers are found to be more likely to seek funding opportunities. Unlike projective and evaluative fishers, iterational fishers are most likely not able or willing to navigate through additional bureaucracy required to obtain subsidies. During the workshop, experts agreed that there are sufficient subsidies for fisheries in place already and therefore monetary incentives are not seen as an appropriate tool for bycatch mitigation.

Regulative instruments can include: identifying high-risk areas and seasons especially for bird bycatch and closing them in an adaptive, real-time management approach [69]; mandatory reporting of bycaught taxa as well as usage of bycatch mitigating gears. Choosing an adaptive approach, managers could link e.g. a fishing license to certain gear, the application of a mobile phone app or the use of cameras to document bycatch. Evaluative and projective fishers who used e.g. weirs before are more likely to work with new gear than iterational fishers, who see no alternative to gillnets. Although interviewed fishers argue that they have always been avoiding high-risk areas for bycatch of seabirds, they also stated that some fishers would still visit these sites, which underlines the need for adaptive regulations.

When creating different instruments, managers need to keep in mind that any type of fisher is considerably immobile locally, which can be due to their view of fishing as way of life [70].

5.4. Complementary findings and further research questions

This research captured the heterogeneity of fishers and although the analysis was conducted inductively and predetermined characteristics were not used, a typology similar to those of other studies was developed [32]. This can support the hypothesis of general forms of social practices and agency beyond the fisheries research context. Research with British fishers seeking to improve communication with fishers found that fishers differed mainly in their orientation towards an uncertain future. Fishers were named leaders, lieutenants and followers [29] and present similarities to projective, evaluative and iterational fishers found in this study. Another study focussed on resilience in fishers and applied a different model of agency as the one we found fruitful for developing management instruments [60]. Four types of agency were identified, which are oriented towards everyday goals or strategic goals, as well as personal or political agenda: Getting out, Getting (back) at, Getting by and Getting organized [60]. The first two are close to evaluative fishers, \`getting by\` is a strategy of iterational fishers and \`getting organized\` is close to projective fishers. Interestingly enough, if studies were conducted in another natural resource management context and focussed on different research objectives, their results presented comparable types of actors, e.g. for farmers [71, 72] or graziers [73]. Because of those similar examples of social practices, the bespoke management instruments, developed according to different types of agency, could be transferable to other contexts in natural resource management.

It is strongly suggested to research the heterogeneity of fishers further and quantify them according to agency types, which will allow for prioritized and targeted management execution. If e.g. 80% of gillnet fishers show a dominating projective agency, researchers and managers can discuss if the 20% of evaluative and iterational fishers could be neglected in bycatch management and instead focus on the 80% with programs and management instruments that will challenge and motivate projective fishers to mitigate bycatch. It would also be very interesting to quantify how fishers outline bycatch discourse. Within the qualitative data, there are some indications that fishers with large landings and many fishing trips are more prone to non-normalize bycatch. Maybe fishers with high fishing effort could have a lot of porpoise bycatch and therefore non-normalize it? The assessment of porpoise bycatch could be different between fishers with a lot and a little bycatch. Future research should think of innovative ways to generate reliable bycatch data, which is a problem in a lot of bycatch research [65, 74], to find out if the quantity of bycatch events correlates to fishers´ agency or fishers´ discourse on bycatch. Using such correlations can lead to further bespoke management in bycatch contexts.

Due to the lack of census data on bycatch, it was decided to prioritize selecting fishers with the highest fishing effort based on the assumption that high fishing effort could lead to potentially more bycatch events. It is however unclear if this is representative of the total fisher population as also vessels with less or little effort may have considerable numbers of bycatch. Future studies should therefore aim to sample a representative sample of the gillnet fishery. Moreover, it could also be an option to e.g. select fishers based only on their proximity to conservation areas instead of their fishing effort.

For further inspiration on fisheries management, comparisons with research on farmers and landholders management could be fruitful, since farming typologies have been studied and applied numerous times [72, 75–77].

Due to the sample, the case study was conducted with male fishers. Therefore, only male types of agency and male perspectives on bycatch can be presented. It would fill a research gap to conduct a similar study with female interview partners, e.g. in British Columbia where there are numerous female fishers. It is important to diversify perspectives on bycatch and mitigation instruments, since women and men manage their knowledge differently, which influences their practices in natural resource management [78].

5.5. Conclusion

Through this study, biological and ecological mitigation research was extended with the concept of fishers´ agency and it was assessed how fishers of different types can react to local fisheries-management instruments. Using data on fishers´ heterogeneity, researchers can expand questions towards more specific management issues, assess the efficiency of management instruments in manifold contexts and develop bespoke instruments accordingly.

Informed management must take into account the heterogeneity of fishers, consider how to address different groups and judge if all groups need addressing. With the introduction of the concept of fishers’ agency, a contribution towards the establishment of qualitative social-science methods in fisheries research is made which shall encourage researchers to apply and expand the concept to their research and frameworks.

Fisheries scientists and fisheries-management processes almost never explicitly consider social-science research on fishers´ actions [26]. This study brought together research on fishers as well as on management instruments and in combing these, tried to minimize the effect of unintended management outcomes. One of the most striking findings is that similar types of agency have been established in other studies and contexts as well, suggesting that a general concept of social practices was identified, not only for gillnet fishers but beyond. Integrating these findings into frameworks and models can contribute towards a holistic understanding and management of socio-ecological systems.

Acknowledgement

The authors wish to thank all of the fishers and fisheries experts for their knowledge and time in spite of having no direct gain from their contribution. The authors also wish to thank the researchers who regularly participated in the workshops for the interpretation of the transcripts and Nakula Plantener for designing the map. We thank two anonymous reviewers for their insightful and constructive comments and suggestions which resulted in a stronger manuscript.

Funding Source

This work was supported by the German Federal Agency for Nature Conservation [Bundesamt für Naturschutz, project no. 3516821300, Entwicklung von alternativen Managementansätzen und Fangtechniken zur Minimierung der Konflikte zwischen Stellnetzfischerei und Naturschutzzielen in der deutschen AWZ der Ostsee – STELLA].

Glossary

The voluntary agreement of Schleswig-Holstein is an agreement between gillnet fishers, their representatives, the Baltic Sea Information Centre of Eckernförde and the Ministry of Environment. Fishers bind themselves to voluntary measures to mitigate bycatch of sea birds and harbour porpoises. It asks fishers, inter alia, to avoid feeding places of seabirds during wintertime, reduce their nets during summer time and use harbour porpoise alert devices (PALs) in order to protect porpoises. It also states that fishers actively participate in monitoring of said animals and the development of bycatch mitigating gear [53] .

Appendix

App. A – interview guideline for problem-centred interview, translated into English

category	**question**
introduction	
	narrative stimulus: „I would like to ask you to tell me about your story as a fisher. Please start with telling me, how you got into fisheries in the first place and then go on telling me about what happened little by little ever since. Please take your time for details. Everything is of interest to me, what you have to say.”
	steering question: „Can you tell me something about your different procurements during this time?”
fishery	
motivation	narrative stimulus: Please tell me what you find special about fishing? „Erzählen Sie doch mal, was Ihnen besonders gut an der Fischerei gefällt?“ Ad hoc question, if „nature“ is part of the answer: „What do you mean by `nature`? Can you elaborate on that?“
	steering question: „What do you find important for your work?”
daily professional life	narrative stimulus: „Please tell me about your last day at work in detail. Please start with telling me, when you got up.”
resources	steering question: „Do you fish alone? Are you always fishing alone?”
challenges	steering question: „What do you find especially challenging in fisheries?“
bycatch mitigation of sea birds and sea mammals	
work practice	narrative stimulus: „You know, that I would like to talk about bycatch of sea birds and sea mammals. Every fisher knows that kind of situation (when there is a bird in the gillnet). Please remember such a situation. How did you handle it?”

category	**question**
mitigation	steering question: „How do you manage to avoid / to have less bycatch (of sea birds and sea mammals)?“
problem	steering question: „What is, in your opinion, the problem with bycatch (of sea birds and sea mammals)?”
management options	
alternative gear	narrative stimulus: “Please tell me about your experience with alternative gear?” steering questions: „Have you worked with alternative gears e.g. pods before?“ “How should / could an alternative gear be design to be used (by you)?”
	steering questions: „Would you use alternative gears, if financial loss would be compensated?” “Would you use alternative gears, if you could reach a higher sale price, e.g. due to ecological certification?” “Would you use alternative gears, if you would be rewarded a higher quota?” The following question was left out of the interviews after some interviews, because fishers did not understand it and it therefore did not produce any analysable answer: “If there was a theoretical construct such as a quota for bycatch of sea birds and mammals, what would that have to look like?”
voluntary agreement of Schleswig-Holstein	“Are you part of the agreement?” narrative question: „Please tell me, how you came to participate / not participate in the voluntary agreement?” steering question “How does the agreement work?”
participative management	narrative stimulus: `Are you engaged in fisheries management, e.g. in producer organisations? Or like now, in cooperation with scientists?” “Could you please tell me more about what you are doing and how you came around to do it?”
	steering question: How could you imagine engaging in fisheries management?
spatial and temporal closures	Narrative question: „How do spatial and temporal closures change your fishing practice?“ Steering questions: „What are you doing when the sea bird map shows a red area where you just wanted to go fishing?” (depends if voluntary agreement is an option)
economics	
income	steering questions: „Do you have another source of income apart from fishing?“ „Would you continue to fish if you would not depend on it financially?“
compliance	
	narrative question: „Could you please describe to me how a fisheries´ inspection is carried out?”
future / end of the interview	
future	narrative question: „In your opinion, how will the future of gillnet fishing in the Baltic Sea look like?“ steering question „How do you plan your personal future as a fisher?”
wishes	steering question: „What would you propose for fisheries management?“ steering question: “What would you wish for from fisheries management?”
closing question	narrative question: „We have reached the end of the interview – is there anything else you would like to add or talk about?“

App. B – short questionnaire, translated into English

short questionnaire
How old are you?
Since when are you fishing?
How do you sell your fish?
Can you tell me your income last year?
What´s your school-leaving qualification?
Are you part of a fishing cooperative?
In which generation are you fishing?
What is your current herring / cod – quota? Do you have other quotas?
How many vehicles do you own?
Are other members of your family also part of fisheries?

References

[1] Regular P, Montevecchi W, Hedd A, Robertson G, Wilhelm S. Canadian fishery closures provide a large-scale test of the impact of gillnet bycatch on seabird populations. Biology letters 2013; 9(4): 20130088.

[2] ASCOBANS. Conservation Plan for the Harbour Porpoise Population in the Western Baltic, the Belt Sea and the Kattegat; 2012.

[3] Council of the European Communities. COUNCIL DIRECTIVE 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora: DIRECTIVE92/43/EEC; 1992.

[4] Salomon M, Markus T, Dross M. Masterstroke or paper tiger – The reform of the EU's Common Fisheries Policy. Marine Policy 2014; 47: 76–84.

[5] Hamilton S, Baker GB. Technical mitigation to reduce marine mammal bycatch and entanglement in commercial fishing gear: lessons learnt and future directions. Rev Fish Biol Fisheries 2019; 29(2): 223–47.

[6] Almeida A, Ameryk A, Campos B, Crawford R, Krogulec J, Linkowski T et al. Study on Mitigation Measures to Minimise Seabird Bycatch in Gillnet fisheries; 2017.

[7] Campbell LM, Cornwell ML. REVIEW: Human dimensions of bycatch reduction technology: current assumptions and directions for future research. Endang. Species Res. 2008; 5: 325–34.

[8] Leaper R, Calderan S. Review of methods used to reduce risks of cetacean bycatch and entanglements; 2018.

[9] Whitty TS. Governance potential for cetacean bycatch mitigation in small-scale fisheries: A comparative assessment of four sites in Southeast Asia. Applied Geography 2015; 59: 131–41.

[10] Tulloch V, Grech A, Jonsen I, Pirotta V, Harcourt R. Cost-effective mitigation strategies to reduce bycatch threats to cetaceans identified using return-on-investment analysis. Conservation biology the journal of the Society for Conservation Biology 2020; 34(1): 168–79.

[11] Trippel EA, Holy NL, Shepherd TD. Barium sulphate modified fishing gear as a mitigative measure for cetacean incidental mortalities. Journal of Cetacean Research and Management 2008; 10(3): 235–46.

[12] Kratzer I, Schäfer I, Stoltenberg A, Chladek JC, Kindt-Larsen L, Larsen F et al. Determination of Optimal Acoustic Passive Reflectors to Reduce Bycatch of odontocetes in Gillnets. Front. Mar. Sci. 2020; 7.

[13] Bielli A, Alfaro-Shigueto J, Doherty PD, Godley BJ, Ortiz C, Pasara A et al. An illuminating idea to reduce bycatch in the Peruvian small-scale gillnet fishery. Biological Conservation 2020; 241: 108277.

[14] Field R, Crawford R, Enever R, Linkowski T, Martin G, Morkūnas J et al. High contrast panels and lights do not reduce bird bycatch in Baltic Sea gillnet fisheries. Global Ecology and Conservation 2019; 18: e00602.

[15] Mangel JC, Wang J, Alfaro-Shigueto J, Pingo S, Jimenez A, Carvalho F et al. Illuminating gillnets to save seabirds and the potential for multi-taxa bycatch mitigation. Royal Society open science 2018; 5(7): 180254.

[16] Dawson SM, Northridge S, Waples D, Read AJ. To ping or not to ping: the use of active acoustic devices in mitigating interactions between small cetaceans and gillnet fisheries. Endang. Species Res. 2013; 19(3): 201–21.

[17] Chladek J, Culik B, Kindt-Larsen L, Albertsen CM, Dorrien C von. Synthetic harbour porpoise (Phocoena phocoena) communication signals emitted by acoustic alerting device (Porpoise Alert, PAL) significantly reduce their bycatch in Western Baltic gillnet fisheries. Fisheries Research 2020; 232: 105732

[18] Northridge S, Sanderson D, Mackay AI, Hammond PS. Analysis and mitigation of cetacean bycatch in UK fisheries. Final Project Report for Department for Environment, Food and Rural Affairs, London, UK; 2003.

[19] Gormley AM, Slooten E, Dawson S, Barker RJ, Rayment W, Du Fresne S et al. First evidence that marine protected areas can work for marine mammals. Journal of Applied Ecology 2012; 49(2): 474–80.

[20] Murray K, Read A, Solow A. The use of time/area closures to reduce bycatches of harbour porpoises: Lessons from the Gulf of Maine sink gillnet fishery. Journal of Cetacean Research and Management 2000(2): 135–41.

[21] Northridge S, Coram A, Kingston A, Crawford R. Disentangling the causes of protected-species bycatch in gillnet fisheries. Conservation biology the journal of the Society for Conservation Biology 2017; 31(3): 686–95.

[22] Eayrs S, Pol M. The myth of voluntary uptake of proven fishing gear: investigations into the challenges inspiring change in fisheries. ICES J Mar Sci 2019; 76(2): 392–401.

[23] Leenhardt P, Teneva L, Kininmonth S, Darling E, Cooley S, Claudet J. Challenges, insights and perspectives associated with using social-ecological science for marine conservation. Making Marine Science Matter: Issues and Solutions from the 3rd International Marine Conservation Congress 2015; 115: 49–60.

[24] Silva MRO, Lopes PFM. Each fisherman is different: Taking the environmental perception of small-scale fishermen into account to manage marine protected areas. Marine Policy 2015; 51: 347–55.

[25] Mace GM. Ecology. Whose conservation? Science (New York, N.Y.) 2014; 345(6204): 1558–60.

[26] Fulton EA, Smith ADM, Smith DC, van Putten IE. Human behaviour: The key source of uncertainty in fisheries management. Fish and Fisheries 2011; 12(1): 2–17.

[27] Gelcich S, Edwards-Jones G, Kaiser MJ. Heterogeneity in fishers’ harvesting decisions under a marine territorial user rights policy. Ecological Economics 2007; 61(2-3): 246–54.

[28] Quynh CNT, Schilizzi S, Hailu A, Iftekhar S. Fishers’ Preference Heterogeneity and Trade-offs Between Design Options for More Effective Monitoring of Fisheries. Ecological Economics 2018; 151: 22–33.

[29] Creative Research. A Fisherman´s Tale: Being a Fisherman in England in 2009: Report of Research Findings. COI Job No: 291928; 2009.

[30] Christensen A-S. Methdological framework for studying fishermen´s tactics and strategies; 2007.

[31] Christensen A-S, Raakjær J. Fishermen’s tactical and strategic decisions: A case study of Danish demersal fisheries. Fisheries Research 2006; 81(2–3): 258–67.

[32] Abernethy K. Fishing for what?: Understanding fisher decision-making in southwest England. Doctoral Thesis. Norwich; 2010.

[33] Boonstra WJ, Hentati-Sundberg J. Classifying fishers’ behaviour. An invitation to fishing styles. Fish Fish 2016; 17(1): 78–100.

[34] Sønvisen SA. Contemporary fisher images: Ideologies, policies and diversity. Journal of Rural Studies 2014; 34: 193–203.

[35] Kube K. Hochseefischer: Die Lebenswelt eines maritimen Berufstandes aus biografischer Perspektive. 1st ed. Münster: Waxmann Verlag GmbH; 2013.

[36] Teh LSL, Teh LCL, Hines E, Junchompoo C, Lewison RL. Contextualising the coupled socio-ecological conditions of marine megafauna bycatch. Making Marine Science Matter: Issues and Solutions from the 3rd International Marine Conservation Congress 2015; 116: 449–65.

[37] Young C de, Charles A, Hjort A. Human dimensions of the ecosystem approach to fisheries: An overview of context, concepts, tools and methods. Rome: Food and Agriculture Organization of the United Nations; 2008.

[38] Stephenson RL, Paul S, Pastoors MA, Kraan M, Holm P, Wiber M et al. Quo Vadimus: Integrating fishers’ knowledge research in science and management. ICES J. Mar. Sci. 2016; 73(6): 1459–65.

[39] Grafton RQ, Arnason R, Bjørndal T, Campbell D, Campbell HF, Clark CW et al. Incentive-based approaches to sustainable fisheries. Can. J. Fish. Aquat. Sci. 2006; 63(3): 699–710.

[40] Dias MP, Martin R, Pearmain EJ, Burfield IJ, Small C, Phillips RA et al. Threats to seabirds: A global assessment. Biological Conservation 2019; 237: 525–37.

[41] Giddens A. The constitution of society: Outline of the theory of structuration. 1st ed. Berkeley Calif. u.a.: Univ. of California Press; 1984.

[42] Brand K-W. Umweltsoziologie und der praxistheoretische Zugang. In: Groß M, editor. Handbuch Umweltsoziologie, 1st ed. Wiesbaden: VS, Verl. für Sozialwiss; 2011, p. 173–198.

[43] Schallnus RN. Mitarbeiterqualifizierung und Wissensnutzung in Konzernen und Unternehmungsnetzwerken: Eine Prozessanalyse mit erklärten Beispielen aus der IT-Branche. Dissertation. Berlin; 2006.

[44] Bohnsack R, Nentwig-Gesemann I, Nohl A-M (eds.). Die dokumentarische Methode und ihre Forschungspraxis: Grundlagen qualitativer Sozialforschung. 3rd ed. Wiesbaden: Springer VS; 2013.

[45] Nohl A-M. Narrative Interview and Documentary Interpretation. In: Bohnsack R, Pfaff N, Weller W, editors. Qualitative analysis and documentary method in international educational research. Opladen: Budrich; 2010, p. 195–217.

[46] Weber M. Gesammelte Aufsätze zur Wissenschaftslehre. Tübingen: J. C. B. Mohr (Paul Siebeck); 1922.

[47] Emirbayer M, Mische A. What Is Agency? American Journal of Sociology 1998; 103(4): 962–1023.

[48] Meyer S, Krumme U. Disentangling complexity of fishing fleets: using sequence analysis to classify distinguishable groups of vessels based on commercial landings. Under review in Journal of Fisheries Management and Ecology.

[49] Tregenza N, Berrow SD, Hammond PS, Leaper R. Harbour porpoise (Phocoena phocoena L.) by-catch in set gillnets in the Celtic Sea. ICES Journal of Marine Science 1997; 54: 896–904.

[50] Witzel A. Das problemzentrierte Interview. Forum Qualitative Sozialforschung / Forum: Qualitative Social Research 2000; 1(1): Artikel 22.

[51] Fuß S, Karbach U. Grundlagen der Transkription: Eine praktische Einführung. Opladen, Stuttgart: Budrich; UTB; 2014.

[52] Böcher M, Töller AE. Umweltpolitik in Deutschland: Eine politikfeldanalytische Einführung. Wiesbaden: Springer Fachmedien Wiesbaden; 2012.

[53] Landesfischereiverband Schleswig-Holstein, Fischereischutzverband Schleswig-Holstein, Ostsee Informations-meyerCenter Eckernförde, Ministerium für Energiewende, Landwirtschaft, Umwelt und ländliche Räume des Landes Schleswig-Holstein. Freiwillige Vereinbarung zum Schutz von Schweinswalen und tauchenden Meeresenten; 2015.

[54] Ferretti J. Elements of successful processes in dealing with human-wildlife interactions: Recommendations for the process design for developing a conflict management plan fisheries –seals in Mecklenburg-Vorpommern (Germany). Studie im Auftrag des Landesministeriums für Landwirtschaft und Umwelt Mecklenburg-Vorpommern (unpublished); 2019.

[55] Waldo S, Paulrud A, Blomquist J. The economic costs of seal presence in Swedish small-scale fisheries. ICES J Mar Sci 2020; 77(2): 815–25.

[56] Schwermer H, Barz F, Zablotski Y. A Literature Review on Stakeholder Participation in Coastal and Marine Fisheries. In: Jungblut S, Liebich V, Bode-Dalby M, editors. YOUMARES 9 - The Oceans: Our Research, Our Future. Cham: Springer International Publishing; 2020, p. 21–43.

[57] Verweij MC, van Densen WLT, Mol AJP. The tower of Babel: Different perceptions and controversies on change and status of North Sea fish stocks in multi-stakeholder settings. Marine Policy 2010; 34(3): 522–33.

[58] Fischer L-B, Newig J. Importance of Actors and Agency in Sustainability Transitions: A Systematic Exploration of the Literature. Sustainability 2016; 8(5): 476.

[59] Steins NA, Kraan ML, Reijden KJ, Quirijns FJ, Broekhoven W, Poos JJ. Integrating collaborative research in marine science: Recommendations from an evaluation of evolving science-industry partnerships in Dutch demersal fisheries. Fish Fish 2020; 21(1): 146–61.

[60] Coulthard S. Can We Be Both Resilient and Well, and What Choices Do People Have? Incorporating Agency into the Resilience Debate from a Fisheries Perspective. E&S 2012; 17(1).

[61] Eayrs S, Cadrin SX, Glass CW. Managing change in fisheries: A missing key to fishery-dependent data collection? ICES Journal of Marine Science 2015; 72(4): 1152–8.

[62] Soykan CU, Moore JE, Zydelis R, Crowder LB, Safina C, Lewison RL. Why study bycatch? An introduction to the Theme Section on fisheries bycatch. Endang. Species Res. 2008; 5: 91–102.

[63] Nolde Nielsen K, Holm P, Aschan M. Results based management in fisheries: Delegating responsibility to resource users. Marine Policy 2015; 51: 442–51.

[64] Kennelly SJ, Broadhurst MK. By-catch begone: changes in the philosophy of ®shingtechnology. Fish and Fisheries 2002(3): 340–55.

[65] Komoroske LM, Lewison RL. Addressing fisheries bycatch in a changing world. Front. Mar. Sci. 2015; 2: 83.

[66] Jenkins LD. The Invention and Adoption of Conservation Technology to Successfully Reduce Bycatch of Protected Marine Species. PhD Thesis. Durham, NC; 2006.

[67] Peckham SH, Maldonado Diaz D, Walli A, Ruiz G, Crowder LB, Nichols WJ. Small-scale fisheries bycatch jeopardizes endangered Pacific loggerhead turtles. PloS one 2007; 2(10): e1041.

[68] Bowles S. Policies designed for self-interested citizens may undermine “the moral sentiments”: evidence from economic experiments. Science (New York, N.Y.) 2008; 320(5883): 1605–9.

[69] Dunn DC, Maxwell SM, Boustany AM, Halpin PN. Dynamic ocean management increases the efficiency and efficacy of fisheries management. Proceedings of the National Academy of Sciences of the United States of America 2016; 113(3): 668–73.

[70] Yuerlita, Perret SR, Shivakoti GP. Fishing farmers or farming fishers? Fishing typology of inland small-scale fishing households and fisheries management in singkarak lake, west sumatra, indonesia. Environmental management 2013; 52(1): 85–98.

[71] Barnes AP, Willock J, Toma L, Hall C. Utilising a farmer typology to understand farmer behaviour towards water quality management: Nitrate Vulnerable Zones in Scotland. Journal of Environmental Planning and Management 2011; 54(4): 477–94.

[72] Kees V. Adapted farming systems for a rural landscape. Sociologia Ruralis 1992; 32(1): 146–62.

[73] Bohnet IC, Roberts B, Harding E, Haug KJ. A typology of graziers to inform a more targeted approach for developing natural resource management policies and agricultural extension programs. Land Use Policy 2011; 28(3): 629–37.

[74] Lewison RL, Soykan CU, Cox T, Peckham H, Pilcher N, LeBoeuf N et al. Ingredients for Addressing the Challenges of Fisheries Bycatch. BMS 2011; 87(2): 235–50.

[75] McElwee G, Bosworth G. Exploring the strategic skills of farmers across a typology of farm diversification approaches. Journal of Farm Management 2010; 13(12): 819–38.

[76] Guillem EE, Barnes AP, Rounsevell MDA, Renwick A. Refining perception-based farmer typologies with the analysis of past census data. Journal of environmental management 2012; 110: 226–35.

[77] Emtage N, Herbohn J, Harrison S. Landholder Profiling and Typologies for Natural Resource–Management Policy and Program Support: Potential and Constraints. Environmental Management 2007; 40(3): 481–92.

[78] Yianna L. A Typology: Participatory Research and Gender Analysis in Natural Resource Management Research; 2001.

Arbeitspaket 4 – Dissertation “Boats don’t fish, people do”

Barz, F. 2021. `Boats don´t fish, people do´: a sociological contribution towards holistic fisheries bycatch management. Dissertation, University of Rostock, Germany, 230 p. Veröffentlicht als Thünen-Report 95 (2022), 244 p, DOI:10.3220/REP1652092494000

Zusammenfassung

Der Mensch nutzt seit jeher die natürlichen Ressourcen des Meeres, mit verschiedensten Auswirkungen die Fischbestände und die Meeresumwelt. Ein Problem, das sich aus der Interaktion der Menschen, insbesondere der Fischer, mit dem Meer ergibt, ist das Verfangen von Meeresvögeln und -säugetieren in Fischfanggeräten, insbesondere in Stellnetzen, wodurch diese luftatmenden Tiere ertrinken. Diese Vorfälle werden als Beifang bezeichnet. Stellnetze haben allerdings eine lange Tradition in der Fischerei in der Ostsee und sind weltweit eines der am häufigsten verwendeten Fanggeräte. Der Beifang von Seevögeln und Meeressäugern in der Stellnetzfischerei stellt daher eine Gefahr für den weltweiten Naturschutz dar. Die bisherigen Maßnahmen zur Verringerung des Beifangs im Fischereimanagement beruhen meist auf technischen und ökologischen Erkenntnissen. Trotz der Bedeutung für ein effektives Fischereimanagement mangelt es daher oft an Wissen über die Heterogenität der Handlungspraxis und Motivationen von Fischern.

In dieser Dissertation wurde die deutschen Stellnetzflotte in der Ostsee betrachtet, um ein ontologisches Verständnis der sozialen Praktiken der Fischer zu entwickeln, das als Grundlage für das Management und die Entwicklung von Maßnahmen zur Beifangreduzierung und - vermeidung dient.

Die Soziologie der natürlichen Ressourcen bietet eine Perspektive, um dieses Forschungsanliegen zu erreichen. Die vorliegende Dissertation wendet die praxeologische Theorie der Strukturierung, erweitert um das Konzept der Handlungsfähigkeit (Agency), auf die Forschungsfragen an. Die qualitative empirische Forschung wurde mittels problemzentrierter Interviews durchgeführt, die mit der dokumentarischen Methode ausgewertet wurden. Ein Experten-Workshop zu politischen und administrativen Aspekten des Beifangmanagements ergänzte die empirische Forschung.

Aus praxeologischer Sicht und unter Anwendung des Konzepts der Handlungsfähigkeit (Agency) wurden drei Arten der dominierenden Handlungsfähigkeit von Fischern unterschieden:

(1) Fischer mit einer dominierenden projektiven (zukunftsorientierten) Handlungsweise planen langfristig, halten sich über aktuelle Entwicklungen in der Fischerei auf dem Laufenden und entwickeln teleologische Projekte.

(2) Fischer mit einer vorherrschenden evaluativen (gegenwartsorientierten) Handlungsweise bewerten ständig ihre Situation neu. Evaluative soziale Praktiken sind nicht teleologisch ausgerichtet und zeichnen sich in der Fischerei eher durch Entscheidungen aus, die sich an aktuellen Situationen orientieren. Dies kann sich auch in abweichendem Verhalten zeigen

(3) Fischer mit einer vorherrschenden iterativen (vergangenheitsorientierten) Handlungsweise zeichnen sich durch die Iteration bekannter Handlungsschemata aus, diesomit soziale Praktiken ständig reproduzieren. Solche iterativen Aspekte zeigen sich bei Fischern, die ausschließlich Stellnetze einsetzen.

Darüber hinaus ergab die Analyse der Beifangpraktiken zwei verschiedene Perspektiven auf Beifangereignisse: (i) Nicht-Normalisierung des Beifangs, vor allem in Bezug auf den Beifang von Schweinswalen, ist eine kritische Situation, welche die tägliche Routine unterbricht, während (ii) Normalisierung des Beifangs, vor allem in Bezug auf den Beifang von Seevögeln, als Teil einer Routine verstanden wird. Bei der Anwendung des Wissens über die verschiedenen Fischertypen und Beifangpraktiken auf mögliche Managementinstrumente wurden zahlreiche Maßnahmen ermittelt, die von Fischereimanagern in Betracht gezogen werden können, und deren potenzielle Wirksamkeit im Hinblick auf die Heterogenität der Fischer diskutiert. Schlussfolgernd ist zu sagen, dass die Berücksichtigung der sozialen Praktiken von Ressourcennutzer:innen einen wichtigen Beitrag zur

Entwicklung wirksamer Instrumente für das Management natürlicher Ressourcen darstellen kann. Der Einbezug der Soziologie sowie soziologisch fundierter Theorien und qualitativer rekonstruktiver Methoden hat zu praxisrelevanten Erkenntnissen darüber geführt, wie das Wissen über menschliches Handeln ins Management einfließen und somit Beifang reduzieren kann.

Vollständige Veröffentlichung (Open Access)

https://literatur.thuenen.de/digbib_extern/dn064849.pdf

Thünen Report

Bereits in dieser Reihe erschienene Hefte **–** *Volumes already published in this series*

1 - 75	siehe http://www.thuenen.de/de/infothek/publikationen/thuenen-report/
76	Mirko Liesebach (ed.) **Forstpflanzenzüchtung für die Praxis, 6. Tagung der Sektion Forstgenetik/Forstpflanzenzüchtung vom 16. bis 18. September 2019 in Dresden, Tagungsband**
77	Hans-Dieter Haenel, Claus Rösemann, Ulrich Dämmgen, Ulrike Döring, Sebastian Wulf, Brigitte Eurich-Menden, Annette Freibauer, Helmut Döhler, Carsten Schreiner, Bernhard Osterburg, Roland Fuß **Calculations of gaseous and particulate emissions from German agriculture 1990 – 2018** **Berechnung von gas- und partikelförmigen Emissionen aus der deutschen Landwirtschaft 1990 – 2018**
78	Alexandra Purkus, Jan Lüdtke, Dominik Jochem, Sebastian Rüter, Holger Weimar **Entwicklung der Rahmenbedingungen für das Bauen mit Holz in Deutschland: Eine Innovationssystemanalyse im Kontext der Evaluation der Charta für Holz 2.0**
79	Peter Elsasser, Kerstin Altenbrunn, Margret Köthke, Martin Lorenz, Jürgen Meyerhoff **Regionalisierte Bewertung der Waldleistungen in Deutschland**
80	Lutz Laschewski, Andreas Tietz **Auswirkungen überregional aktiver Investoren in der Landwirtschaft auf ländliche Räume : Ergebnisse aus zwei Fallstudien**
81	Martin Ohlmeyer, Friederike Mennicke, Saskia Poth **Erarbeiten eines objektiven Verfahrens unter Berücksichtigung der Besonderheiten von Holz und Holzwerkstoffen bei der Bewertung ihres Einflusses auf die Innenraumluftqualität (HoInRaLu), TV 1: Untersuchungen unter realen Raumluftbedingungen**
82	Marlen Haß, Martin Banse, Claus Deblitz, Florian Freund, Inna Geibel, Alexander Gocht, Peter Kreins, Verena Laquai, Frank Offermann, Bernhard Osterburg, Janine Pelikan, Jörg Rieger, Claus Rösemann, Petra Salamon, Maximilian Zinnbauer, Max-Emanuel Zirngibl **Thünen-Baseline 2020 – 2030: Agrarökonomische Projektionen für Deutschland**
83	Marc Simon Weltersbach, Carsten Riepe, Wolf-Christian Lewin, Harry V. Strehlow **Ökologische, soziale und ökonomische Dimensionen des Meeresangelns in Deutschland**
84	Claus Rösemann, Hans-Dieter Haenel, Cora Vos, Ulrich Dämmgen, Ulrike Döring, Sebastian Wulf, Brigitte Eurich-Menden, Annette Freibauer, Helmut Döhler, Carsten Schreiner, Bernhard Osterburg, Roland Fuß **Calculations of gaseous and particulate emissions from German agriculture 1990 – 2019** **Berechnung von gas- und partikelförmigen Emissionen aus der deutschen Landwirtschaft 1990 – 2019**
85	Andreas Tietz, Richard Neumann, Steffen Volkenand **Untersuchung der Eigentumsstrukturen von Landwirtschaftsfläche in Deutschland**
86	Katja Butter, Martin Ohlmeyer **Emissionen flüchtiger organischer Verbindungen von Holz und Holzwerkstoffen**
87	Kim Pollermann **Regional Governance: Begriffe, Wirkungszusammenhänge und Evaluationsansätze**

88 Gerold Rahmann, Frédéric Rey, Reza Ardakani, Khalid Azim, Véronique Chable, Felix Heckendorn, Paola Migliorini, Bram Moeskops, Daniel Neuhoff, Ewa Rembiałkowska, Jessica Shade, Marc Tchamitchian (eds.)
From its roots, organic inspires science, and vice versa. Book of Abstracts of the Science Forum at the Organic World Congress 2021, September 8-10, 2021. Rennes, France

89 Walter Dirksmeyer, Klaus Menrad (eds.)
Aktuelle Forschung in der Gartenbauökonomie : Digitalisierung und Automatisierung - Welche CHancen und Herausforderungen ergeben sich für den Gartenbau? Tagungsband zum 3. Symposium für Ökonomie im Gartenbau am 15. November 2019 in Freising / Weihenstephan

90 Tobias Mettenberger, Patrick Küpper
Innovative Versorgungslösungen in ländlichen Regionen: Ergebnisse der Begleitforschung zum Modellvorhaben Land(auf)Schwung im Handlungsfeld „Daseinsvorsorge“ : Band 1 der Begleitforschung Land(auf)Schwung

90 Gesine Tuitjer, Christian Bergholz, Patrick Küpper
Unternehmertum, Netzwerke und Innovationen in ländlichen Räumen: Ergebnisse der Begleitforschung zum Modellvorhaben Land(auf)Schwung im Handlungsfeld „Regionale Wertschöpfung“ : Band 2 der Begleitforschung Land(auf)Schwung

91 Cora Vos, Claus Rösemann, Hans-Dieter Haenel, Ulrich Dämmgen, Ulrike Döring, Sebastian Wulf, Brigitte Eurich-Menden, Annette Freibauer, Helmut Döhler, Carsten Schreiner, Bernhard Osterburg, Roland Fuß
Calculations of gaseous and particulate emissions from German agriculture 1990 – 2020
Berechnung von gas- und partikelförmigen Emissionen aus der deutschen Landwirtschaft 1990 – 2020

92 Kurt-Jürgen Hülsbergen, Harald Schmid, Hans Marten Paulsen (eds)
Steigerung der Ressourceneffizienz durch gesamtbetriebliche Optimierung der Pflanzen- und Milchproduktion unter Einbindung von Tierwohlaspekten – Untersuchungen in einem Netzwerk von Pilotbetrieben

93 Heike Peter, Cornelia Tippel, Annett Steinführer
Wohnstandortentscheidungen in einer wohnbiographischen Perspektive : Eine explorative Studie in ländlichen und großstädtischen Kontexten

94 Daniel Ziche, Erik Grüneberg, Winfried Riek, Nicole Wellbrock
Comparison of the LUCAS 2015 inventory with the second National Forest Soil Inventory : Comparability and representativeness of two soil inventories conducted in Germany

95 Fanny Barz
Boats don’t fish, people do – A sociological contribution towards holistic fisheries bycatch management

96 Jacob Jeff Bernhardt, Lennart Rolfes, Peter Kreins, Martin Henseler
Ermittlung des regionalen Bewässerungsbedarfs für die Landwirtschaft in Bayern

97 Uwe Krumme, Steffi Meyer, Isabella M. F. Kratzer, Jérôme C. Chladek, Fanny Barz, Daniel Stepputtis, Harry V. Strehlow, Sarah B. M. Kraak, Christopher Zimmermann
STELLA - Stellnetzfischerei-Lösungsansätze : Projekt-Abschlussbericht

THÜNEN

Thünen Report 97

Herausgeber/Redaktionsanschrift

Johann Heinrich von Thünen-Institut
Bundesallee 50
38116 Braunschweig
Germany

www.thuenen.de

ISBN 978-3-86576-244-3
9 783865 762443