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Preface

This report presents the work on discard survival of undersized European plaice (*Pleuronectes platessa*) in towed fishing gears conducted at DTU Aqua in 2016-2018 and 2020-2023. The work was conducted in a project titled “Caught and released: an Overview of fishes’ sensitivity to being discarded as a tool to aid Pursuing Ecosystem-based management (COPE)” coordinated by Dr. Junita D. Karlsen and its follow-up project “COPE 2” coordinated by Dr. Esther Savina. Both projects were funded by the European Maritime and Fisheries Fund (grant no. 33113-B-16-086 and grant no. 33113-B-20-162, respectively). The projects were based on interest from managers in the Ministry for Food, Agriculture and Fisheries and the Danish Fishermen Producer Organisation (DFPO) to explore the opportunities to seek high survival exemptions from the landing obligation as detailed in the European Common Fisheries Policy, and to collect the associated scientific evidence required.

While the COPE project operated in Skagerrak with the aim of obtaining high survival exemption for the North Sea, Skagerrak, and Kattegat areas, the COPE2 project operated in the Baltic Sea to provide discard survival estimates for the Western Baltic Sea where Danish fishers operate.

Discard survival is highly variable due to the species’ different resilience to stressors and stressor combinations, in addition to differences between and within fisheries as well as fleet segments. Both projects have therefore focused on understanding which operational, environmental, and biological factors affect discard survival most in Danish waters. In COPE, the focus was on differences in discard survival between fisheries (gear type, target species, gear design, fishing season), and how air exposure affected survival estimates. In COPE2, additional focus was given on the effect of oxygen and temperature conditions and the physical impact of ingested hard-shelled prey items.

Direct observation of survival in captivity is resource demanding. In contrast, proxies for discard survival, for example vitality, are easier and cost-efficient to collect. Proxies of discard survival have furthermore the potential of giving estimates that cover a broader range of operational, environmental, and biological conditions compared with estimates from direct observations of fish in captivity. In COPE, it was however proven difficult to obtain good predictions of discard survival using established proxies which indicates that important processes influencing discard survival are not well understood. For this reason, attention was given in COPE2 to develop an optimized proxy to improve discard survival predictability, and to evaluate the proxy methodology for future improvements.

This report is primarily meant for the managers involved in seeking high survival exemptions through the Regional Group Joint Recommendations; DFPO, to identify fisheries-and-species combinations for which high survival exemptions can be relevant; fishers who are interested in optimizing their fishing and catch handling processes to improve the survival of their bycatch in fisheries relevant for high survival exemptions; and for scientists to inform future discard survival studies and contribute to the understanding of factors affecting discard survival estimates.

Both the COPE and COPE2 projects were conducted in collaboration with the DFPO, who was involved in the selection of the species and fisheries to be investigated and facilitated the identification and collaboration with the fishing vessels involved in the experiments. DFPO has neither been involved in the scientific work or its outcome, nor has participated in making this report or had any influence on its content. The experiments that led to discard survival estimates were performed under the animal welfare approval no. 2020-15-0201-00668 and conducted according to the International Council for the Exploration of the Sea (ICES) Guidelines on Methods for Estimating Discard Survival. The responsible researchers were members of the ICES expert groups Workshop and Working Group on Methods for Estimating Discard Survival (WKMEDS, WGMEDS). Advice on scientific evidence with respect to high survival exemptions from the European Union (EU) landing obligation was given to the Ministry for Food, Agriculture and Fisheries. The results in this report have been disseminated to various stakeholders of the management, industry, and the public through presentations and dissemination articles, as well as to the scientific community through peer-reviewed publications. Furthermore, the results are continuously being used for educational purposes.

The authors thank the immensely helpful crews of the fishing vessels S84 Ida-Katrine, S15 Vera-Marie, and R3 Orion who agreed to welcome us onboard, as well as R41 Polarbjørn, R254 Katrine Kim and R419 Emanuel who kindly collected oxygen data for us during normal gear operation, as well as Henrik Lund from DFPO, and the Skagen and Bornholm fishermen organizations. We would also like to thank our colleagues at DTU Aqua for their involvement in the project: the crew of R/V Havfisken for initial trials in COPE; Per Christensen, Søren Eskildsen, Søren Grønby, Brian Thomsen, and Kasparas Bagdonas for providing essential support during the sea trials; Dr. Manuel G. Rodriquez, Dr. Lars-Flemming Petersen, Dr. Carlos Letelier-Gordo, Reinhardt Jensen and Rasmus Frydenlund Jensen for help with the design, installation and operation of the observation system at the facility in Hirtshals and Dr. Sune Riis Sørensen in Bornholm; Helle Andersen for help with assessing the fish during the monitoring period in Hirtshals; and Ulla H. Sproegel for analyzing water samples. We owe our thanks to our colleagues Josefine Egekvist and Kirsten Birch Håkansson for their help with extracting fleet data from the Data Collection Framework and logbook databases. We owe our thanks to our neighbor, Martin Riis at the Nordsøen Oceanarium, for good advice with respect to fish transport and Claus Drivsholm at the Nordsøen Forskepark for access to experimental facilities in Hirtshals. We are grateful for the warm welcome at Bornholms Lakseklækkeri and for the assistance of Gert Jørgensen and Eskild Aae in assessing the fish during the monitoring period in Bornholm. We are thankful for the guidance given by special consultant Leif R. Lund at the Animal Experiments Inspectorate during the application process for the animal welfare approval.

The authors acknowledge and are grateful for the contributions of the members of the ICES WGMEDS, especially Thomas Catchpole, Marie Morfin, Hugues Benoit, Michael Alves Teixeira, and Mike Breen for the meta-regression work. We would especially like to highlight the involvement of ILVO by letting our Belgian colleague (Sebastian Uhlmann, Bart Ampe) not only help with training and harmonizing of the reflex and damage assessments (during field visits in 2017 and 2020), but also share their exciting optimization and temperature investigations. Sebastian Uhlmann acknowledges the receipt of a fellowship from the OECD Co-operative Research Program “Sustainable Agricultural and Food Systems” in 2022. We are also grateful to Lisbeth Nielsen and Sonja Østerlund Feldthaus from the Ministry for Food, Agriculture and Fisheries, and the Scheveningen and BALTFISH Groups for preparation of requests for high survival exemptions from the EU landing obligation in the Joint Recommendations, the North Sea Advisory Council (NSAC) Skagerrak and Kattegat working group for discussion of the results, and to experts and chairs at the Scientific, Technical and Economic Committee for Fisheries (STECF) Expert Working Group (EWG) on the evaluation of landing obligation joint recommendation, and especially Dominic Rihan.

December 2023

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Summary

The reform of the European Union (EU)'s Common Fisheries Policy (CFP) in 2013 has led to significant changes in fisheries management, including an obligation to land all catches from regulated stocks, i.e. a ban on throwing unwanted catch back into the sea. The goal of the landing obligation is to promote more selective and targeted fishing that reduces unwanted bycatch. It is possible to put fish back into the sea instead of landing them if it can be scientifically proven that there is a high survival rate in a specific fishery. However, the criterion for what counts as "high" is not set and is evaluated for each individual case by the EU.

This report presents the work of DTU Aqua on discard survival of undersized European plaice (*Pleuronectes platessa*, below 27 cm in the North Sea and Skagerrak, below 25 cm in the Baltic) caught using towed gears in commercial demersal fisheries for human consumption. This work has focused on:

- estimate survival rates with the aim of obtaining exemptions from the landing obligation,
- improve our understanding of how operational, environmental, and biological stressors affect discard survival rates,
- explore the opportunity to create robust discard survival estimates from meta-analysis; iv) investigate the effect of the environment (temperature) on reflex impairment,
- develop and test the performance of an optimized reflex and injury index,
- use expert knowledge (Bayesian modelling) to predict discard survival.

We estimated survival rates as scientific documentation for seeking exemptions from the landing obligation in the EU CFP for three fleets: the Danish seine and bottom otter trawl fleets[1] operating in Skagerrak, Kattegat, and the North Sea (ICES subdivision 3a and 4), and bottom otter trawls operating in the Baltic Sea (ICES subdivisions 22-25). Survival estimates considered the characteristics of the gear (gear types and designs), fishing practices (target species, seasonality, and handling practices) and ecosystem (e.g., hazards from hard-shelled prey items, or area-specific variability in oxygen conditions in the Baltic Sea), as required by the CFP.

The studies found the following survival rates in different situations:

- In a conservative scenario, i.e., discard survival during the warm water season (August-October) in Skagerrak, the discard survival in the demersal mixed fishery using an otter trawl with a 90 mm codend and a 120 mm SELTRA-panel fishing was 44% (95% confidence interval CI: 37%-52%).
- In comparison, it was 78% (95% CI: 67%-87%) in the Danish seine fishery fishing simultaneously. The discard survival rate for the otter trawl when targeting plaice improved to 75% (95% CI: 67%-83%) in the cold-water season (March).
- When fishing for Norway lobster (*Nephrops norvegicus*), the discard survival rate during winter was reduced to 40% (95% CI: 28%-57%) due to more injuries to the plaice when caught together with *Nephrops*.
- When we changed the design into a divided codend separating fish from *Nephrops*, the survival rate of plaice was higher with mean 94% (95% CI: 81%-100%) when caught together with fish in the upper panel than when caught in the lower compartment with *Nephrops* (61%, 95% CI: 48%-73%) or when mixed with *Nephrops* in the standard gear. The number of individuals was however low due to the high selectivity in the fish compartment.

[1] These two gear types are managed together but have a very different fishing process.

- The lowest estimates of discard survival were observed when fishing plaice in the Baltic Sea with an otter trawl during a warm water period (autumn). A delayed survival rate of only 27% (95% CI: 9%-55%) was obtained when fishing with a T90 codend, and 14% (95% CI: 4%-29%) when using a Bacoma codend. In the cold-water season (November to April)[2], the survival rate was 87% (95% CI: 82%-92%).

Based on the project's results, the EU Commission granted a year-round high survival exemption for plaice caught in the Danish seine fishery in Skagerrak and Kattegat (ICES Division 3a) and North Sea (ICES Subarea 4; EU, 2018, §16). The bottom otter trawl fishery was granted an exemption for the winter season (EU, 2018, §17). For the Baltic Sea, in line with Kraak *et al.* (2018) in the German mixed demersal trawl fishery in ICES subdivision 22, the discard survival observed in our study might be considered "high" for plaice in winter. However, the High-Level Regional Group (BALTFISH) decided not to include a request for high survival exemption for plaice in the Joint Recommendation.

We investigated the effect of dissolved oxygen level at capture on delayed plaice mortality. Oxygen levels were related to seasons, with lower levels in autumn than in winter (confounding factors). Hypoxia-resistant priapulids were more common in stomachs from plaice caught in autumn, likely because a part of these stomachs comes from areas with severe hypoxia. The data on stomach contents indicate that plaice are performing excursions between areas or depths of different levels of hypoxia - a part of them probably feeds in severe hypoxia and returns to moderate hypoxia / normoxia to digest and recover, like it seems to be the case for cod in the eastern Baltic Sea. Fish discarded to hypoxic waters had a more severe stress response and a prolonged recovery period but recovered their measured biochemical indicators and oxygen consumption rates to pre-stress conditions within 24h, with no stress-related mortalities. Fish that were exposed to trawl simulation and discarded to hypoxic conditions showed no indications of trying to escape oxygen-poor conditions. Instead, they all burrowed in the sediment immediately following release. It remains unequivocal whether simulated trawl exerts the same magnitude of stress as experienced during commercial fishing.

An additional variable contributing to post-catch mortality may be the damage to the intestine during the catch and sorting processes due to sharp shell fragments in situations where plaice are feeding heavily on mussels. The sampled plaice were considered individual specialists, which means that the individual prey type in general is consumed only by a moderate part of the plaice and amounts to a significant part in the stomachs in which it occurs. There were fewer prey categories in wintertime (amphipods and mysids were missing), which is not surprising. There was no visible relationship between survival and shell content[3].

The common way to estimate survival rates is to observe in captivity fish that would be discarded under commercial conditions, until the mortality levels off. Such captive observation studies are labor-intensive, logistically challenging, and financially demanding. As an alternative, measures of impairment in fish condition can be used as an indicator for discard survival providing that they are calibrated with survival likelihood estimates from, e.g., captive observation studies. Promising indicators of fish condition as good survival proxies are external damages and reflexes (scoring the presence or absence of pre-determined attributes) pooled into an index. The optimization procedure aimed at finding the weighing of the reflex and injury attributes into the index (usually fixed to 0.1) with the best predictive performance. Bruising in the head and body were the most important contributors to the survival probability of discarded plaice with 90 and 95% of the best models showing coefficients higher than 0.10. Overall, none of the individual reflex or injury indicators were independent of

[2] With running water in the hopper

[3] Winter data

biological, environmental, technical, and operational covariates when predicting plaice discard survival, both at fish and trip levels. The best models (based on AIC) for each vitality indicator all included the interaction between air exposure and sea temperature. The optimized index did not improve predictions markedly as both the reflex impairment and injury index as well as the less labour-intensive categorical vitality score were almost equally valuable proxies of plaice discard survival. When we compare observed and predicted survival ratio for each trip in the context of management purposes, i.e., assessing whether the survival ration is high, all vitality indicators could correctly predict high (>0.50) or low (<0.50) survival except for one trip.

In contrast to traditional (frequentist) methods previously used in our survival studies, the Bayesian network model approach can integrate expert knowledge regarding life-history traits and the prevailing operational, environmental, and biological conditions of fisheries to predict survival probability after release. This expert system may be suitable as a low-cost decision support tool for fisheries managers. The classification error of the ensemble approach was much lower than fitting a single naive Bayes model on multiple trips simultaneously or from causal network learned from data. Discretising all variables into three levels appeared to be a good trade-off between predictive accuracy, model complexity and predictive accuracy. Introducing the individual reflexes and injuries did not improve the predictive accuracy of the model. We also built an operational Bayesian Belief Network (BNN) model to estimate post-release survival potential of discarded plaice. The BBN model was constructed from a combination of historical data and subject matter expert knowledge. The typical user case would be to identify species-fisheries for which it would be meaningful to collect scientific documentation for a high survival exemption in the context of the CFP. The model output indicates the probability of a survival rate above 50% and can be used as a relative score to compare different scenarios.

While obtaining discard survival estimates have been a main aim of most studies for advisory purposes, investigations on factors affecting the survival rates have been made in parallel to reduce the need for demanding capture observation studies, and at the same time achieve more robust discard survival estimates and to inform how fishing operations can be changed to improve survival rates. Investigations on how various factors influence discard survival could to a higher degree be performed under controlled conditions in the laboratory. The link between observed vitality, reflex impairment, external damages, and survival, is still not well understood, specifically with respect to how quickly (or slowly) fish are able to recover from the capture process.

Sammendrag

Reformen af EU' Fælles Fiskeripolitik i 2013 har ført til betydelige ændringer i fiskeriforvaltningen. En af ændringerne er en forpligtelse til at lande alle fangster fra regulerede bestande, dvs. et forbud mod at smide uønsket fangst tilbage i havet. Målet med landingsforpligtelsen er at fremme et mere selektivt og målrettet fiskeri, der mindsker uønsket bifangst.

Ifølge reglerne er der mulighed for at sætte fisk tilbage i havet i stedet for at lande dem, hvis det kan påvises videnskabeligt, at der er en høj overlevelsesrate i det specifikke fiskeri. Kriteriet for hvad der regnes som "høj" er dog ikke fastsat og evalueres for hver enkelt sag af EU. Denne rapport præsenterer DTU Aquas undersøgelser af overlevelsen hos rødspætter (*Pleuronectes platessa*) under mindste reference størrelsen (mindre end 27 cm i fiskeriet i Nordsøen og Skagerrak og under 25 cm i Østersøen). Rødspætterne er fanget med trawlredskaber i det kommercielle demersale fiskeri til menneskeligt konsum.

Arbejdet har haft fokus på
- at estimere overlevelsesrater med det formål at opnå undtagelse fra landingsforpligtelsen,
- at forbedre viden om, hvordan operationelle, miljømæssige og biologiske stressfaktorer påvirker overlevelsesraten hos fisk, der sættes tilbage i havet efter at være blevet fanget,
- at udforske muligheden for at skabe robuste estimater over overlevelsen ved hjælp af metaanalyse,
- at undersøge effekten af miljøet (temperaturen) på forringelsen i fiskens reflekser,
- at udvikle og teste ydeevnen af et optimeret refleks- og skadesindeks,
- at anvende ekspertviden (Bayesian-modellering) til at forudsige overlevelsen ved udsmid.

Undersøgelserne omfatter tre fiskeri flåder: det danske fiskeri med snurrevod og bundtrawl[4] i Skagerrak, Kattegat og Nordsøen (ICES-område 3a og 4) og det danske fiskeri med bundtrawl i Østersøen (ICES-område 22-25). Som krævet i den fælles fiskeripolitik har vurderingen af overlevelsen taget hensyn til redskabets karakteristika (redskabstype og design), fiskemetoder (målarter, sæsonvariation og håndtering) og økosystemet (f.eks. risikoen for at skaldyr kan skade fiskene under fangst eller områdespecifikke variationer i iltforholdene i Østersøen).

Undersøgelserne fandt følgende overlevelsesrater i forskellige situationer:
- I et konservativt scenarie, dvs. i en årstid (august-oktober), hvor vandet er varmt i Skagerrak, var overlevelsen 44% efter udsmid i det demersale blandede fiskeri med bundtrawl med en 90 mm fangstpose og et 120 mm SELTRA-panel (95%-konfidensinterval: 37%-52%).
- Sammenlignet hermed var overlevelsen 78% (95%-konfidensinterval: 67%-87%) i det danske snurrevodfiskeri, som foregik samtidig.
- Overlevelsesraten i bundtrawlsfiskeriet efter rødspætter forbedrede sig til 75% (95%-konfidensinterval: 67%-83%), når vandet var koldere (marts).
- Når der blev fisket efter jomfruhummer (*Nephrops norvegicus*), var overlevelsesraten om vinteren reduceret til 40% (95%-konfidensinterval: 28%-57%) på grund af flere skader på rødspætterne, når de blev fanget sammen med jomfruhummere.
- Når vi ændrede designet til en opdelt fangstpose, der adskiller fisk fra jomfruhummere, var overlevelsesraten for rødspætter højere med et gennemsnit på 94% (95%-konfidensinterval: 81%-100%) ved fangst sammen med fisk i den øverste del af redskabet end ved fangst i den nedre del sammen med jomfruhummere (61%, 95%-konfidensinterval: 48%-73%), eller når rødspætterne blev blandet med jomfruhummere i standardredskabet. Antallet af individer var dog lavt på grund af den høje selektivitet i fiskedelen af redskabet.

[4] Disse to redskabstyper bruges sammen, men har meget forskellige fiskeprocesser.

- De laveste estimater på overlevelse efter udsmid blev observeret ved fiskeri efter rødspætter i Østersøen med snurrevod i den varme årstid (efterår). En forsinket overlevelsesrate på kun 27% (95%-konfidensinterval: 9%-55%) blev opnået ved fiskeri med T90, og 14% (95%-konfidensinterval: 4%-29%) ved brug af Bacoma. I årstider med koldt vand (november til april)[5] var overlevelsesraten 87% (95%-konfidensinterval: 82%-92%).

På baggrund af projektets resultater, gav EU-Kommissionen i 2018 en helårlig undtagelse med høj overlevelse for rødspætter fanget i det danske snurrevodsfiskeri i Skagerrak og Kattegat (ICES-område 3a) og Nordsøen (ICES-subområde 4; EU, 2018, §16) gældende fra 2019. Fiskeriet med bundtrawl fik samtidig en undtagelse for landingsforpligtelsen for rødspætter i vintersæsonen (EU, 2018, §17). Denne undtagelse er senere blevet udvidet til flere maskestørrelser og redskabsdesign. I Østersøen kunne overlevelsen observeret i vores undersøgelse betragtes som "høj" for rødspætter om vinteren, hvilket er i overensstemmelse med undersøgelser (Kraak et al., 2018) i de tyske blandede demersale fiskeri med bundtrawl i ICES-område 22. Dog besluttede den regionale forvaltningsgruppen BALTFISH ikke at inkludere en undtagelse fra landingsforpligtelsen i dette tilfælde i den fælles anbefaling.

Vi undersøgte også effekten af iltniveauet ved fangsten på dødeligheden hos rødspætterne. Iltniveauerne varierede efter årstiden med lavere niveauer om efteråret end om vinteren. Om efteråret var pølseorme (Priapulida), som kan tåle lave iltniveauer, mere almindelige i maverne fra de rødspætter, der blev fanget – sandsynligvis fordi en del af rødspætterne kom fra områder med alvorlig iltmangel. Data for maveindholdet indikerer, at rødspætter flytter sig mellem områder eller dybder med forskellige niveauer af ilt. En del af dem søger sandsynligvis føde i områder med alvorlig iltmangel og vender tilbage til områder med moderat iltmangel eller normalt iltindhold for at fordøje og komme sig, ligesom det synes at være tilfældet for torsk i Østersøen. Fisk, der blev sat tilbage i farvande med iltmangel, havde en mere alvorlig stressrespons, og det tog længere tid for dem at komme sig, men inden for 24 timer var de biokemiske indikatorer og evnen til at optage ilt tilbage på samme niveau, som før de blev fanget, og der var ingen stress-relaterede dødsfald. Fisk, der blev udsat for en simuleret fangst i trawl og sat ud i vand med iltmangel, viste ikke tegn på at forsøge at undslippe de iltfattige forhold. I stedet gik de alle ned i sedimentet umiddelbart efter udsætningen. Det er uklart, om simuleret trawlfiskeri udøver samme grad af stress, som fisken vil opleve under kommercielt fiskeri.

En yderligere faktor, der bidrager til dødeligheden efter fangst, kan være skader på tarmen under fangst- og sorteringsprocessen. Det kan skyldes skarpe dele fra skaller, når rødspætterne har spist muslinger. I undersøgelsen var der ingen synlig sammenhæng mellem overlevelse hos rødspætterne og skalindhold i maverne[6]. Hos de rødspætter, der indgik i undersøgelsen, kunne man se, at de er individuelle specialister i fødesøgning, dvs. at hver type byttedyr generelt kun bliver spist af en moderat del af rødspætterne, men udgør en betydelig del af indholdet i maverne, hvor den forekommer. Der var færre kategorier af byttedyr om vinteren (amfipoder og mysider manglede), hvilket ikke er overraskende.

Den almindelige måde at estimere overlevelsesrater på er at observere fisk i fangenskab, som ville blive kasseret under kommercielle forhold, indtil dødeligheden flader ud. Sådanne studier er arbejdskrævende, logistisk udfordrende og dyre. Som et alternativ kan målinger af forringelser i fiskens tilstand bruges som indikator for overlevelse ved udsmid. Det forudsætter, at indikatorerne kalibreres med overlevelsesestimater fra f.eks. observationsstudier i fangenskab. Lovende indikatorer for fisks tilstand, som er gode til at forudsige overlevelseschancen, er reflekser og udvendige skader. Der gives point for tilstedeværelse eller fravær af forudbestemte markører, og resultatet samles i et indeks.

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[5] Med rindende vand i pounderen.

[6] Vinterdata.

DTU Aqua har arbejdet med at optimere vægtning af refleks- og skadesmarkørerne i indekset (normalt fastsat til 0,1) for at få den bedste forudsigelse. Blå mærker på hoved og krop er de markører, der havde størst betydning for chancen for at overleve hos rødspætter, der skal smides tilbage i havet. De bedste modeller inkluderede altid en forbindelse mellem fiskens udsættelse for luft og havvandstemperaturen, uanset hvilken indikator der blev undersøgt. Det optimerede indeks forbedrede ikke forudsigelser markant, da både reflekssvækkelse og skadesindeks samt den mindre arbejdsintensive kategoriske vitalitetsscore var næsten lige så værdifulde proxyer for overlevelse af rødspætteudsmid. Når vi sammenligner observeret og forudsagt overlevelsesratio for hver tur i forbindelse med ledelsesformål, dvs. vurderer, om overlevelsesrationen er høj, kunne alle vitalitetsindikatorer korrekt forudsige høj (>0,50) eller lav (<0,50) overlevelse undtagen for en tur.

I modsætning til traditionelle metoder (baseret på hyppighedsgrad), der blev brugt i vores overlevelsesstudier, kan en Bayesian-netværksmodeltilgang integrere ekspertviden om livshistorietræk og de operationelle, miljømæssige og biologiske forhold i fiskeriet og på den måde forudsige sandsynligheden for, at fisken overlever efter at være sat tilbage i havet. Dette ekspertsystem kan være egnet som et omkostningseffektivt beslutningsstøtteværktøj for fiskeriforvaltere. Inddragelse af information om fiskenes individuelle reflekser og skader forbedrede ikke modellens nøjagtighed. Vi udviklede også en operationel Bayesian Belief Network (BNN)-model til at estimere overlevelsespotentiale for rødspætter, efter at de er smidt tilbage i havet. BBN-modellen blev konstrueret ud fra en kombination af historiske data og viden fra eksperter. Den typiske anvendelse vil være at identificere arts-fiskerier, hvor det ville være meningsfuldt at indsamle videnskabelig dokumentation for høj overlevelse for at kunne få en undtagelse for landingsforpligtelsen i Den Fælles Fiskeripolitik. Outputtet fra modellen angiver sandsynligheden for en overlevelsesrate over 50% og kan bruges som en relativ score til at sammenligne forskellige scenarier.

Selvom hovedformålet med rapporten har været at fremlægge skøn over overlevelsen hos rødspætter efter udsmid, har vi parallelt undersøgt faktorer, der påvirker overlevelsesraten. Formålet med disse supplerende undersøgelser har været at reducere behovet for krævende observationsstudier af fisk i fangenskab, at få mere robuste skøn over overlevelsen og at få viden om, hvordan fiskeriet kan ændres for at forbedre overlevelsesraterne. Undersøgelser af, hvordan forskellige faktorer påvirker overlevelsen efter udsmid, kunne i højere grad udføres under kontrollerede forhold i laboratoriet. Sammenhængen mellem observeret vitalitet, refleksnedsættelse, ydre skader og overlevelse er stadig ikke godt forstået, især med hensyn til hvor hurtigt (eller langsomt) fisk er i stand til at komme sig efter at være blevet fanget.

1. Background

1.1. Introduction

The reform of the European Union (EU) Common Fisheries Policy (CFP) in 2013 has introduced a substantial change to fisheries management, including a phased introduction from 2015 to 2019 of an obligation to land all catches taken from regulated stocks. The aim of this landing obligation is to end the wasteful practice of discarding by encouraging the fishermen to avoid unwanted catches and improve the selectivity of their fishing processes. The transition from landing quotas to catch quotas lowers the quota value and increases the risk of choke-species, i.e., saturation of low-quota species that prevent the use of other, higher-quota species if the low-quota species cannot be avoided. However, article 15 paragraph 4b of the CFP regulation (EU) No 1380/2013 allows for the possibility of returning at sea species for which scientific evidence demonstrates high survival rates (EU, 2013). Such exemptions aim at reducing the risk under the European landing obligation of bringing onshore individuals that may otherwise survive the capture-and-discard process.

Central to any proposal for an exemption is the requirement for clear and defensible scientific evidence on discard survival rates. The survival rate needs, according to the CFP regulation, to consider "the characteristics of the gear, of the fishing practices and of the ecosystem". In a case-by-case approach, the Scientific, Technical and Economic Committee for Fisheries (STECF) evaluates survival estimates in the context of the fishery seeking an exemption, especially regarding the habitat, season, and handling practices as well as the implications an exemption may have for a given fish stock by evaluating the amount of discard and the discard ratio in the fishery (Bailey *et al.*, 2018; STECF, 2017).

The opportunity of getting high survival exemptions from the landing obligation has led to increasing requests from managers and the fishing industry throughout Europe for research on discard survival to obtain survival estimates for specific species, fishing gears, and fishing areas. The studies presented in this report aim at providing survival estimates for European plaice (*Pleuronectes platessa*, hereafter referred to as plaice) in different Danish fisheries and understanding how different stressors affect discard survival as well as developing methodology to aid future investigations. Specifically, the studies have focused on the following research aspects:

i) Estimation of survival rates with the aim of scientifically documenting survival to support requests for exemptions from the landing obligation.

ii) Improving our understanding of how operational, environmental, and biological stressors affect discard survival.

iii) Exploring the opportunity to create robust discard survival estimates from meta-analysis.

iv) Investigating the effect of the environment (temperature) on reflex impairment.

v) Developing and testing the performance of an optimized reflex and injury index.

vi) Using expert knowledge to predict discard survival.

1.2. High survival exemption process and advice

The scientific evidence supporting each request for exemption is based on data collected in a fishery-specific study and is delivered as scientific advice to the respective member state managers (Figure 1). The proposed exemptions need to achieve agreement in a High-Level Group composed of managers from all the member states surrounding the water body in which the respective fishery is conducted. Relevant for the work presented in this report is the Scheveningen Group, which is the High-Level Group for the Skagerrak, Kattegat, and North Sea areas, and BALTFISH, which is the High-Level Group for the Baltic Sea. Details of proposed exemptions under the high survival provision are then provided by regional managers in Joint Recommendations for amendment in multiannual or discard plans. After consulting the regional Advisory Group for the North (Skagerrak and Kattegat sub-group) or Baltic Seas, the Joint Recommendations are submitted to the European Commission (EC). Consultations between the Directorate-General for Maritime Affairs and Fisheries (DG MARE), STECF and the High-Level Group follows and proposals approved by the EC are enacted as a Commission Delegated Regulation. The Delegated Regulations are reviewed triennially. Some of the exemptions may be issued with special conditions such as providing further scientific evidence for a continued exemption to be approved.

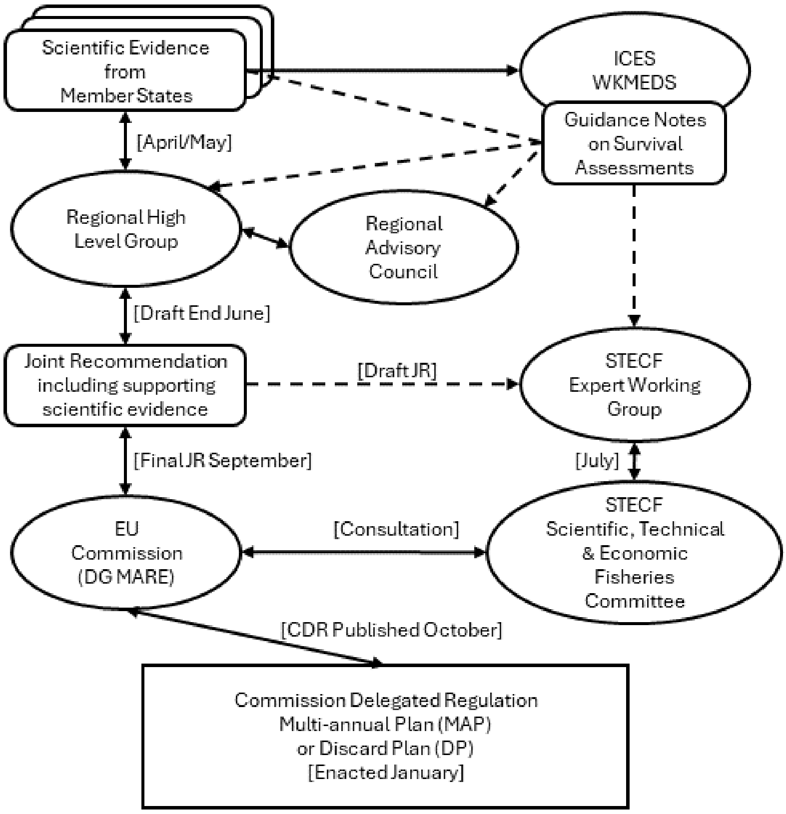

Figure 1. The process of requesting a high survival exemption from the landing obligation with approximate timeline (from Viva et al., 2016).

The level at which survival is considered ‘high’ is not defined in the CFP. It involves trade-offs between different management and societal objectives prioritized for a given fishery at a given time (Rihan *et al.*, 2019). Although ‘high survival’ implies that a larger proportion of a species survives than dies, exemption has been granted in cases where the survival rate is less than 50% (Rihan *et al.*, 2019). STECF recommends that the underlying evidence supporting the request for exemption should include i) a description of the stock of the species (see 1.5) and the fishery (e.g., vessel characteristics of the fishing fleet, seasonal catch patterns, and discard rates; see 1.6) for which the exemption is being sought; ii) a description of how representative the survival data are for the fishery (see 2.8); and iii) a description of the available scientific evidence on discard survival rates relevant to the fishery (see 2.8; STECF, 2015).

For the cases studies presented in this report, the EC granted a year-round high survival exemption for plaice caught in the Danish seine fishery in Skagerrak and Kattegat (ICES Division 3a) and North Sea (ICES Subarea 4; EU, 2018, §16; EU, 2019b, §19). The bottom otter trawl fishery (OTB, PTB) with a mesh size of at least 120 mm when targeting fish was granted an exemption for the winter season (1 November to 30 April) in the same areas (EU, 2018, §17, Article 6(1b); EU, 2019b, §20). Both exemptions were granted for the period 2019-2021. In 2019 the regulation was corrected to include the trawl category OTT (EU, 2019a, Article 1(2)). The exemptions for both gear types remained in the subsequent evaluation for the period 2021-2023 (EU, 2020, §14-§15).

In 2019, an exemption for plaice caught in trawl fisheries during the summer as well as for a larger range of mesh sizes, i.e., including at least 90-99 mm equipped with a SELTRA panel in Skagerrak and Kattegat (ICES Division 3a) and at least 80-99 mm in the North Sea (ICES Subarea 4), was granted for one year (2020-2021) with the opportunity to collect more evidence by 1 May 2020 (EU 2019b, §25-§26; Article 6(2)). The exemption for the summer months was not extended, but sufficient evidence was provided for the 2021-2023 period to extend the exemption to include mesh size of 90 to 119 mm equipped with SELTRA panel with a top panel of 140 mm mesh size (square mesh), 270 mm mesh size (diamond mesh) or 300 mm mesh size (square-mesh) in Skagerrak and Kattegat, and mesh size of 80 to 119 mm in the North Sea (EU 2020, §15, Article 6(1cii-iii)). In 2021, the trawl exemption was further broadened to use square mesh panels of at least 120 mm in Kattegat in the period 1 October to 31 December (EU, 2021, §5, Article 1(1)). The exemptions are being evaluated in 2023 for the next period 2023-2025.

For the Baltic Sea, the High-Level Regional Group BALTFISH decided not to include a request for high survival exemption for plaice in the Joint Recommendation.

1.3. Species catalogue of discards for fisheries involving flatfish

When receiving requests for high survival exemptions from the CFP landing obligation, STECF is evaluating the survival estimates in relation to the amount of discard of the given species in the given fishery. It is typically evaluated in two complementary ways; i) the absolute amounts of discards given for example in weight, and ii) the discard ratio, i.e., the proportion of fish discarded of the total landed over a given time period (e.g., annually). A fishery may have a large amount of discard, but when seen in relation to the total catch, the discard ratio may be low. Similarly, a fishery may have a high discard ratio, but if the catches are small, the absolute amount of discard measured in weight may be low.

A species catalogue including both discard measures (absolute amount and discard ratio) was established for the most important flatfish species, brill (*Scophthalmus rhombus*), common dab (*Limanda limanda*), European flounder (*Platichthys flesus*), lemon sole (*Microstomus kitt*), plaice, common sole (*Solea solea*), turbot (*Scophthalmus maximus*), and witch flounder (*Glyptocephalus cynoglossus*) caught in the fishing areas Skagerrak (ICES Subdivision 20), Kattegat (ICES Subdivision 21), and the North Sea (ICES Subarea 4; Supplementary material A). The aim of the catalogue was to facilitate the management evaluation of the implications a potential high survival exemption for a given species and fishing fleet (active or passive gear type, mesh size, and target catch) would have on the associated fish stock. For each species, discard survival estimates from studies reported in the literature in 2018 or earlier were included, but additional discard survival rates have been estimated for several species in recent years (e.g., common sole, Oliver *et al.* 2019; plaice, Savina *et al.*, 2019; Noack *et al.*, 2020), including other animal groups such as roundfish (European seabass, *Dicentrarchus labrax*, Randall *et al.*, 2021; Atlantic cod *Gadus morhua*, Oliver *et al.*, 2022), elasmobranchs (e.g., undulate ray, *Raja undulata*, Morfin *et al.*, 2019; sharks, Hutchinson *et al.*, 2022), and invertebrates (e.g., *Asterias rubens*, *Atelecyclus undecimdentatus*, *Aphrodita aculeata*, *Buccinum undatum*, *Maja brachydactyla*, and *Pagurus* sp., Boussarie *et al.*, 2020; *Nephrops*, Fox *et al.*, 2020; *Cancer pagurus*, Rodrigues *et al.*, 2021). Also, a qualitative assessment and ranking of species according to their robustness, where higher robustness means a higher chance to survive the capture and discard processes, and discard amounts was included in the species catalogue (Table A.14 in Supplementary material A).

1.4. Choice of the species and Danish fisheries to be investigated

At the onset of the discard survival investigations in 2017, the identification of which species, fishing gears, fishing areas, and seasons to include in the case studies was done in collaboration with managers and the Danish Fishermen Producer Organisation (DFPO). Based on the importance of the fishery in terms of the level of landings and absolute discards and expected resilience to the catching and handling process as suggested from the literature and the experience of the fishers, it was decided to focus on flatfish species. The managers and DFPO identified four candidate species for which potential high survival exemptions from the landing obligation were relevant. In order of priority, these were: plaice, common sole, lemon sole, and common dab. Both stakeholders gave the highest priority to plaice, which was selected as the study species.

Plaice was an important target species in Danish fisheries for human consumption throughout Danish waters in 2017 and still is (DFPO, 2018, 2023). Plaice has no swim bladder and is considered robust with respect to surviving the fishing process, partly due to its sedentary lifestyle that has evolved towards enhanced metabolic adaptation to hypoxia (Benoît *et al.*, 2013; Morfin *et al.*, 2017a, b). It therefore was as a good candidate species for investigating discard survival.

It was further decided to conduct the experiments on discard survival in the demersal trawl fishery as this is capturing high amounts of plaice. Furthermore, the industry requested to conduct parallel studies for the Danish seine fishery. Here, fish is caught towards the end of the catching process (Noack *et al.*, 2019), and so was likely to obtain a higher discard survival compared to trawl fisheries. The strategy was to choose the most hazardous operational and environmental conditions during the experiments to investigate discard survival in a “worst-case” scenario as high survival rates under these conditions would also be valid for less stressful conditions.

The experiments in the Danish seine (Case study 1) and bottom otter trawl (Case study 2) fisheries were conducted in Skagerrak (ICES Subdivision 20) in 2017-2018, and for the bottom otter trawl fishery, experiments (Case study 3) were extended to the Western Baltic Sea (ICES Subdivision 24) in 2020-2021 (Table 1; Figure 2).

Table 1. Naming structure of the fishing areas relevant for the experimental Case studies and the associated exemptions from the landing obligation defined by Food and Agriculture Organisation of the United Nations (FAO) (FAO, 2023). This structure of fishing areas is also a basis for ICES advisory areas.

Fishing area	Geographical area
Area 27	Northeast Atlantic
Subarea (27) 3	Skagerrak, Kattegat, Sound, Belt Sea, and Baltic Sea
Division (27) 3a	Skagerrak, Kattegat
Subdivision 20	Skagerrak
Subdivision 21	Kattegat
Division (27) 3d	Baltic Sea
Subdivision 24	Western Baltic
Subarea (27) 4	North Sea

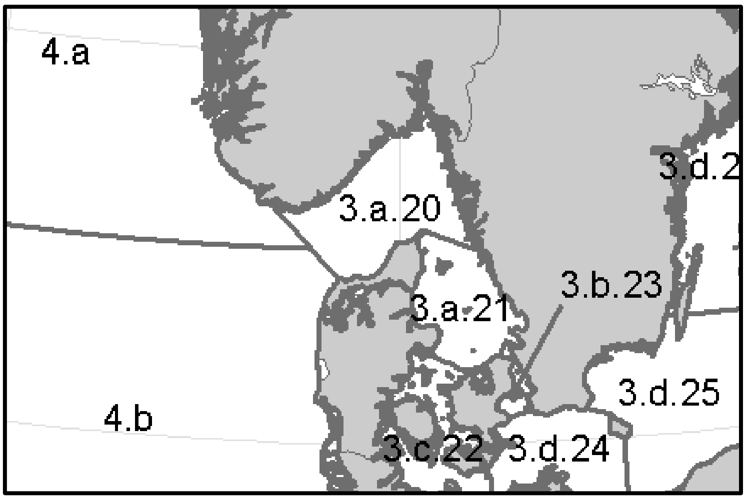

Figure 2. Map of ICES Subarea 4 (North Sea) divided into Division 4a (Northern North Sea) and Division 4b (Central North Sea), and ICES Subarea 3 divided into Divisions of which Division 3a (Subdivision 20, Skagerrak; and Subdivision 21, Kattegat) and Division 3d (Subdivision 24) are relevant for the conducted discard survival studies (adapted from ICES area maps, 2016).

1.5. Plaice stock status

When high survival exemptions from the landing obligation are granted for a given species and fishery, individuals under Minimum Conservation Reference Size (MCRS) may be returned to their stock. The level of discard survival of plaice presented in the scientific evidence is being evaluated in relation to the health of the associated plaice stock and the impact an exemption may have on the stock if granted. It is therefore relevant to present the health of the plaice stocks for the areas in which the Case studies were conducted and additional areas included in the requests for exemptions: Skagerrak and the North Sea; Kattegat, Belt Seas, and Sound; and the Baltic Sea.

1.5.1. Skagerrak and North Sea stock

Plaice in the Skagerrak where Case study 1 and 2 were conducted in 2017-2018, has been assessed together with the North Sea stock since 2015 (ICES Advice, 2018b). Plaice under MCRS were included in the high survival exemptions from the landing obligation both for Skagerrak and the North Sea in 2018. At that time, the stock was considered to have full reproductive capacity and to be sustainably harvested. Fishing pressure on the stock was below FMSY and spawning-stock size is above MSY $B_{trigger}$, B_{pa}, and B_{lim}, and this is also the current stock status (Figure 3, ICES Advice, 2023a and 2023b).

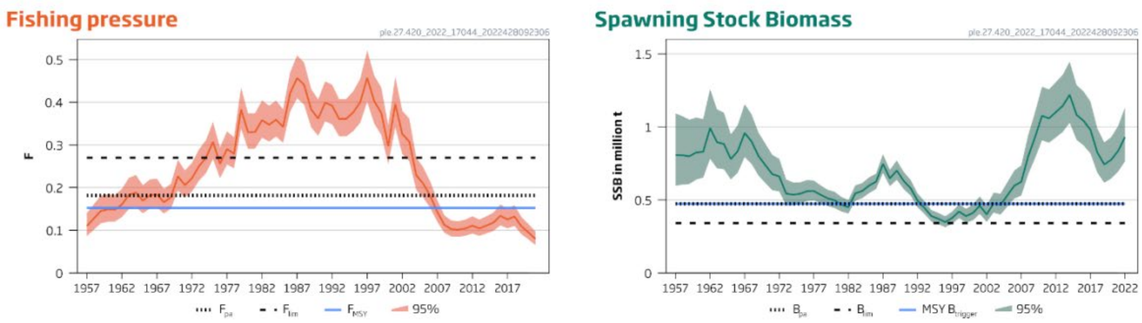

Figure 3. Plaice stock in the Skagerrak and North Sea. Development of the fishing pressure (left) and the spawning stock biomass (right) (from ICES, 2023a).

1.5.2. Kattegat, Belt Seas, and the Sound

Plaice under the MCRS in the Kattegat were included in the high survival exemptions from the landing obligation in 2018 and could therefore be discarded from 2019. The plaice in this area is managed together with plaice in the Belt Seas and the Sound. The stock at the time of the experiment was harvested sustainably and had full reproductive capacity (ICES, 2018), which is also the current stock status (
Figure 4; ICES, 2023b).

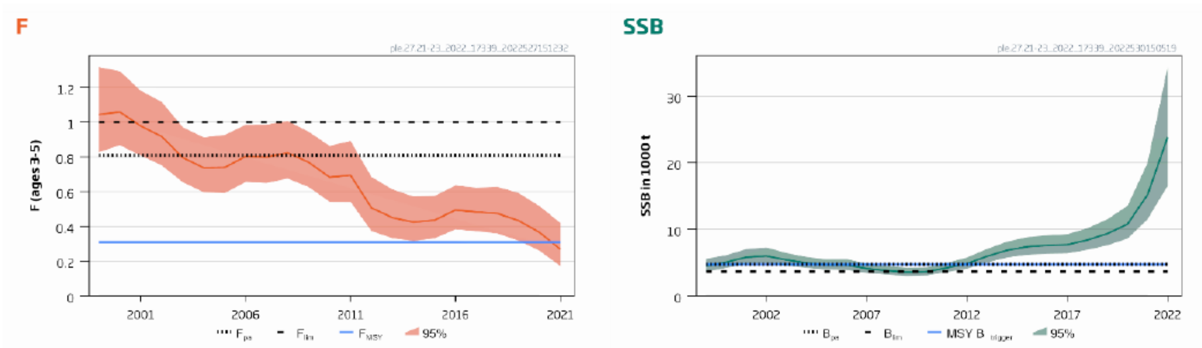

Figure 4. Plaice stock in the Kattegat, Belt Seas, and the Sound. Development of the fishing pressure, F (left) and the spawning stock biomass, SSB (right) (from ICES, 2023b).

1.5.3. Baltic Sea stock

Discard survival of plaice in the Western Baltic Sea (Case study 3) was conducted in Subdivision 24. Plaice in this area is managed together with those in the rest of the Baltic Sea (Subdivisions 25-32). During the discard survival experiments in 2020-2021, the Baltic Sea plaice stock was sustainably harvested. The fishing pressure was below F_{MSY} and spawning-stock size was above MSY $B_{trigger}$ and B_{lim} (Figure 5; ICES, 2023c). The fishery in Subdivisions 24–32 has in recent years changed from being a directed cod fishery to becoming a targeted flatfish fishery. In this area, the plaice stock is experiencing extraordinarily high recruitment pulses from the 2019- and 2020-year classes, which is confirmed from both surveys and commercial catches (ICES, 2023c). Depending on the nature of the demersal fisheries, high catches of plaice below minimum size are to be expected (ICES, 2023c).

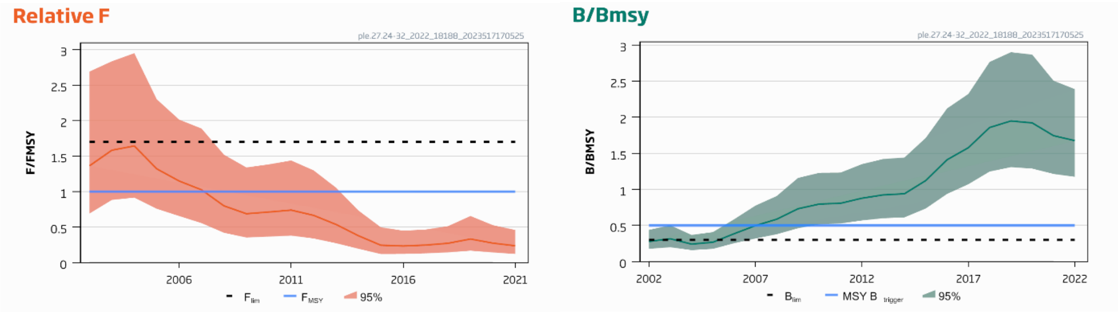

Figure 5. Development in relative fishing mortality, F, of plaice (left) and the plaice biomass (B) (from ICES, 2023c).

In 2022, the landings decreased by nearly 50% compared to 2020 and 2021. This is likely caused by the low fishing opportunities for cod in the eastern Baltic, a fishery in which plaice is caught as by

catch (ICES, 2023c). In the same period, the fishing fleet has been drastically reduced as fishers were offered support from EU funds to permanently decommission their vessels[7].

1.6. Fleet characteristics

The absolute number of discards is higher in fisheries using active fishing gear than those using passive fishing gear due to the higher total catch weights when using active fishing gear. The stakeholders chose to have discard survival investigated for plaice caught by Danish seine (Case study 1), and bottom otter trawl (Case study 2 and 3).

At the onset of the studies in 2017, discard survival of several species had been investigated for different demersal trawl fisheries in other parts of Europe but there were no previous investigations of discard survival in the Danish seine (SDN) fishery. The two fisheries have common technical regulations (Council Regulation (EC) 850/80), which also includes Scottish seine (SSC), but operationally they are very different (Noack *et al.*, 2017). When fishing demersal fish (DEF) with a Danish seine, the fish are being caught in the net at the end of the fishing process (Noack *et al.*, 2019). First, the gear is set by dropping an anchor, laying out the first seine rope, setting the net, laying out the second seine rope and returning to the anchor buoy. Second, the two seine ropes are hauled while the vessel is at the anchor buoy and so herd the fish as the area enclosed by the sein ropes decreases. Third, the netting is hauled towards the vessel to catch the fish. The fish thereby stay in the netting for a relatively short time. It is well known by the fishing industry that this causes less catch damages to the catch compared with a trawl in which fish may stay in the codend for several hours (Karlsen *et al.*, 2015). Consequently, the survival of discarded fish was expected to be different and therefore both fisheries were investigated. Scottish seiners move forwards during the hauling of the seine ropes and is thus considered to be a hybrid between Danish seining and bottom otter trawling (Eigaard *et al*, 2016). The seine ropes (4000-6000 m) are typically shorter than those in Danish seining, and the haul process is generally shorter than for trawling.

In the bottom otter trawl (OTB) fishery in Skagerrak in 2017-2018 (Case study 2), the largest landings were in the mixed crustacean and demersal fish (MCD) segment. Vessels using codends with mesh sizes between 90-119 mm in Skagerrak typically target *Nephrops*, while those using ≥120 mm codends target demersal fish. In the North Sea, the highest landings were from vessels using ≥120

[7] https://oceans-and-fisheries.ec.europa.eu/news/fisheries-eu-reaches-provisional-agreement-reducing-fishing-fleet-baltic-support-eu-funds-2020-09-23_en#share

mm codends, while in the Baltic Sea, bottom otter trawling was done both with ≥120 mm codends (T90) and 105 mm diamond mesh with nominal 120 mm BACOMA panel. A small mesh netting has a larger surface than a large mesh netting and might have a larger mechanical influence on the surface of the fish body during the catch process, especially since codends are commonly made of knotted netting. It was therefore decided to use a 90 mm diamond mesh codend in Skagerrak (Case study 2). In addition, a horizontally divided codend was included. This consisted of a 120 mm square mesh upper compartment and a 60 mm square mesh lower compartment. A previous EFF-project, VærdiFisk (grant no. 33010-12-k-0235), found that the number of damages was significantly reduced if fish was separated from *Nephrops* during the catch process (Karlsen *et al.* 2015). Thus, using this codend could increase the discard survival of fish. Also, as the catch is partly sorted during fishing, sorting time onboard could potentially be reduced. This would be a major advantage since air exposure is a key factor affecting survival (Morfin *et al.* 2017b; van der Reijden *et al.* 2017). In the Baltic Sea in 2020-2021 (Case study 3), both a 120 mm T90 codend and a 105 mm diamond mesh with nominal 120 mm BACOMA panel were investigated.

1.6.1. The Danish seine fleet in Skagerrak (Case study 1)

In 2017 when Case study 1 was conducted, the Danish seine fleet targeting the demersal fish (DEF) counted 22 vessels in Denmark (logbook database 2017). The fleet operating in Skagerrak counted 19 vessels in the size range of 15-32 m (122-681 kW). Of these, 5 vessels in the size range 15-20 m (vessel power 139-381 kW) used mesh sizes smaller than 120 mm, and 18 vessels in the size range 13-32 m (vessel power 122-681 kW) used mesh size equal to or larger than 120 mm. I.e., some vessels altered between gears in the two mesh size categories. The mean length and power of vessels using ≥ 120 mm were 17 m and 203 kW, respectively (Figure 6 and Figure 7). The mean length was similar to that of the vessel used during Case study 1 (16.1 m), but the mean power of the fleet was higher than that of the vessels used in the study (142 kW). The same fleet segment in the North Sea counted eight vessels (size range 18-32 m, power: 139-681 kW), and so some vessels operated in both geographical areas. Of these, only one vessel (18m, 139 kW) used mesh size smaller than 120 mm (Figure 6 and Figure 7). All eight vessels used mesh size equal to or above 120 mm (mean: 20.3 m, 236 kw).

Most of the SDN fishery targeting DEF was conducted with >120 mm mesh size. The fishery in Skagerrak occurs year-round, while in the North Sea it occurs mainly from March-November (Figure 8). The largest catches occurred from May to October in both areas. The proportion of unwanted catch of plaice varied between months but was on average 8% in volume in Skagerrak and 1% in the North Sea (data from the Data Collection Framework database).

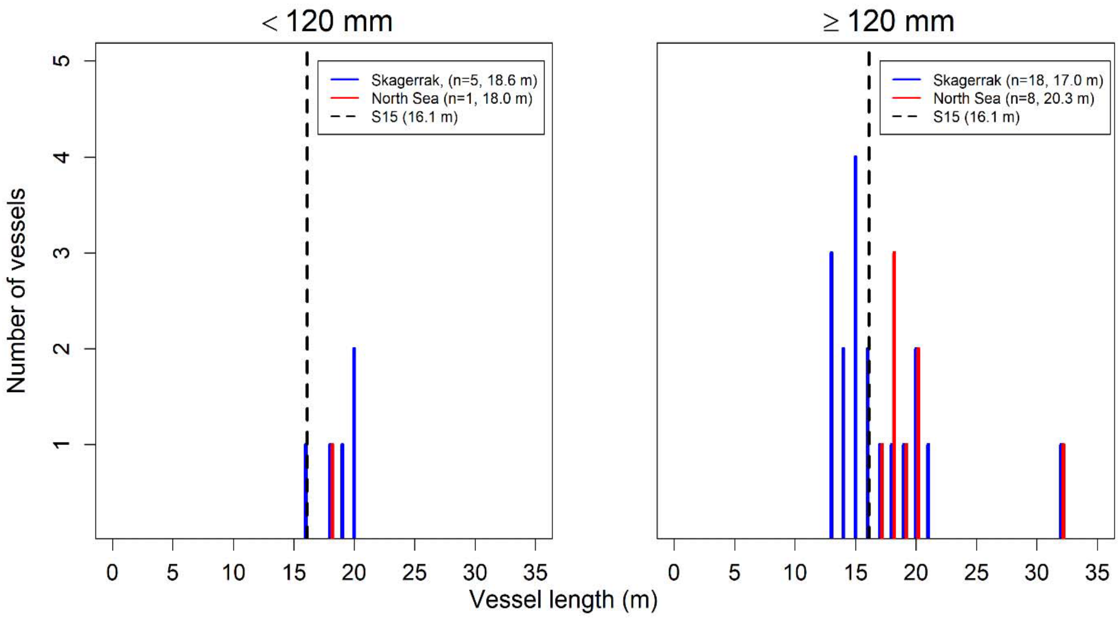

Figure 6. Frequency distribution of vessel size for Danish seiners using meshes smaller than 120 mm (left) and 120 mm or larger meshes (right) for the fleet operating in Skagerrak (blue) and North Sea (red).

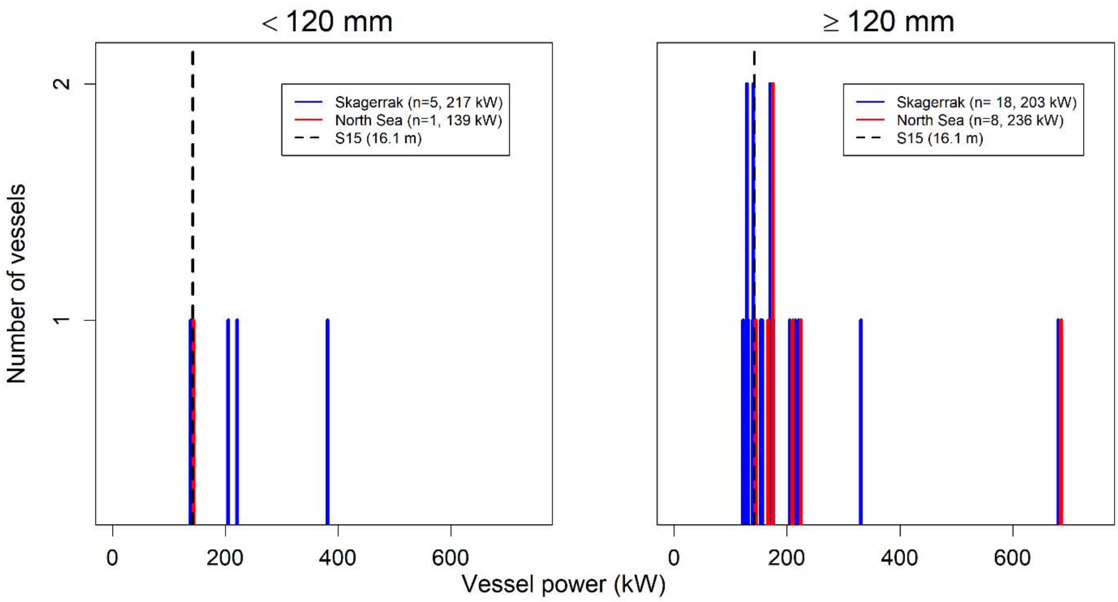

Figure 7. Frequency distribution of the vessel power of the Danish seines using meshes smaller than 120 mm (left) and 120 mm or larger meshes (right) for the fleet operating in Skagerrak (blue) and North Sea (red).

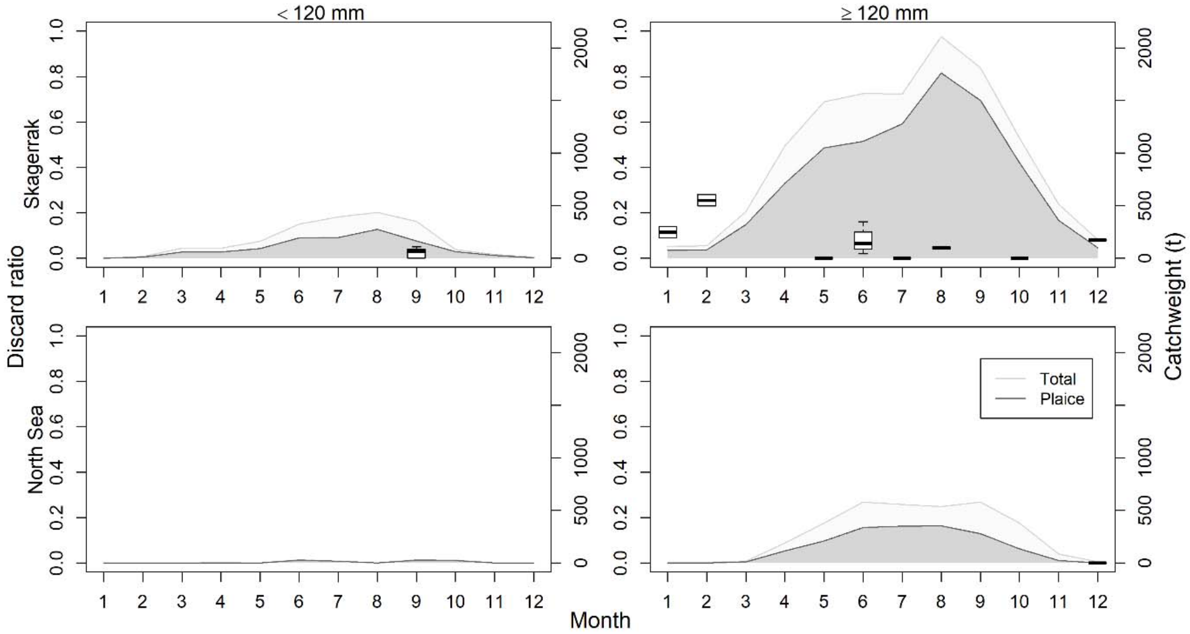

Figure 8. The total landed catch weight in tons (light grey) and landed catch weight of plaice in tons (dark grey) of the Danish seines using meshes smaller than 120 mm (left) and 120 mm or larger meshes (right) for the fleet operating in Skagerrak (upper panels) and North Sea (lower panels) in the period 2015-2017.

1.6.2. Bottom otter trawl fleet in Skagerrak (Case study 2)

In Case study 2, discard survival of plaice caught with OTB was investigated in 2017-2018. The OTB fleet in the Mixed Crustacean Demersal (MCD) fishery in Skagerrak counted 102 vessels in the size range 11.00-19.99 m and power range 67-365 kW (2017, logbook database). The same fleet segment in the North Sea counted only 11 vessels (size and power ranges of 11.00-16.99 m and 126-365 kW, respectively; 2017, logbook database) (Figure 9 and Figure 10).

Plaice and *Nephrops* were caught year-round both in the Skagerrak and the North Sea (Figure 11). In Skagerrak, the largest landings of plaice occurred in the autumn and winter. In the North Sea, the largest landings occurred in the summer but are all year round at least as large as in Skagerrak (Figure 11). Although discard ratios of plaice were usually higher for smaller mesh sizes, i.e., when targeting *Nephrops* in all seasons except for autumn in the Skagerrak (Figure 11), absolute numbers of discarded plaice were usually higher when the proportion of plaice in the total catch is larger, i.e., using larger mesh sizes. The proportion of unwanted catch of plaice was on average 60.4% in volume with 90-119 mm mesh size and 7.4% with >120 mm mesh in the Skagerrak, and 6.4% in volume with 90-119 mm mesh size and 3.4% with >120 mm mesh in the North Sea (data from the Data Collection Framework database in the period 2015-2017).

Fish and *Nephrops* were often caught on separate fishing operations. I.e., when *Nephrops* dominated the catch the proportion of plaice was low and vice versa (Figure 12). This should be highlighted as the presence of *Nephrops* in the catch can increase damages and therefore fish mortality (Karlsen *et al.*, 2015).

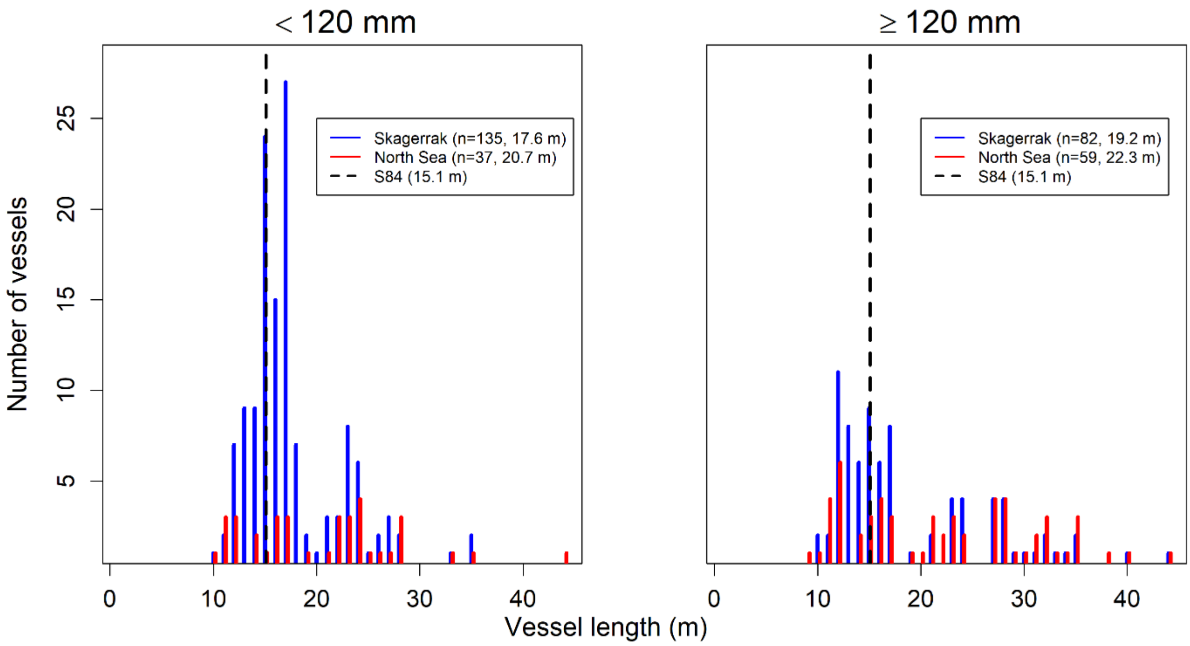

Figure 9. Number of Danish vessels in the OTB fleet by length category in m by area and mesh size (2017, logbook database). The dashed black line represents the length of the vessel used in the experiment (S84). In brackets in the legend is the average vessel length for each area and mesh size.

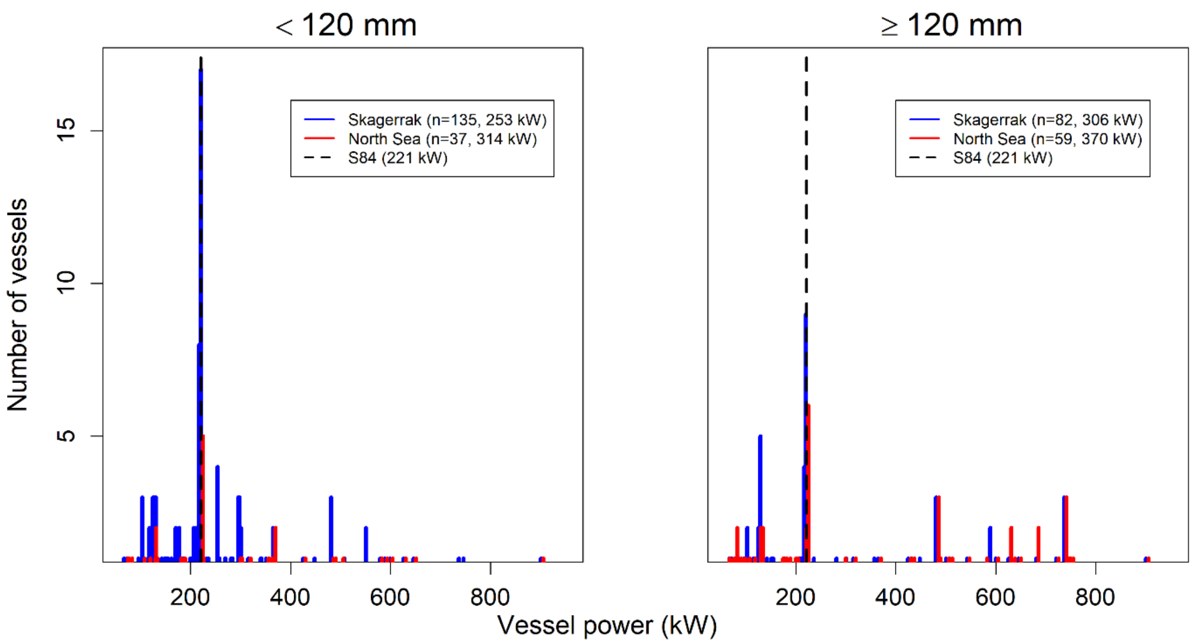

Figure 10. Number of Danish vessels in the OTB fleet by power category in kW by area and mesh size (2017, logbook database). The dashed black line represents the power of the vessel used in the experiment (S84). In brackets in the legend is the average vessel power for each area and mesh size.

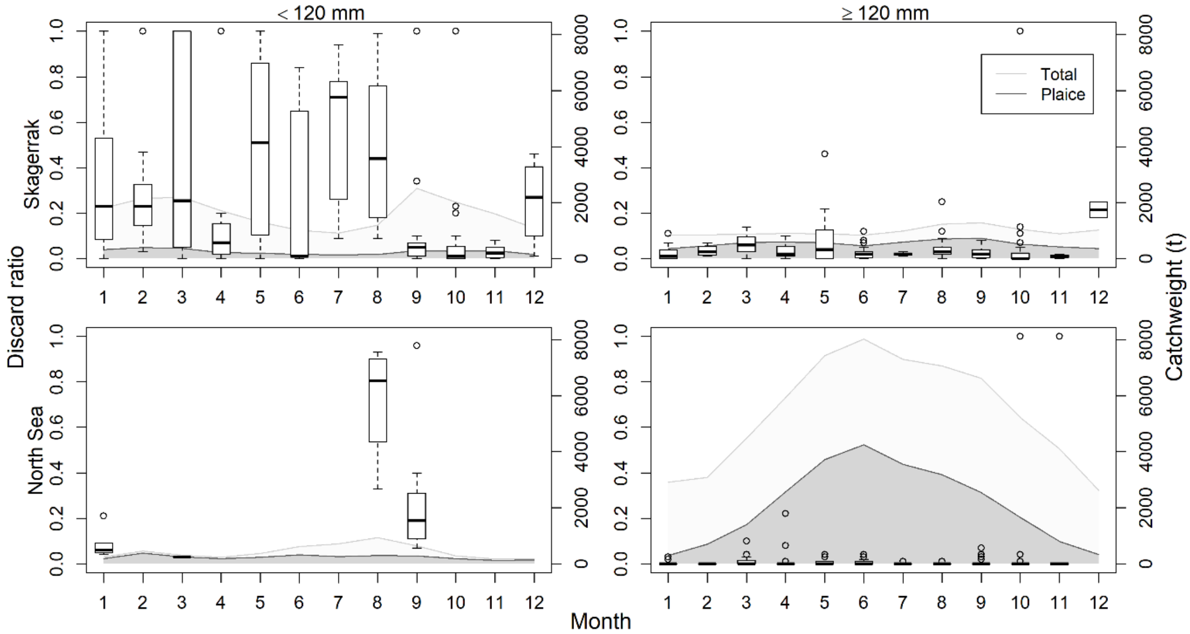

Figure 11. Total landed catch in tons (light grey), plaice landed catch in tons (dark grey) and discard ratio (boxplot) by month for the Danish OTB fleet by area and mesh size (2015-2017, logbook database, Data Collection Framework database).

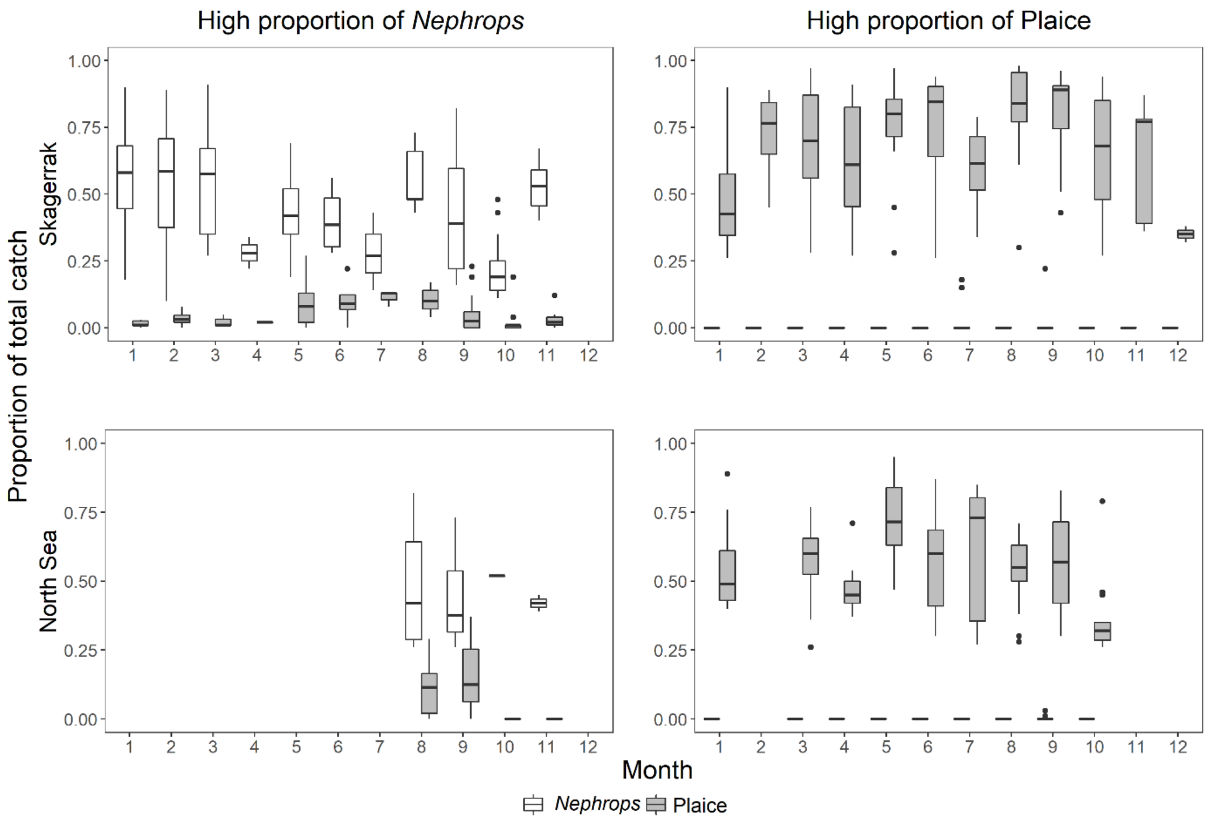

Figure 12. Proportion of plaice and Nephrops in the total catch when targeting plaice (i.e., high proportion of plaice) and Nephrops (i.e., high proportion of Nephrops) by month for the Danish OTB fleet separated by area (2015-2017, logbook database).

1.6.3. Bottom otter trawl fleet in Western Baltic Sea (Case study 3)

Case study 3 was investigating discard survival of plaice caught with OTB in the Western Baltic Sea in 2020-2021. The Danish bottom trawl fleet operating in the Baltic Sea consisted of an average of 90 vessels (range: 89-91) in 2017-2019 but decreased during the years, counting 61 vessels in 2021 (Figure 13, Table 2). The vessels were allocated to the OTB_DEF metier as this was the gear type, they used the most (i.e., highest number of trips). In 2021, almost the entire fleet (97%; n = 59) consisted of vessels shorter than 18 m (Figure 13). Only two vessels were larger.

The vessels were fishing in ICES subdivisions 22-25 (Figure 13), with some vessels fishing in several of these areas. Furthermore, the same vessels may change between trawl gears, e.g., change mesh size or alternate between the Bacoma and T90 gear designs. Both the Bacoma and T90 designs were used in the fishery (Figure 15). The extent of the fishery decreased during the period 2017-2021 (Figure 15).

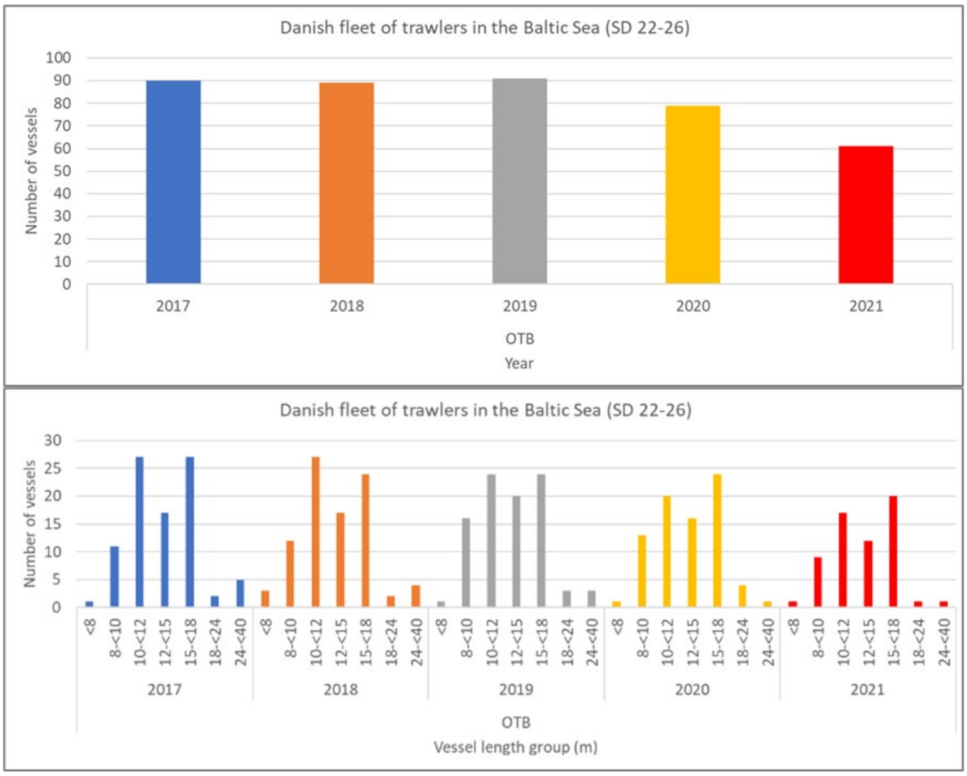

Figure 13. The Danish fleet of otter trawlers that operated in ICES subdivisions 22-26 of the Baltic Sea in the period 2017-2021 (upper panel), and the distribution of these vessels in different length groups (lower panel).

The Danish demersal fishery with active gears in the Baltic is a mixed species fishery with few dominating species; cod (*Gadus morhua*), plaice, flounder (*Platichtys flesus*), and dab. The fleet of active gears includes four seine vessels (see 1.6.4). Table 2 gives a summary of the fishing fleet, including landings, discards, and discard ratios. The main target species in the fishery has been cod with plaice as an important bycatch species.

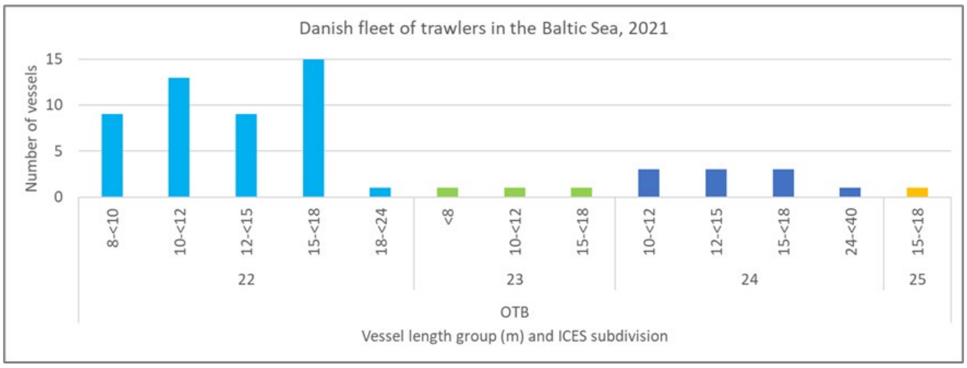

Figure 14. Distribution of the OTB fleet (n = 61) in 2021 given for each vessel length group in subdivisions 22-25; the vessels were allocated to the area in which they have conducted most of their trips.

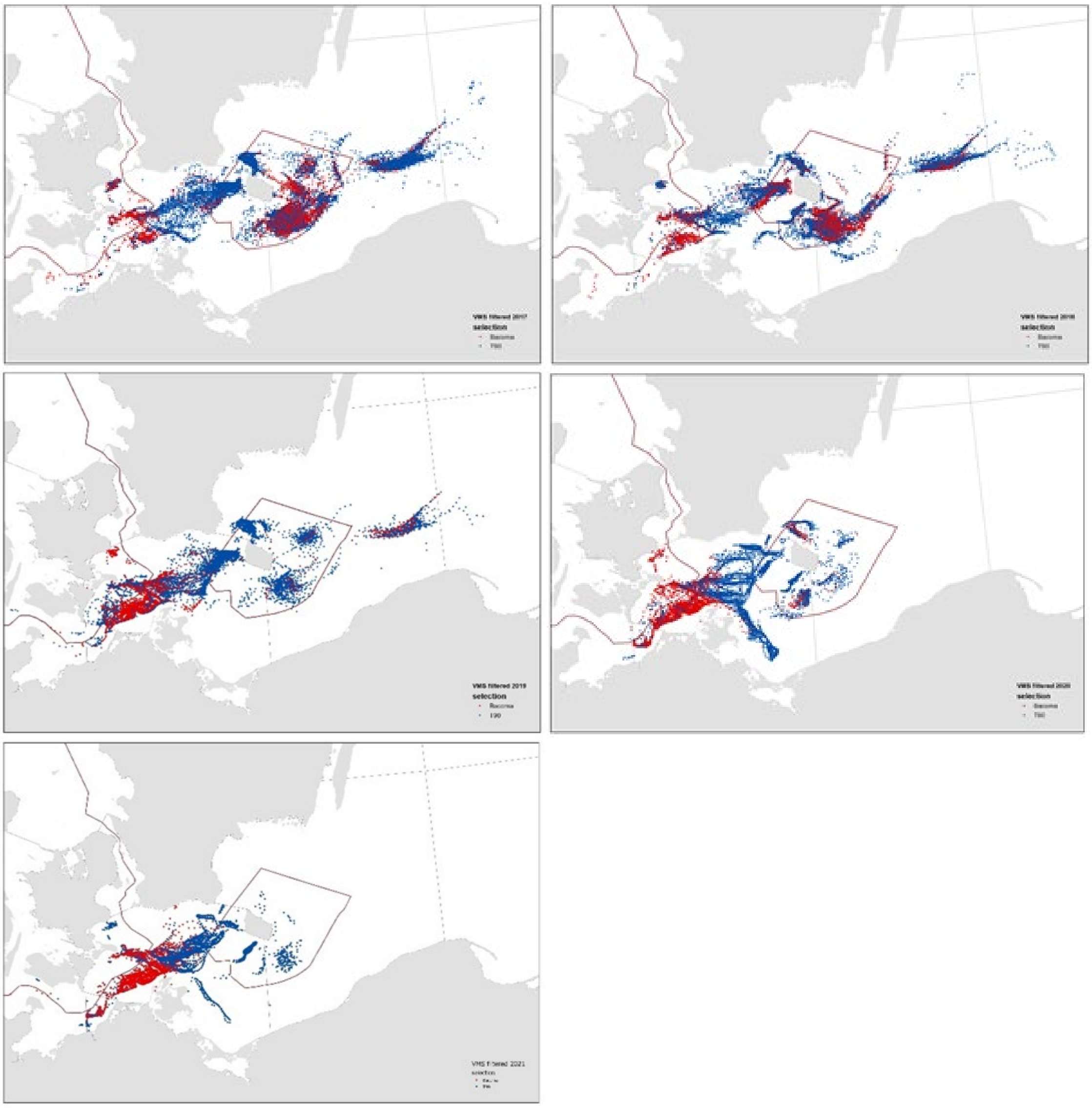

Figure 15. VMS data from 2017-2021 (top left to bottom right) for trawl vessels that have fished with gears >100 mm mesh size in ICES subdivisions 24-25 in the Baltic Sea. Bacoma (red): <115 mm mesh size. T90 (blue): ≥ 115 mm mesh size."

Table 2. Summary of the Danish fishery in the Baltic. Average (range) landings and discards (kg) are given for plaice from observer data for 2021.

Country	Exemption applied for					Fishery				Landings and discards				Evidence
	Species	Area	Gear*	Season	Status	Species as bycatch or target	No. of vessels**	Season	Catch com-position	No. of observer trips	Landings (kg)	Discards (kg)	Discard rate (%)	Status of the evidence
DK	Plaice	22-25	OTB_DEF	Nov-Apr	New ex-emption	Target and by-catch	61	Quarter 1-4 (Q1+4: 74%)	Mix of fish (mainly cod, plaice, dab, and flounder)	72	89 (3-246)	40 (0.2-403)	31 (8-62)	New evidence
DK	Plaice	22-25	SDN_DEF	Nov-Apr	New ex-emption	Target and by-catch	3	Quarter 1-2,4 (Q1+4: 85%)	Mix of fish (mainly cod, plaice, dab, and flounder) and inverte-brates (spe-cies not spec-ified)	8	74 (37-161)	12 (2-20)	14 (6-11)	New evidence
DK	Plaice	22-25	SCC_DEF	Nov-Apr	New ex-emption	Target and by-catch	1	Quarter 1-2 (Q1: 38%)	Mix of fish (mainly plaice, and flounder)	12	18 (7-35)	13 (1-38)	41 (15-52)	New evidence

*Gears limited to those used to catch species for human consumption.

**Numbers are from FDI-data (Fisheries Dependent Information). The vessels are allocated to the gear type they use the most (i.e., highest number of trips).

In the last few years, the conditions for the Baltic Sea fishery have changed dramatically. The low TACs due to the poor cod status both in western (subdivision 22-24) and eastern (subdivision 24-32) Baltic (ICES, 2021a, b) is expected to introduce a transition from targeting roundfish to targeting plaice and other flatfish if the fish condition is good under the new environmental conditions. The TAC on plaice is shared among four Member States. Denmark holds 72%, Poland 15%, Germany 8%, and Sweden 5%. The fishery targeting plaice takes place during the months of low sea temperatures, i.e., November to April. In other parts of the year, plaice are mainly caught as bycatch by the trawl fleet.

With the reduction in number of vessels (Figure 13 for trawlers and Figure 20 for seiners), the total number of fishing days and the size of the total landings has reduced in the period 2017 to 2021 (Figure 16). However, the landings of plaice have been stable (Figure 16). The vessels in the length group from 15 m to smaller than 18 m (15-<18 m) have the highest annual total landings as they also have many fishing days (Figure 17). Vessels that are 18 m or longer have smaller annual total landings and a small number of fishing days. The largest landings of plaice were also provided by vessels in the length group 15-<18 m (Figure 18). The landings in 2021 were smaller than in 2019 and 2020 and were at the level of 2017 landings. When corrected for the number of fishing days, the plaice landings of vessels in the length group 15-<18 m were larger or comparable to larger vessels in four of the five last years (in 2019 vessels in the length group 18-<24 m had larger plaice landings per fishing day).

The fishing vessel used to obtain the survival rates of plaice was 15.7 m long and represented well both the smaller and the larger vessels in the fishing fleet using active gears.

In 2021, the Danish fleet mostly landed in plaice in ICES Subdivisions 22 and 24, to a lesser degree in Subdivision 23 and almost nothing in Subdivision 25 (Figure 19).

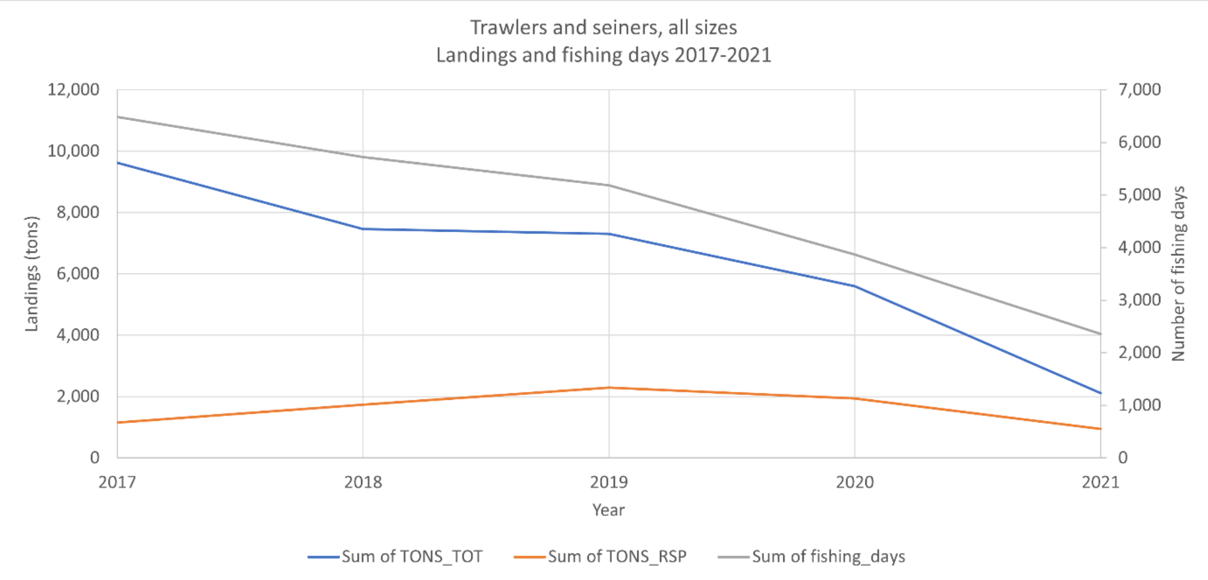

Figure 16. Trend in annual total landings (blue line), and annual landings of plaice (red line) for the Danish fleet using active gears as well as the number of fishing days (grey line) in 2017-2021.

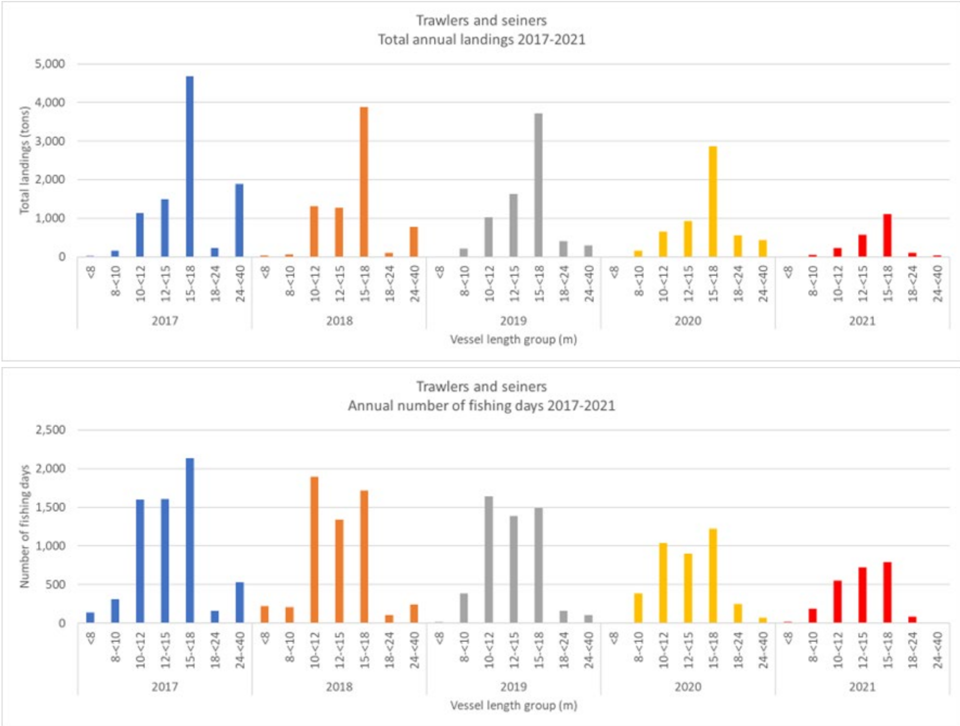

Figure 17. Distribution of total landings (upper panel) and fishing days (lower panel) by vessel length group for 2017-2021.

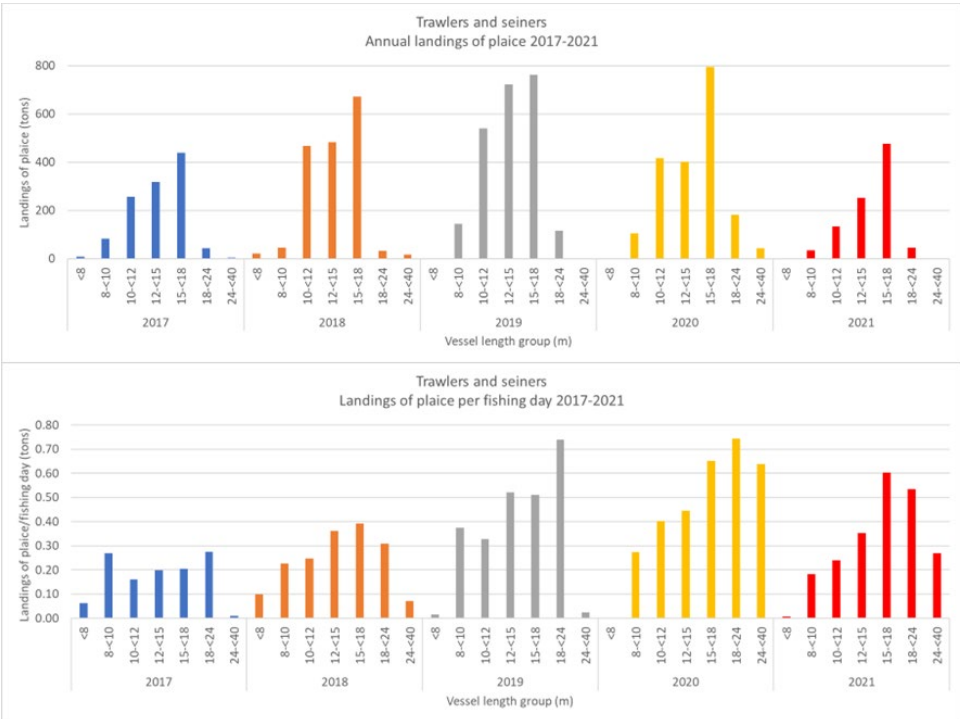

Figure 18. Annual landings of plaice (upper panel) and landings corrected for the number of fishing days (lower panel) by vessel length group in 2017-2021.

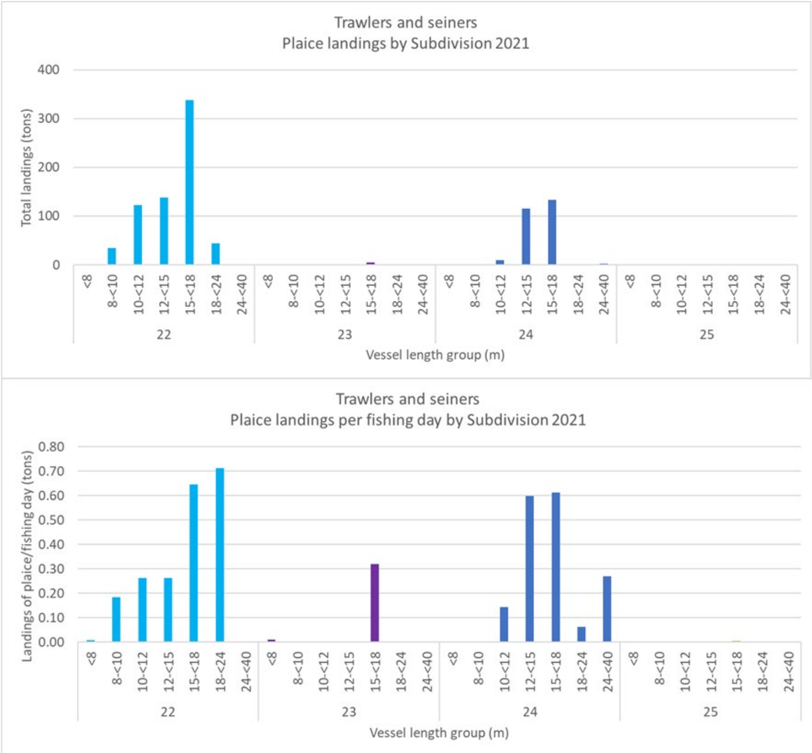

Figure 19. Geographic distribution in ICES Subdivision 22-25 of the annual landings of plaice (upper panel) and landings corrected for the number of fishing days (lower panel) by vessel length group in 2021.

1.6.4. Danish seine fleet in Western Baltic (for exemption request)

There was not conduced any discard survival study with seines in the Baltic Sea. Based on the higher survival rates obtained in Skagerrak with Danish seine (Noack *et al.*, 2020), it was assumed that it would be possible to obtain at least the same results as for the bottom otter trawl. The Danish fleet of seine vessels in ICES Subdivision 22-25 was small counting only three Danish seines and one Scottish seine in 2021 (Figure 20, Table 2). This fleet was comparable to the trawl fleet in terms of vessel characteristics and catch compositions. The seiners fished mostly in subdivisions 22 and 24 (Figure 21). According to logbook data, the fleet was fishing in the first, second, and fourth quarters of the year and their average catch weights of plaice (landed and discard) were lower than that for trawls (Table 2).

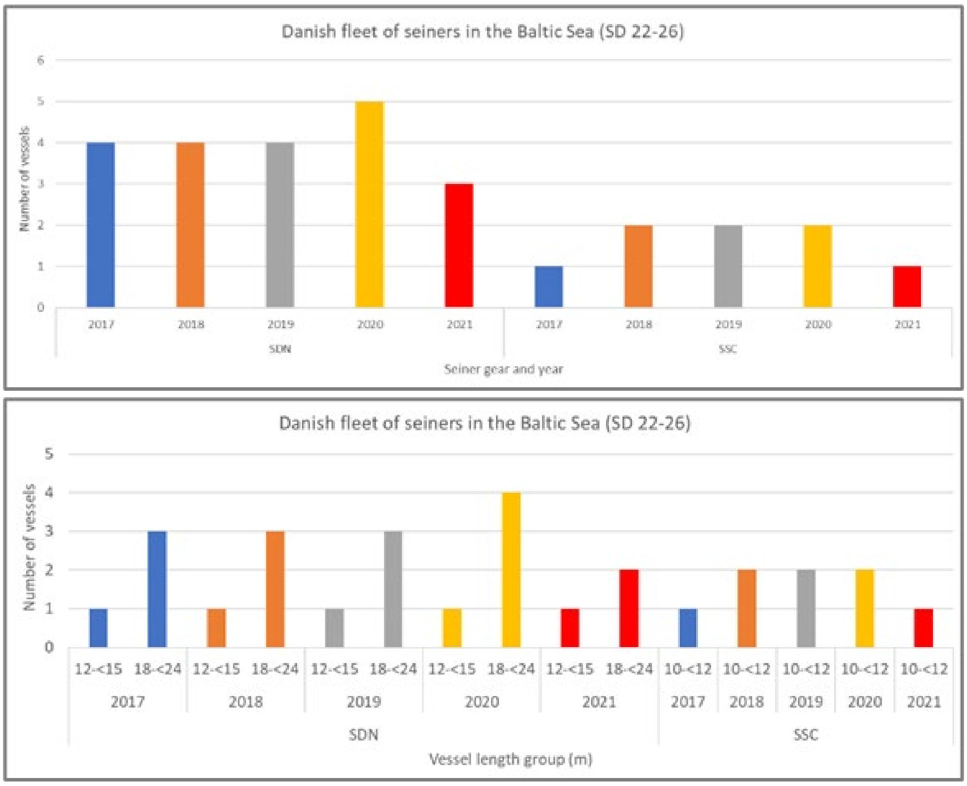

Figure 20. The Danish fleet of seiners (SDN and SSC) that operated in ICES subareas 22-26 of the Baltic Sea in the period 2017-2021 (upper panel), and the distribution of these vessels in different length groups (lower panel).

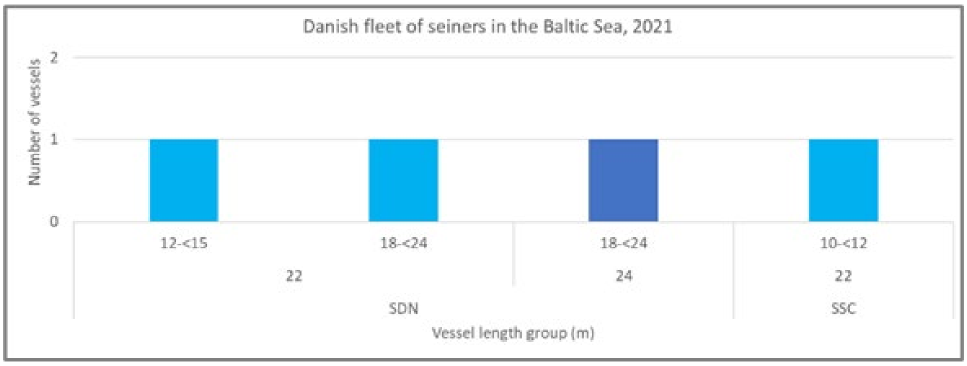

Figure 21. Distribution of the fleet seiners (SDN and SSC, n = 4) of 2021 in subdivisions 22-25 when the vessels are allocated to the area in which they have conducted most of their trips.

2. Estimating discard survival

Discard survival estimates were made for plaice under the MCRS of 27 cm in Skagerrak (Case study 1 and 2), and 25 cm in the Western Baltic Sea (Case study 3).

2.1. Guidelines for discard survival studies

Discard survival studies are associated with several challenges related to the large knowledge gap in how the multitude of operational, environmental, and biological factors influence discard survival for different species, as well as the difficulties of observing individuals being discarded and obtaining true control individuals. The International Council for the Exploration of the Sea (ICES) expert groups Workshop on Methods for Estimating Discard Survival (WKMEDS[8]) and Working Group on Methods for Estimating Discard Survival (WGMEDS[9]) have established guidelines for how to best design and conduct discard survival studies obtain valid discard survival estimates (Breen and Catchpole, 2021). Some estimates have been published for different species and fisheries across EU member states (Supplementary material A). The regulation requires to consider the characteristics of the gear and the fishing practices. Indeed, the capturing process by the fishing gear, handling practice at the surface and onboard, and release back to the water vary between vessels and fisheries. Also, the array of stressors and potentially injurious events that fish are exposed to are likely to give species-specific responses that will affect their survival potential during the discarding process. Stressors can be biological, (e.g., species, size, age, physical condition, occurrence of injuries), environmental (e.g., temperature, depth, light conditions), or technical (e.g., fishing method, catch size and composition, handling practices, air exposure).

When assessing mortality, DTU Aqua used the captive observation method. This technique isolates the captive population from their natural predators, so it does not account for any predation effects on discard survival (ICES, 2014), including sea birds that feed on fish that are discarded. Accounting for predation usually requires a tagging study that has other limitations (e.g., effect of tagging and uncertainties in estimating discard survival rates, low sampling size; ICES, 2014). There is to our knowledge no available data on how vulnerable fish are to predation in general, and relative to their vitality in particular. It is therefore agreed that the up-to-standards methodology currently used in all European studies for estimating discard survival might overestimate discard survival by not accounting for the potential effect of predation. On the other end, these studies also tend to underestimate discard survival due to minor transportation/captivity effects. These limitations are inherent to the choice of the method.

2.2. Representative vessels and gears

The vessels and fishing gears used to collect the discard survival rates were chosen in collaboration with the Danish fishermen organization to represent as much as possible the commercial practices of the fleet.

Plaice was caught on commercial fishing grounds with both sandy and muddy bottoms (flat soft). The choice of fishing ground is greatly influenced by (i) proximity to the holding facility so that any negative effect of fish transportation is limited, and (ii) fishing at commercial sites expected to represent the most stressful conditions for plaice, e.g., lower salinity, occurrence of anoxic areas, and high density of flounder in the catch, so that the observed survival rate can be considered conservative. Ultimately,

[8] https://www.ices.dk/community/groups/Archive%20for%20Community%20pages/WKMEDS.aspx

[9] https://www.ices.dk/community/groups/Archive%20for%20Community%20pages/WGMEDS.aspx

the choice of fishing grounds was made by the fishers in agreement with the scientists. Slight differences between fishing grounds may happen due to the fishing season.

The fishers handled the catch following commercial practices, but these will vary between crew members and vessels.

Air exposure is in close relation to sorting time. The sorting times during the experimental trials were within commercial practices, as discussed with the crew and the DFPO. There is no data available on the sorting times at the fleet level from which we could assess the proportion of hauls with sorting times within the range of sorting times included in our study. The sorting time depends on catch weight (and thus also vessel size), catch composition, and crew size onboard the vessel.

If we take the example of Case study 2, experience from DTU-Aqua observers at sea programme suggests that in commercial conditions, sorting time is up to 1 h when plaice is the main target species and up to 2.5 h when *Nephrops* is the main target species. A proxy for sorting time is catch weight. For hauls, conducted between 2015 and 2017 in the Skagerrak, the average catch weight per haul for trawlers using mesh sizes ≥120 mm (i.e., targeting plaice or round fish) was 674 (53-2957) kg (Table 3). For trawlers using mesh sizes <120 mm (targeting *Nephrops*), it was 559 (121-2236) kg (Table 3), i.e., catches of our experiment are within the range of these values.

Table 3. Characteristics of commercial hauls conducted between 2015 and 2017 (Data Collection Framework database). Values shown as mean (min-max).

Area	Mesh size	Haul duration (min)	Catch weight (kg)	Length of plaice discarded (cm)
Skagerrak	<120 mm	248 (142-300)	559 (121-2236)	23 (11-37)
	≥120 mm	215 (75-300)	674 (53-2957)	25 (13-39)
North Sea	<120 mm	296 (290-299)	985 (226-1932)	26 (18-40)
	≥120 mm	258 (34-300)	1643 (175-4949)	26 (17-39)

2.3. Selection of individuals

Handling and assessments were done according to ICES WKMEDS guidelines (ICES, 2014). All biological and operational factors of the experiment were representative of commercial practices in Danish waters and sampled plaice were representative of the biological conditions at the time of the experiment, i.e., in line with the length distribution of the fish discarded in the fishery. The catch was hauled on deck, emptied into the pounder, and sorted by the crew according to normal commercial practices (Figure 22). Fish were randomly sampled throughout the sorting process to cover the entire air exposure time of the catch sorting. In total, 30-40 fish per haul were assessed for vitality, measured in length, and tagged for individual recognition.

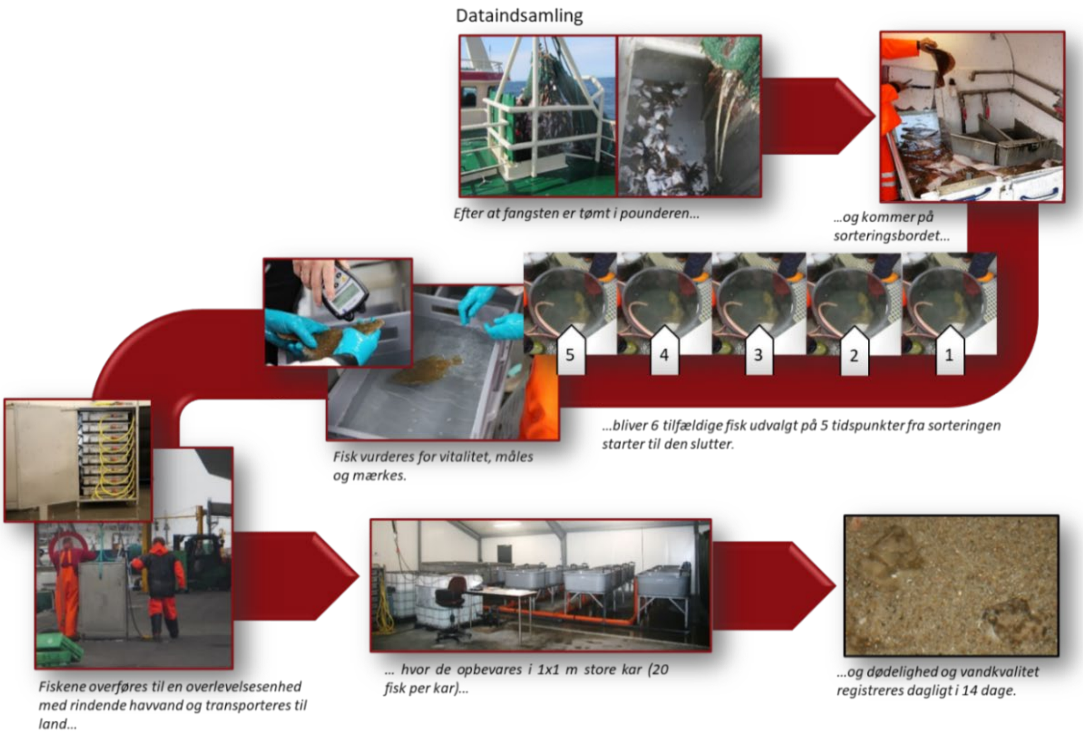

Figure 22. The collection of plaice individuals in Skagerrak for captive observation in the holding facility.

Figure 23. Survival unit to hold fish onboard the vessel (top) and transportation tank to the holding facility with oxygen supply (left and right).

Fish were stored in custom-made survival units to minimize the effects of handling, holding and transportation on mortality (Figure 23). The survival units were continuously supplied with running seawater whilst oxygen and temperature were monitored.

2.4. Captive observation

Fish were transported to nearby holding facilities (Figure 23) and transferred into 1x1m tanks in a common garden set-up to prevent a tank-effect on mortality (Figure 24). The tanks had a semi-circulated water supply, and the bottom was covered with a 2 cm sand layer. For 14 days, mortality was assessed, and water parameters were monitored. After the first week, the fish were fed each day.

Figure 24. Facility with three lines of eight tanks (left) with a sandy bottom (right).

Two weeks are usually considered sufficient to observe all delayed mortalities resulting from capture and handling without adding additional stress. This was set out in Yochum *et al.* (2015) as a general principle and verified in previous observations on plaice by Uhlmann *et al.* (2016) and van der Reijden *et al.* (2017).

Due to space limitations during transport and holding on land, repetition of the experiment allowed collecting a higher number of individuals to increase the robustness of the survival estimates.

2.5. Controls

The control group are subjected to observation-induced effects, whereas the experimental group are subjected to observation-induced and treatment-induced effects. Currently, no knowledge exists on the interaction between observation-induced and treatment-induced effects (Breen and Catchpole, 2021). It cannot be assumed that there is a simple, predictable relationship between the two. Individuals subjected to treatment-induced effects are more likely to be sensitive to additional observation-induced stressors such as temperatures under the optimal range compared to control individuals subjected to observation-induced effects only. Controls can be used to control for the effect of handling, assessing, transporting, and holding the fish, i.e., all the experimental steps that would take place after the fish would normally be discarded in commercial fisheries. If caught prior to the experiment, controls can be acclimatized and fed ad libitum after a week in captivity.

In Skagerrak (Case study 1 and 2), plaice in control groups “land” and “acclim.” were caught prior to the study using the research trawler R/V Havfisken (Figure 25). These fish were allowed to acclimatise before inclusion in the study. Control group “land” was used to control for the land-based holding facilities. Plaice in control group “acclim.” were brought onboard the commercial vessel, and thus underwent the transportation to and from the fishing ground, and vitality assessment, length measurement and tagging. This group controlled for transport and assessment when held up against control group “land”. Plaice in control group “trawl” were caught with the commercial trawler (short hauls) and entered the experiment without acclimatisation. This group controlled for the same as control group “acclim.” in addition to the fishing process and commercial handling. A fourth control group was added during the winter sub-cruises to disentangle the effects of transportation and fish assessment. Plaice in the control group “land+tag” were caught by Havfisken and acclimatized beforehand, and experienced the assessment and tagging procedure, but underwent no transportation process.

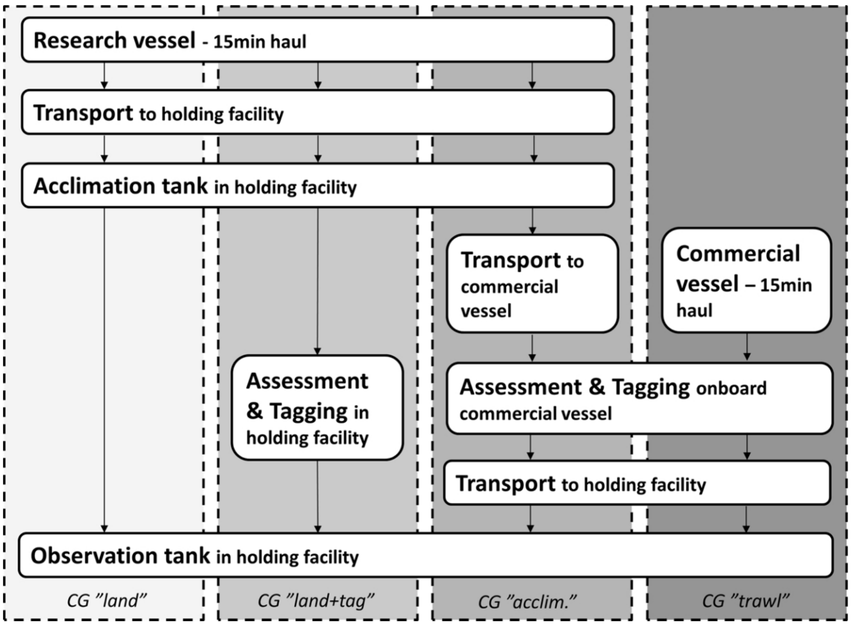

Figure 25. Overview of four types of Control Groups (CG) (Savina et al. 2019).

The survival of the four control groups were high, but there might be some influence of transportation on survival (Table 4).

In the Western Baltic, a pilot study in the autumn showed high mortality even for short- haul durations, so we did not use fish caught on the day of the sea trial as controls. Control fish were primarily sourced by the control fish used in a pilot study in the autumn and caught by the T90 trawl, as well as fish from trammel nets (250 m long with 70 mm mesh size) soaked for 24 hours. Control fish were not tagged. These fish were representative of the subject population group and controlled for the conditions in the holding facility.

Table 4. Survival of the control groups, separated by season and target species.

Season	Target	Control group	Number of individuals	Observed survival
Summer	Plaice	Control 1 (land)	50	1.00
		Control 2 (HV)	60	0.92
		Control 3 (S84)	60	0.87
Winter	*Nephrops*	Control 1 (land)	16	1.00
		Control 2 (HV)	10	1.00
		Control 3 (S84)	10	1.00
		Control 4 (land+tag)	16	0.94
	Plaice	Control 1 (land)	10	1.00
		Control 2 (HV)	10	1.00
		Control 3 (S84)	16	1.00
		Control 4 (land+tag)	16	1.00

2.6. Tagging

The individuals included in the investigation of survival were tagged with a PIT-tag. This relatively small tag (12 mm) was inserted in the muscle behind the dorsal side of the head on the pigmented side of the fish using a needle (Figure 26). The tag contained an ID number and was used to keep track of each individual throughout the study. Naturally, this procedure differs from that when fish are discarded during commercial fishery and could potentially add extra stress and affect mortality. In particular, there was a concern that additional stress could affect survival for individuals that have been subject to long air exposure times.

Figure 26. Indication of PIT tag location (placement as shallow as possible under the skin).

From 14 hauls (seven 180 min hauls and seven 15 min hauls) conducted with R/V Havfisken in the Skagerrak, a total 329 plaice were collected for investigating the effect of tagging on survival. Of the individuals' samples, 217 plaice (66%) were tagged. The fish were caught at an average depth ranging from 26.5-51.0 m. Catch sizes ranged from 10-34 kg for the 15 min hauls and 130-726 for the 180 min hauls. Survival was assessed for air exposures 0 min, 45 min and 90 min. There was no effect of tagging, and no effect of air exposure on the tagging effect.

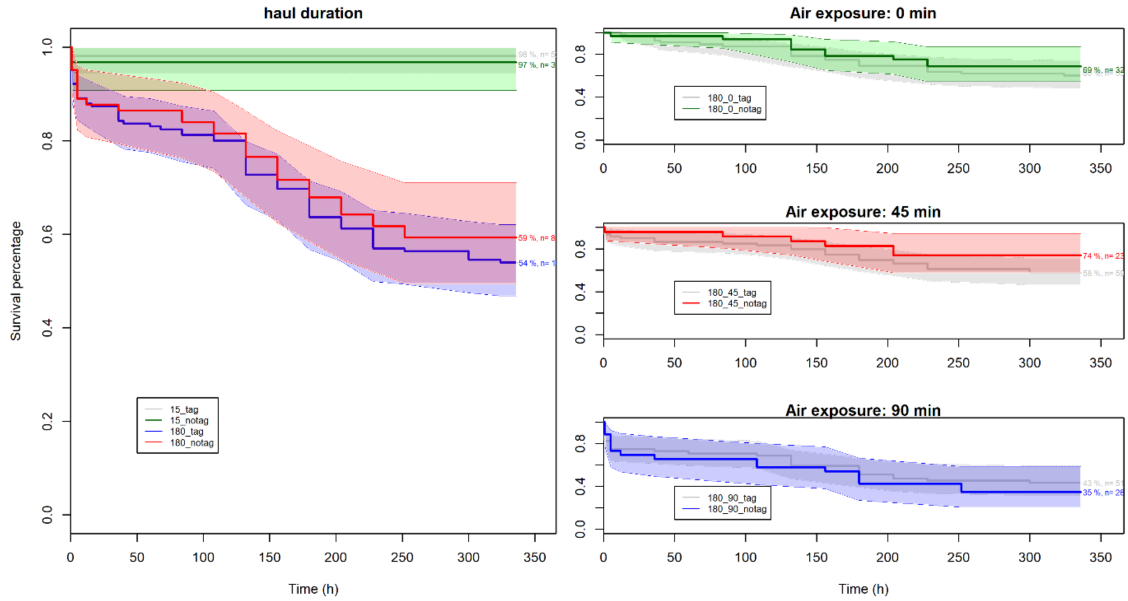

Figure 27. Kaplan Meier survival curves for plaice.

2.7. Data analysis

The general idea of the survival rates is to look at the proportion of individuals alive throughout time. This is the survival function and looks like a curve that:

(1) decrease with time, due to the individuals that die because they were affected by the capture and handling process.

(2) eventually levels off, because all the affected individuals died, leaving only alive individuals that were unaffected by the fishing process.

The post-release survival probability is the proportion of individuals alive at the end of the captivity observation when mortality has levelled off (at asymptote).

Depending on the objectives of the investigation there are different ways to analyse survival data. If one is interested in the mechanisms underlying the shape of the survival curve over time, modelling the survival curve is of relevance. However, if one is mostly interested in delivering a survival probability in each given fishery for management purpose, analysing the survival rate at asymptote might be enough.

In our studies, we used either non-parametric (Kaplan-Meier, double bootstrap) or parametric (Weibull mixture distribution model, logistic regression) approaches (ICES, 2019). The advantage of a non-parametric approach is that very few assumptions are made, whereas parametric models allow not only a description of the observed data but also make predictions for the fishery, including sources of uncertainties due to the captivity conditions or differences between hauls for example, but also make inferences on the mechanisms underlying the shape of the curve, e.g., how air exposure is influencing the survival for example.

2.7.1. Non-parametric Kaplan-Meier curve

The non-parametric Kaplan-Meier curve gives the proportion of observed individuals alive at each time point during captivity (Benoît *et al.*, 2012; Kaplan and Meier, 1958).

The Kaplan-Meier can be used to estimate the probability of survival at a given time point but is mostly useful for (1) exploratory data analysis (visualizing how the proportion of observed alive individuals changes with time), and (2) identifying the parametric models to use for further data analysis.

Used in the project for exploratory purposes, i.e., to check that a mortality asymptote was reached, and explore the effects of the operational, environmental, and biological factors.

2.7.2. Parametric Weibull mixture distribution model

A parametric approach makes it possible to model the survival curve in the same manner as the one represented by the Kaplan-Meier, but with known parameters. This is the case of the parametric Weibull mixture distribution model that we used, which can be defined using three parameters.

Used in the project for estimating survival rates with confidence intervals (accounting for variability within and between hauls) and quantifying the effects of operational, technical, environmental, and biological parameters; the log-normal survival model showed to be a successful alternative in the Bayesian approach.

2.7.3. Non-parametric double bootstrap at asymptote

The double bootstrap method is well-established for evaluating fishing gear selectivity and catch efficiency (Herrmann *et al.*, 2012; Wienbeck *et al.*, 2014). It accounts for within and between-haul variation in the obtained survival probability by selecting fish and hauls with replacement from the pool of fish and hauls during each bootstrap repetition.

Used in the project to compare survival probabilities between seasons, target species and catch components after 14 days of observation averaged over hauls.

2.7.4. Logistic regression model at asymptote

One may also model mortality at asymptote at the fish level with 0 for alive and 1 for dead as the response variable (binomial).

Used in the project for optimisation of the vitality indicators to predict survival.

	Parametric	**Non-parametric**
Survival over time (survival curve)	Weibull mixture	Kaplan-Meier
Survival probability at asymptote	Logistic regression	Double bootstrap

2.7.5. Meta-analysis

Meta-analysis is the statistical combination of results from several different studies to create a summary estimate (with its confidence interval) that is based on an increased statistical power compared with each of the studies separately (Hoffman, 2015). Indeed, pooling information from multiple discard survival studies can identify large-scale survival patterns, improve understanding of the discard survival variability, and provide more accurate survival estimates. The objective of doing a meta-analysis is to provide managers with a reliable estimate of discards survival with uncertainty estimates and the effects of explanatory factors (e.g., gear, season, air exposure) by means of a systematic synthesis and statistical analysis of a collection of previous studies (ICES, 2015).

Discard survival has been studied in many different fisheries. However, each study has focused on restrained conditions in agreement with STECF recommendations (STECF, 2013). The economic cost of conducting these experiments limits the sampling to a selection of the variety of conditions that can occur, even in a fishery-specific context, despite that operational, environmental, and biological conditions have been shown to affect discard survival, at both individual and haul levels (ICES, 2014). This methodological heterogeneity is a challenge when conducting meta-analysis and has thus required the development of a framework for a meta-regression (hierarchical mixed effects) that accounts for differences in experimental design, quality, and context specificity between individual studies to produce reliable inferences.

All the work related to the meta-analysis in this project was done as part of the International Council for the Exploration of the Sea WKMEDS and WGMEDS.

2.8. Case studies on discard survival of plaice

2.8.1. Case study 1: Survival of plaice caught with Danish seine in Skagerrak

The survival rate and vitality of plaice under the MCRS of 27 cm in Skagerrak were investigated during August-October 2017 (Figure 28). This is when the water temperature is at its highest during the year and thus represents a worst-case scenario for survival. The commercial vessel used in the study was chosen in collaboration with DFPO and the local fishers association in Hirtshals. The seiner S15 'Vera-Marie' (vessel length 16.1 m, vessel power 142 kW) used a 125 mm codend representative for the demersal fisheries (DEF) with Danish seine fisheries (Figure 28).

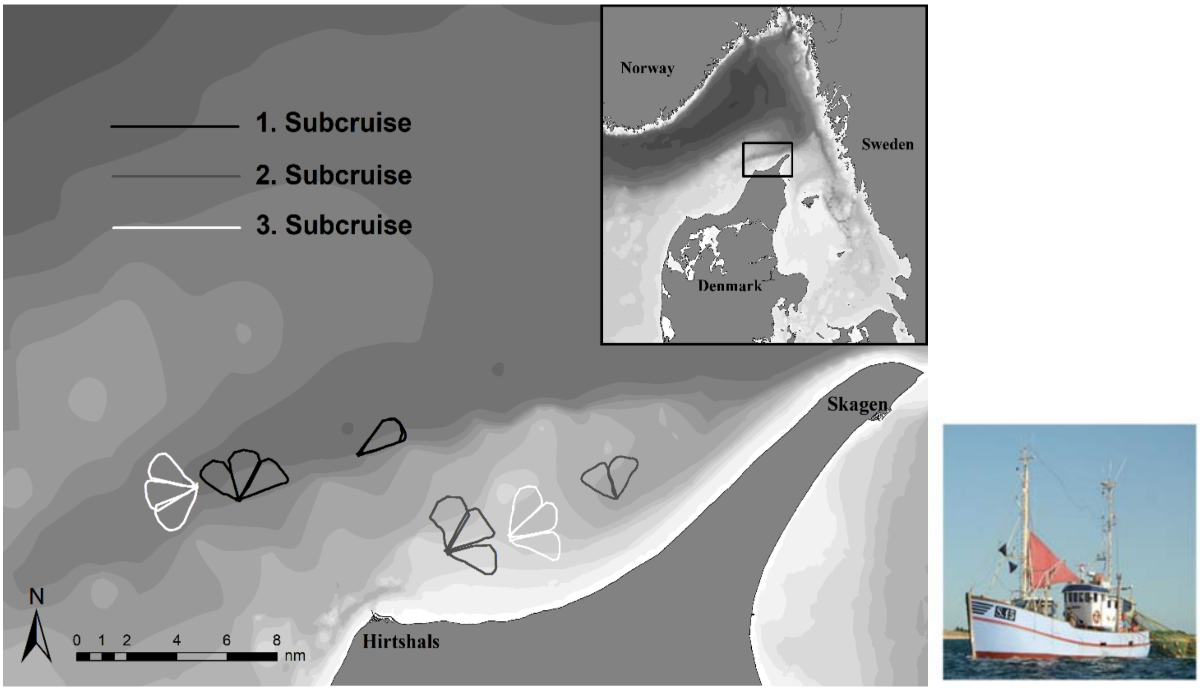

Figure 28. Left: Data collection at commercial fishing grounds in Skagerrak. The droplet-shaped tracks were hauls from the Danish seiner. The three sub-cruises were conducted in August, September, and October 2017. Right: The commercial vessel used in the study to represent the Danish seine fleet in the demersal mixed fisheries.

2.8.2. Case study 2: Survival of plaice caught with otter trawl in Skagerrak

Plaice and *Nephrops* are caught year-round both in the Skagerrak and the North Sea. However, fish and *Nephrops* are usually caught on separate fishing operations, which should be highlighted as the presence of *Nephrops* in the catch can increase damages and therefore fish mortality (Karlsen *et al.* 2015), i.e., when *Nephrops* dominate the catch, the proportion of plaice is low and vice versa.

The survival rate and vitality of plaice under the MCRS of 27 cm in the trawl fishery in Skagerrak was investigated during summer (August, September, and October) 2017 and winter (March and April) 2018. The study was done onboard the commercial vessel S84 'Ida Katrine' chosen in collaboration with the Danish Fishermen Organisation DFPO (Figure 29). The trawler represents the mixed demersal fishery targeting fish (including plaice and *Nephrops*), with a length of 15.1m and a power of 221kW, working in a twin rig.

Figure 29. The commercial vessel used in the study to represent the bottom otter trawl fleet in the demersal mixed fisheries.

In the summer, two commercial 90 mm diamond codends representative for the mixed demersal fishery were used to target plaice. A 90 mm mesh size was chosen to account for the 'worst case scenario', but fishers commonly use a 120mm diamond codend instead when targeting plaice. Together with improving size selectivity, a larger mesh size in the codend is expected to reduce potential damage in fish and therefore improve discard survival.

In the winter, in addition to the standard commercial 90 mm diamond codend, a modified experimental codend was tested (Figure 30). This horizontally divided codend with 120 mm square mesh upper compartment and 60 mm square mesh lower compartment had previously been used to separate fish from *Nephrops* (Karlsen *et al.*, 2015), and therefore seemed promising to reduce catch damage by limiting frictions in the codend. In the winter, half of the hauls targeted plaice and half of the hauls targeted *Nephrops*.

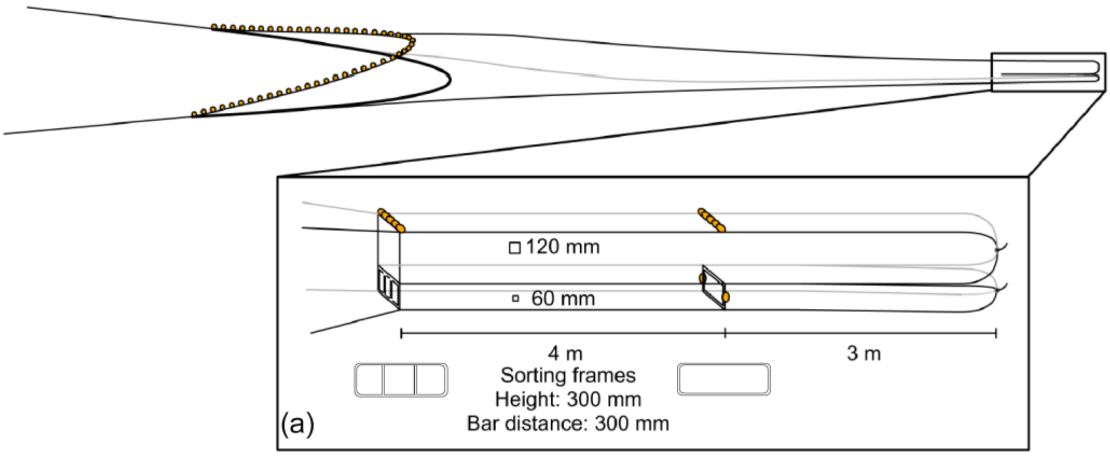

Figure 30. A conceptual drawing of the horizontally divided codend used as one of the codends in the twin-rig of the trawler in the winter.

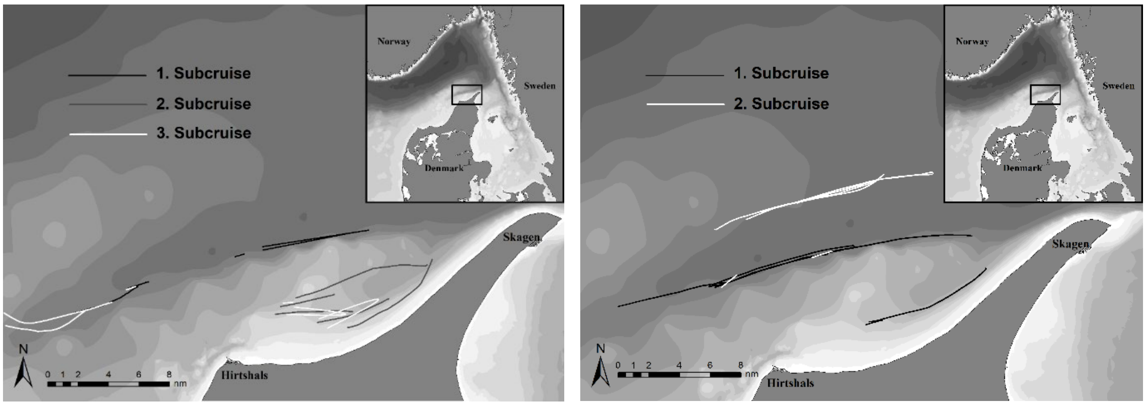

Figure 31. Data collection at commercial fishing grounds in Skagerrak. The five sub-cruises were conducted in the summer (August, September, and October 2017, on the left) and the winter (March and April 2018, on the right).

2.8.3. Case study 3: Survival of plaice caught with otter trawl in the Baltic Sea

Sea trials were conducted onboard the commercial trawler R3 "Orion" (vessel length 15.7 m, vessel power 217 kW, vessel tonnage 39.6 t, Figure 32) in the winter 2021 fishing with T90 and Bacoma (Figure 33). For each gear type, two identical codends were fished in a twin rig.

Figure 32. The vessel used for the sea trial R3 Orion.

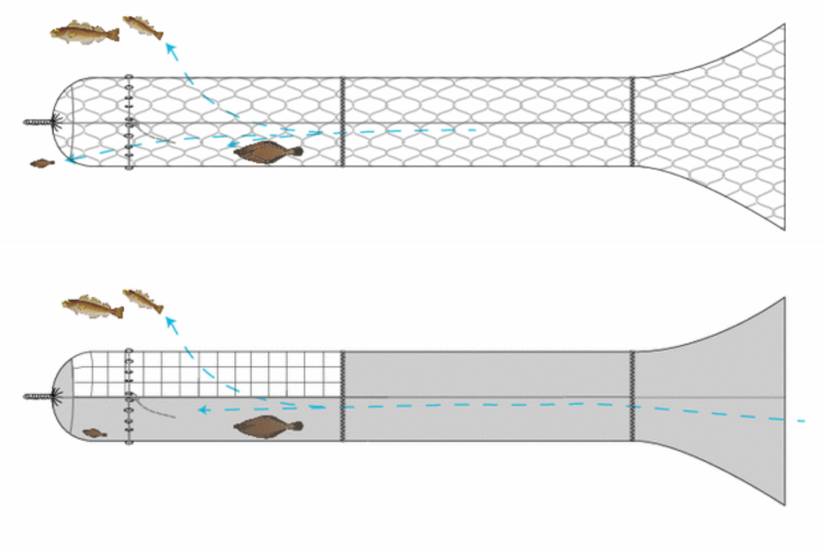

Figure 33. T90 (upper) and Bacoma (lower) codends © Thünen Institut.

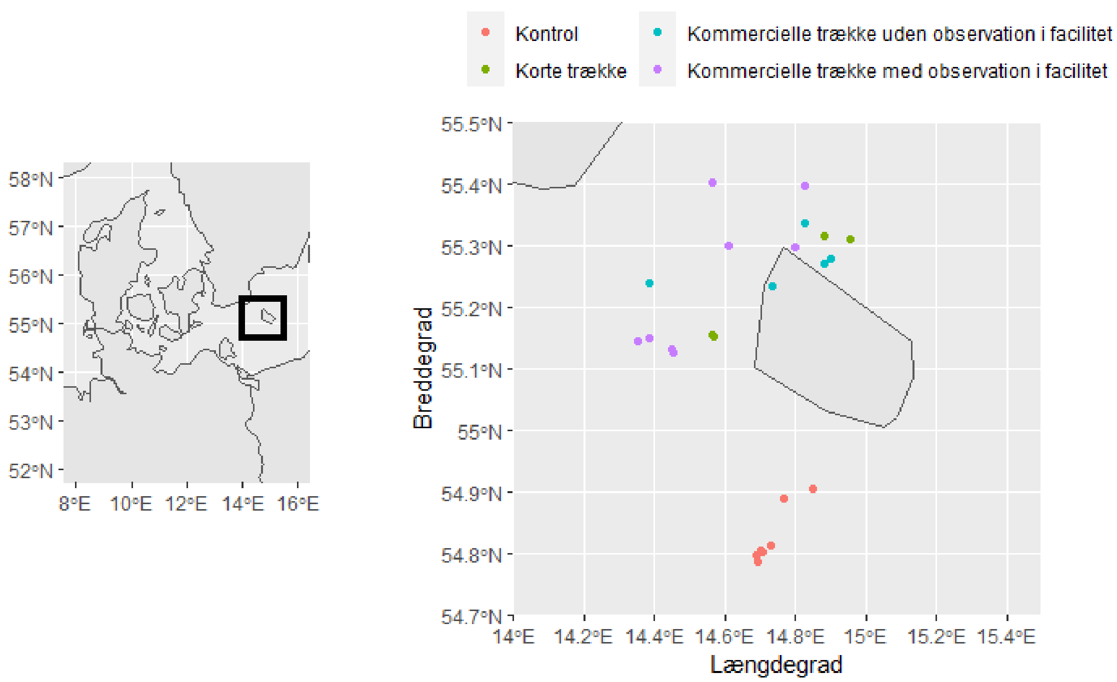

Figure 34. Data collection at commercial fishing grounds in the Baltic: red are hauls for collecting control fish (with acclimatation), green are hauls of short duration also for collecting control fish (without acclimation), blue are hauls where we collected stomach and proxy data, purple are hauls where we collected experimental fish for captive observations.

Figure 35. Handling of the catch onboard the vessel: codends were emptied in the hopper (upper left) supplied with running water (upper middle), from where the individuals were delivered to the sorting table (lower left) and sorted by the fishers (upper right) before sampling for plaice below the MCRS of 25 cm in a 90L tub filled with water (lower right).

3. Stressors affecting discard survival estimates

The variability in discard survival estimates can be high, even within a single study (Breen and Catchpole, 2021). The variability may be related to several factors withing a range of operational, environmental, and biological factors influencing discard survival. To improve our understanding of how discard survival is affected, the effect of several factors has been studied in relation to the different Case studies (Table 5). In this section, the results from these investigations are presented.

Table 5. Operational, environmental, and biological parameters investigated in the different Case studies.

	Parameter	Data source	Case study
Operational	Haul duration (h)	Start and stop time (wheelhouse)	All
	Total catch weight (kg)	Pounder weight, else estimated by the skipper and scientist	All
	Air exposure (min)	Start and stop time for each fish assessed (deck)	All
Environmental	Depth (m)	“CTD” logger (Star-Oddi) underwater (gear)	All
	Salinity (ppt)	“CTD” logger (Star-Oddi) underwater (gear)	3 (Baltic)
	Water temperature (°C)	“CTD” logger (Star-Oddi) underwater (gear)	All
	Dissolved oxygen (mg/l)	“miniDOT” logger (PME) underwater (gear)	3 (Baltic)
	Air temperature (°C)	“Handy Polaris 2” device (Oxyguard) on deck	All
Biological	Fish length (cm)	Measuring board	All
	Pre-capture oxygen level	Fish stomachs	3 (Baltic)
	Intestinal mollusc shells	Fish stomachs	3 (Baltic)
	Physiological stress	Blood, muscle, brain	2 (Skagerrak)
	Hypoxia	Respirometer, blood, muscle	3 (Baltic)

3.1. Operational variables

3.1.1. Gear type (Case study 1 and Case study 2)

Based on comparison in summer in Skagerrak, the mean survival rate for undersized plaice was 78% (95% CI: 67%-87%) for SDN and 44% (37%-52%) for OTB T90.

3.1.2. Target species (Case study 2)

Trawlers targeting plaice usually catch high proportions of plaice and small proportions of *Nephrops*, and vice versa. Catches of plaice cannot be circumvented entirely when targeting *Nephrops*. Survival was significantly higher when targeting plaice than *Nephrops* (Figure 36,
Table 6). Differences in survival of discarded plaice for different catch compositions were also found in the Belgian beam trawl fishery for plaice where immediate on-board mortality was positively associated with physical injury, the total weights of catches and stones, and the proportion of injury-inducing elements among the unwanted catch (Uhlmann *et al.*, 2023).

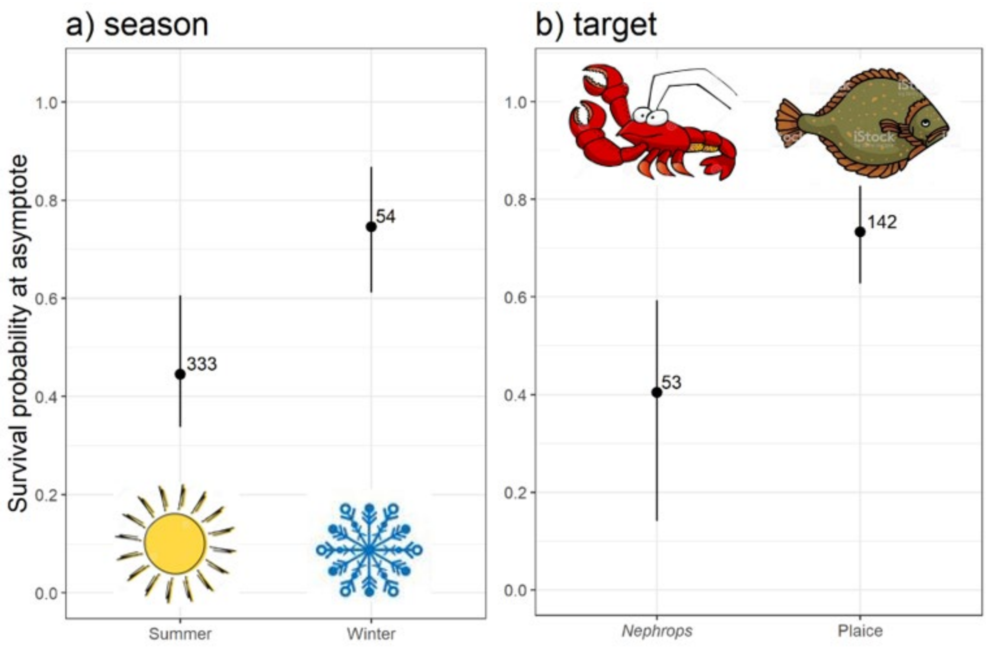

Figure 36. Observed survival probability at asymptote after 14 days with 95% confidence interval of undersized plaice discard for a) season, i.e., summer vs. winter; b) target species, i.e., Nephrops vs plaice.

Table 6. Estimated overall survival rates in % with 95%-confidence interval (* including uncertainty from the haul selection and the conditions of the captivity experiment when the chosen covariates did not depend on the fish selection, ** including uncertainty from the fish selection, the haul selection and the conditions of the captivity experiment) of undersized plaice in the Skagerrak for the OTB targeting plaice and Nephrops in the summer and winter for the standard commercial codend.

Target	Plaice	*Nephrops*
Summer	44 (37-52*, *n*=333)	-
Winter	75 (67-83**, *n*=142)	41 (28-57*, *n*=123)

3.1.3. Gear design

Effect of catch separation on discard survival (Case study 2)

Separating fish from *Nephrops* using a horizontally divided codend can reduce catch-related damages to the fish such as scale loss (Karlsen *et al.*, 2015), but also significantly increased the survival of the undersized plaice in the upper compartment when targeting *Nephrops*.

The upper compartment of the modified codend (120 mm square) showed a better discard survival, but also less undersized (and commercial) individuals due to a higher selectivity.

When using the divided codend, the catch is partly sorted during fishing and sorting time on board could potentially be reduced. This is a major advantage that can be used to reduce discard mortality, as air exposure is a key factor affecting survival (Morfin *et al.*, 2017a; van der Reijden *et al.*, 2017).

We expect significant differences in survival between the compartments of the divided codend when targeting *Nephrops* in the summer as well, but the size of effect may be different to that observed in the winter.

T90 versus BACOMA (Case study 3)

T90 was found to have the lowest survival rate compared to BACOMA during the pilot trial in autumn 2020 in the Baltic (Table 7).

Table 7. Immediate, delayed, and total survival rate in % for the experimental fish (T90 and Bacoma) in the autumn 2020 (Baltic).

	Immediate	Delayed	Total
T90	74.1 [65.2-83.2] (n=260)	26.5 [8.5-54.5] (n=125)	25.2 [7.4-54.5] (n=171)
Bacoma	63.2 [55.0-72.2] (n=273)	21.6 [6.9-40.8] (n=129)	14.4 [3.5-29.0] (n=228)

3.1.4. Air exposure (Case study 2)

Air exposure is in close relation to sorting time. The sorting times during the experimental trials were within commercial practices, as discussed with the crew and the DFPO. There is no data available on the sorting times at the fleet level from which we could assess the proportion of hauls with sorting times within the range of sorting times included in our study. The sorting time depends on catch weight (and thus also vessel size) and composition, and the size of the crew onboard the vessel. Experience from DTU-Aqua observers at sea program suggests that in commercial conditions, sorting time is up to 1 h depending on catch weight when plaice is the main target species, and up to 2.5 h when *Nephrops* is the main target species. A proxy for sorting time is 'catch weight'. For hauls, conducted between 2015 and 2017 in the Skagerrak, the average catch weight per haul for trawlers using mesh sizes ≥120 mm (i.e., targeting plaice or round fish) was 674 (53-2957) kg. For trawlers using mesh sizes <120 mm (targeting *Nephrops*), it was 559 (121-2236) kg, i.e., catches of our experiment are within the range of these values.

In the summer when targeting plaice, discard survival was affected by air exposure duration (Table 8). This was not observed in winter, also when targeting *Nephrops*, as discard survival was primarily driven by damages/loss of reflexes in an overall cold/mild environment. The length range of the sampled fish was limited in the summer but larger in the winter, explaining why this biological factor had an effect in the winter only (Table 8).

Table 8. Effects of operational, environmental, and biological covariates on the parameters of the fitted survival function and mixture proportion for discard survival of undersized plaice caught by a Danish otter trawler targeting plaice and Nephrops with a standard commercial codend in the summer and winter. Only the mixture proportion affects the overall survival estimate (as observed at the end of the experiment when an asymptote is reached).

Target	Season	Survival function (α, γ)	Mixture proportion (π)
Plaice	Summer	-	*Operational:* Air exposure
	Winter	*Operational:* Sorting order *Biological:* Fish length	*Biological:* Fish length
Nephrops	Winter	*Operational:* Sorting order, fail due to harsh weather condition	-

Note the caution mentioned in the above section when comparing overall mean survival rates. Because overall survival rates estimated above are, for some, dependent on the number of observed fish for each level of the selected covariates, we also predicted survival rates for given values of the selected operational covariates independently, within the ranges of the experimental data, i.e., air exposure from 0 to 62 min for OTB targeting plaice in the summer (Figure 37).

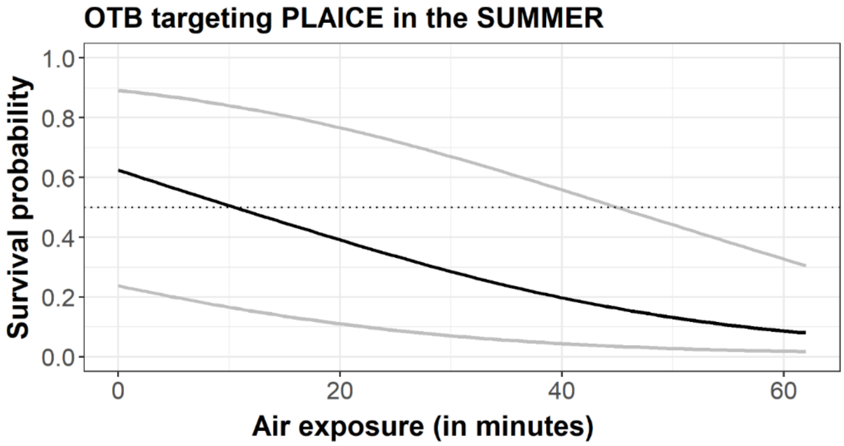

Figure 37. Discard survival as a function of air exposure (black) with 95% confidence intervals estimated by parametric bootstrap accounting for variability from the captivity experiment (grey) for undersized plaice caught by the OTB targeting plaice in the summer.

3.2. Environmental variables

3.2.1. Temperature (season) (Case study 2)

In the Skagerrak, the largest landings of plaice take place in the autumn and winter. In the North Sea, the largest landings take place in the summer, but are all year round at least as big as in the Skagerrak.

Regarding the commercial standard codend (90mm diamond), the mean survival rate for undersized plaice was higher in the winter than in the summer, respectively 44% (95%-confidence interval: 37-52) and 75% (67%-83%) (Table 6, Figure 36). A lower survival at higher temperatures was observed in previous studies (Van der Reijden *et al.*, 2017; Kraak *et al.*, 2018; Schram *et al.*, 2023). The mean survival rate for undersized plaice commercially caught when targeting *Nephrops* was lower than when targeting plaice, as observed in the winter, reaching survival rates similar to those when targeting plaice in the summer, i.e., 41% (28%-57%) (
Table 6). The larger amount of *Nephrops* in the catch caused more damages to the fish by friction in the codend, leading to higher mortalities. Caution must be made when doing direct comparisons. Mean discard survival (with uncertainty estimates) is limited by the conditions during the trials, especially by the factors found to affect the survival rates.

Fish are ectotherm animals so when the temperature in the environment increases, the body temperature of the fish increases correspondingly. An increase in body temperature is followed by an increase in oxygen uptake and other biochemical reactions (Fry, 1971). This in turn contributes to a decline in physiological condition (Benoît *et al.* 2013), which contributed to a reduced probability of surviving the capture and release process.

3.2.2. Oxygen (Case study 3)

When assessing the high survival exemptions, STECF examines whether the study is designed to provide an estimate that is representative of the wider fishery, i.e., that the data is representative of the full range of operational and environmental conditions associated with the fishery. The oxygen conditions are worsening in all basins of the Baltic with an increase in the oxygen debt below the halocline (HELCOM, 2023), and this is why we specifically focused on the effect of oxygen for the Baltic case study.

We documented the environmental conditions of the commercial fishing operations, e.g., water temperature and oxygen conditions, based on in situ measurements by commercial fishers using a sensor on their trawl (vessels R3, R41, R254 and R419) and the available (2020) VMS and research cruise data (Figure 38).

We have developed an overlap index between the fisheries (VMS data) and oxygen conditions at the seabed (oxygen data from previous research cruises and collected at the time of capture by the commercial fishers).

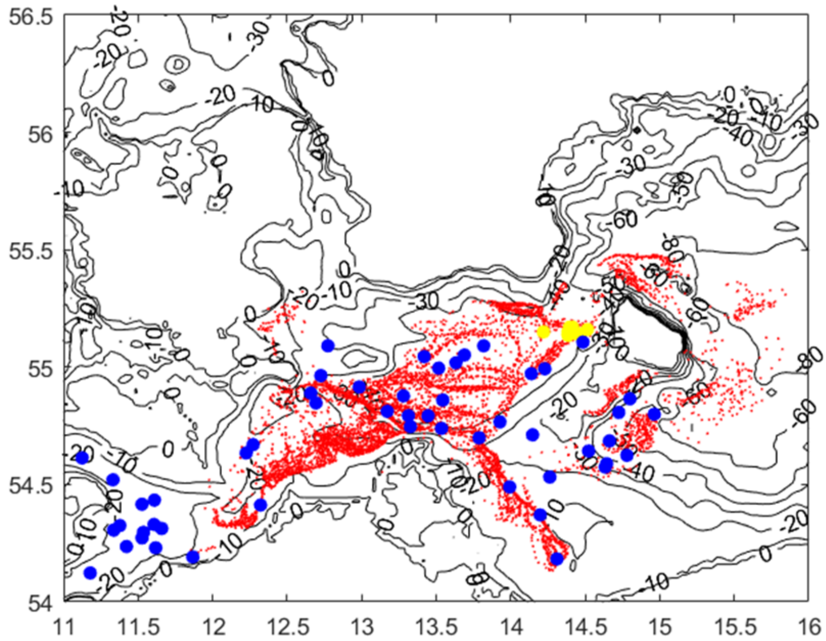

Figure 38. Fishery hauls (red dots), oxygen stations from the Baltic International Trawl survey (blue dots) and fishing stations with oxygen measurements from commercial fishers, all in 2020. Depth contours are derived from a high resolving bathymetric map produced by the institute for Baltic Sea research in Warnemünde.

The fishing grounds were covered well by oxygen measurements from the BITS survey. The survey measurements were taken in February/March 2020, and we assumed the measured oxygen conditions were representative for the conditions during fisheries. The measurements taken by the fishermen did not differ substantially from the survey measurements. The oxygen data were inspected and the measurements at the greatest depth per station were taken as oxygen concentration at the bottom. Subsequently, the spatial measurements were linearly interpolated to derive a map of bottom oxygen concentration (Figure 39).

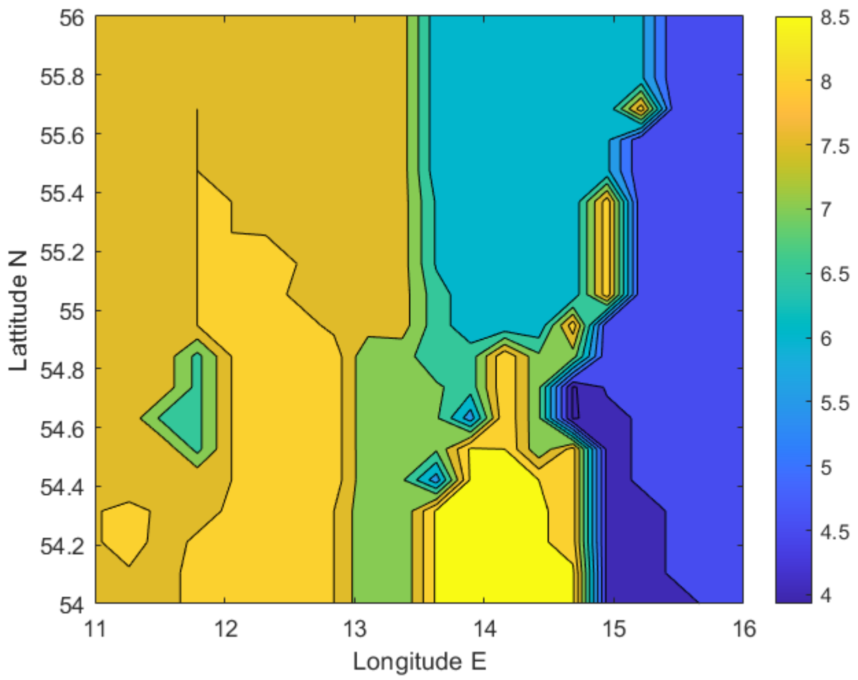

Figure 39. Oxygen concentration (mL/L) at the seabed from BITS survey and fisher measurements.

We extracted the oxygen conditions at every single trawl station from the VMS data from the contour plot of oxygen at the seabed. The resulting cumulative frequency distribution of oxygen concentrations encountered at the fishing locations can be considered an overlap index for fishery and oxygen (Figure 40).

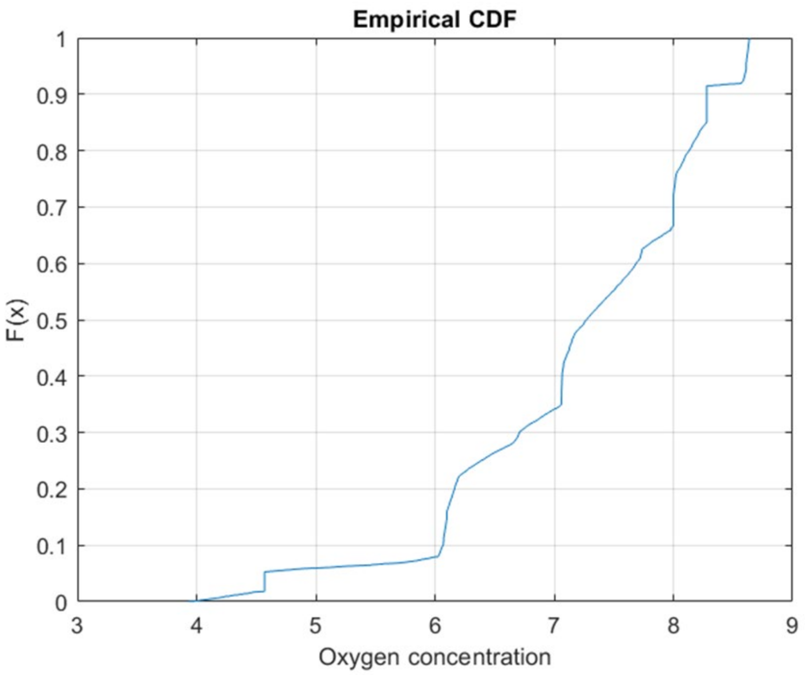

Figure 40. Cumulative frequency distribution of encountered oxygen concentrations during bottom trawl fishing operations in 2020.

90% of the trawls were conducted at oxygen concentrations greater than or equal to 6 ml/l. The corresponding depth distribution of the fishery is shown in Figure 41. Here, more than 90% of all trawls were conducted at depths less than or equal to around 48 m.

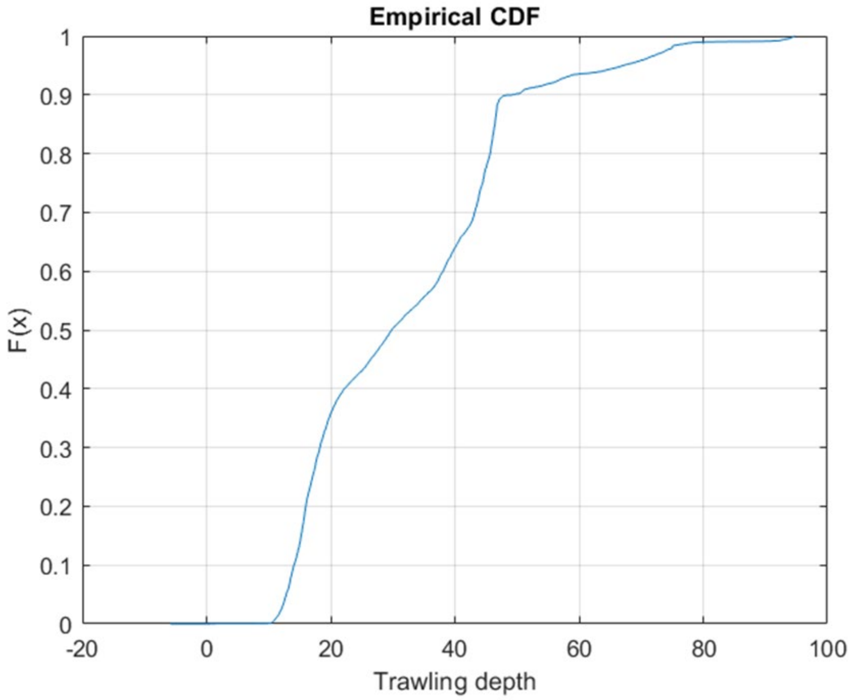

Figure 41. Cumulative frequency distribution of trawling depth for the 2020 VMS data.

We investigated the effect of dissolved oxygen level at capture on delayed plaice mortality. Oxygen levels were however related to seasons with lower levels in autumn than in winter (confounding factors). The seasonal effect was stronger than the oxygen effect, but it was not possible to further investigate the relationship between dissolved oxygen at capture and survival in the field.

3.3. Biological variables

3.3.1. Fish length (Case study 1, Case study 2)

Previous studies have shown an additional effect of fish length on survival probability, which was therefore also tested. However, no effect of fish length was observed, which is in line with previous results from van der Rejden *et al.* (2017) on a similar size range (average fish length of 22.2 cm), similar to the 23 cm length for the trawler and the 25 cm length for the seiner in the present study, with most fish just below MCRS). However, when larger length ranges (23–62 cm total length) have been studied, higher mortalities of smaller fish have been observed relative to larger fish (e.g., Revill *et al.*, 2013).

3.3.2. Pre-capture oxygen and feeding environment (Case study 3)

Plaice feed on a variety of invertebrates with different minimum requirements for oxygen content in the water. Information about the prey composition in their stomachs should therefore provide a dynamic picture of the oxygen environment of the plaice and not just the snapshot situation at catch. The prey information might thus provide a more realistic relationship between oxygen level experienced by the plaice in a time window prior to capture and the survival rate of discarded plaice. The stomachs of undersized (*i.e.*, discard) plaice were therefore sampled in in each of the two cruises in the Baltic Sea for analysis of prey composition in the stomachs. The aim was to relate the results from these analyses to the oxygen level at each trawl haul and the laboratory survival rate of discard-plaice sampled in the same hauls.

Stomachs with signs of regurgitation were discarded and replaced by non-empty stomachs without signs of regurgitation so that the fraction of stomachs with contents in the total sample was not underestimated. The stomachs were removed and frozen on board as soon as possible to prevent excessive digestion and deterioration of the content prior to laboratory analysis. A pair of tweezers was fixed at the anterior part of the esophagus and the esophagus/pharynx was thereafter cut in front of the tweezers to prevent loss of stomach contents from the esophagus while removing the stomach from the body cavity (Figure 42). The esophagus was kept between the tweezers while the rest of the entrails were removed and until the stomach was bagged. The bagged material was frozen in one layer on a metal plate in the freezer on board and transferred to another freezer on Bornholm at harbour arrival. Finally, the stomachs were transferred in a cooling box with ice or cooling elements from Bornholm to Lyngby for laboratory analysis of the contents. The body lengths of all plaice collected for stomach analyses were measured, including fish with empty stomachs.

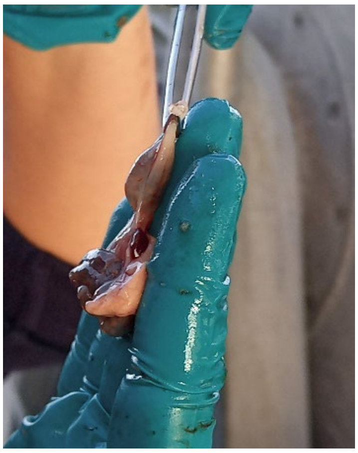

Figure 42. Sampling of plaice stomachs: the oesophagus was kept between the tweezers while the rest of the entrails were removed.

The stomachs were defrosted and those with contents were weighed after removal of excessive visceral material outside the stomach. The content of the individual stomach was then emptied into a petri dish and the empty stomach weighed. The stomach content in the petri dish was identified to the lowest taxon possible. Each prey group was weighed or its contribution to the total stomach content mass was visually estimated.

The feeding strategy and prey mass composition were examined. The feeding strategy was analysed using the modified Costello plot (Amundsen *et al.*, 1996), where the prey-specific abundance (mass here) is depicted against the frequency of occurrence in the stomachs for each prey species/group (Figure 43). The prey-specific abundance is the fraction a prey type comprises of all prey types in only those stomachs that contain the actual prey. The positions of the individual prey in the plot provide information about their importance in the diet of plaice. The grouping of the prey in the plot indicates the food niche width as well as the inter- and intra-individual components of the niche width for the examined plaice population (*e.g.*, whether the plaice are generalists or specialists – and if specialist: whether it is on the population or individual level).

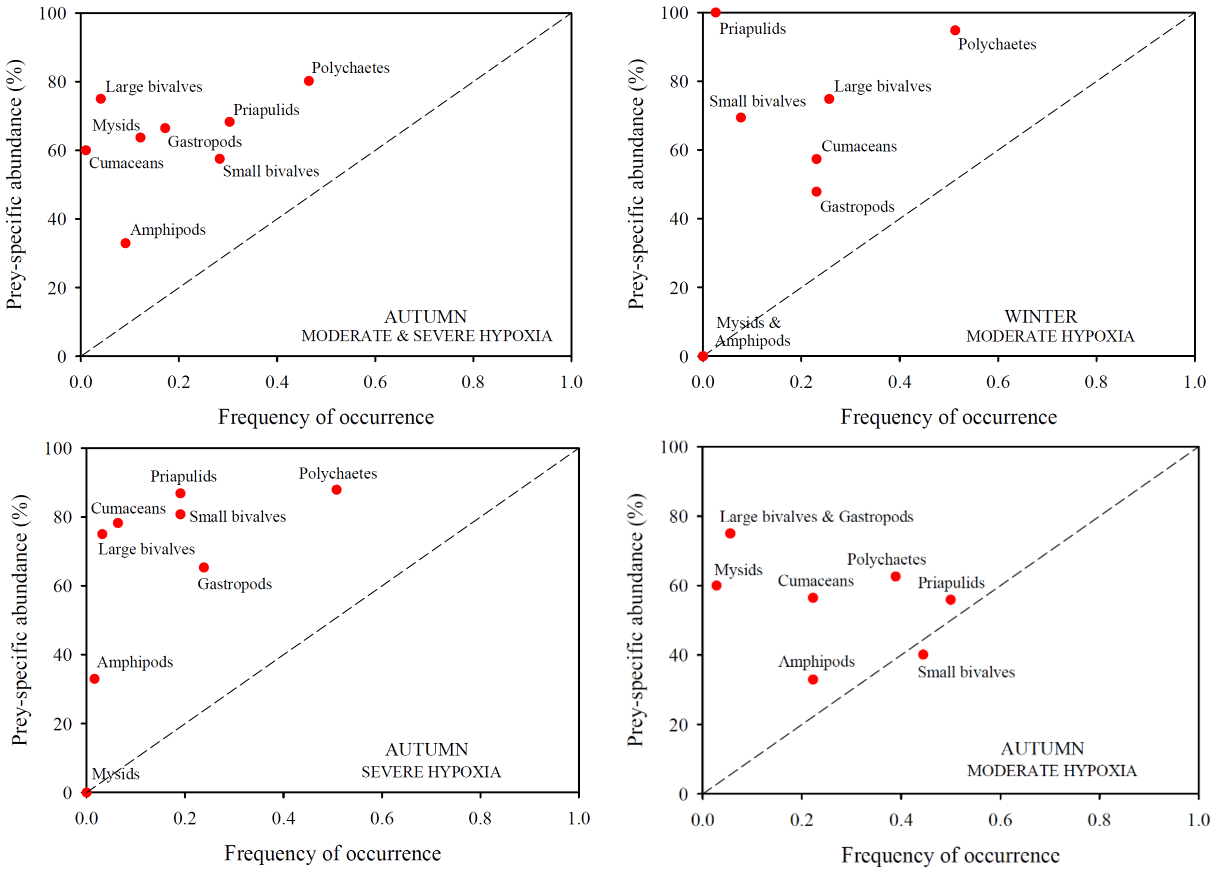

Figure 43. Modified Costello plot for prey obtained from sampled plaice stomachs in the autumn in the eastern Baltic Sea and at wintertime in the western Baltic Sea. The plaice were sampled at bottom conditions of both moderate and severe hypoxia in the autumn, but only moderate hypoxia at wintertime.

The relative contributions of the individual prey groups with each stomach standardized to 100% were used for the statistical analyses testing for differences in prey compositions between two groups of hauls from two areas or two contrasting oxygen conditions at the bottom are tested for statistical differences (Supplementary material B).

The identified prey is listed in Table 9 (grouped for statistical analyses). The sensitivity of the different prey groups to hypoxia increased toward the bottom of the list with *Priapulus caudatus* being far less sensitive (Rosenberg *et al.* 1991, Gogina *et al.* 2016, Haase *et al.* 2020).

A large proportion of the stomachs evaluated to be with prey contents on board the ship showed to be empty when analyzed in the laboratory on land (Table 10). Due to the resulting low numbers in many hauls of stomachs with contents, it was therefore not possible to compare prey compositions from individual hauls statistically, and the haul data had to be grouped. Furthermore, the oxygen condition at the bottom was only contrasting in the autumn cruise (Table 10) with one group of hauls of moderate hypoxia and another one of severe hypoxia. All hauls from the winter cruise were of moderate hypoxia. More detailed basic data on the physio-chemical conditions are provided in Table B.1 in the Supplementary material.

Table 9. Prey list as well as prey grouping for statistical analysis. The sensitivity to hypoxia increases towards the bottom of the table.

Identified prey	Prey group
Priapulis caudatus	Priapulids
Phyllodocid polychaetes	Polychaetes
***Hydrobia* sp.**	Gastropods
Retusa umbilicata	
Abra alba	Small bivalves
Limecola balthica	
Arctica islandica	Large bivalves
Mya arenaria	
***Mytilus* sp.**	
***Gammarus* sp.**	Amphipods
Monoporeia affinis	
Mysids	Mysids
Diastylis rathkei	Cumaceans

Table 10. Number of sampled stomachs as well as temperature and oxygen content at the bottom for each haul.

Date	Haul	Stomachs (*n*)*				Temp.	Oxygen	Depth
	No.	Total	Empty 1	Empty 2	Analysed	°C	% sat.	m
Autumn (eastern Baltic Sea)								
13-10-2020	9	23	5	16	2	7.4	52	41
13-10-2020	10	26	5	17	4	7.4	51	42
13-10-2020	11	17	9	1	7	7.3	54	40
13-10-2020	12	35	13	10	12	7.3	52	41
13-10-2020	13	33	15	7	11	7.9	50	41
20-10-2020	16	33	17	6	10	15.4†	36†	65
21-10-2020	18	83	39	13	31	15.3	36	68
24-10-2020	21	30	21	5	4	15.2	34	65
25-10-2020	22	30	20	1	9	15.4	36	64
25-10-2020	23	41	23	5	13	15.5	39	63
Winter (western Baltic Sea)								
27-01-2021	1	41	21	17	3	8.1	64	45
29-01-2021	6	37	10	17	10	7.8	69	42
31-01-2021	11	27	14	13	0	n/a	n/a	n/a
31-01-2021	12	26	14	9	3	7.4	63	43
31-01-2021	13	53	24	15	14	7.4	63	43
01-02-2021	14	48	24	24	0	n/a	n/a	n/a
02-02-2021	17	50	25	25	0	n/a	n/a	n/a
02-02-2021	18	38	18	13	7	6.1	82	45
03-02-2021	20	59	31	26	2	6.7	72	42

*'Empty 1': stomachs evaluated to be empty on board the ship; 'Empty 2': additional stomachs appeared to be empty in the laboratory on land; 'Analyzed': stomachs with contents for prey composition analysis

† Due to erroneous measurements, temperature and % oxygen saturation is calculated as the averages of the values from hauls 18–23 with similar depth.

The plaice in the sampled areas can be considered individual specialists with most prey categories situated in the upper left corner of the modified Costello plot (Figure 43), which means that the individual prey type is generally consumed by only a moderate part of the plaice and amounts to a significant part in the stomachs in which it occurs.

Comparing all hauls from the autumn with those from the winter (top panels of Figure 44) it appears that there are fewer prey categories in wintertime (amphipods and mysids are missing), which is not surprising. It is also seen here that hypoxia-resistant priapulids are more common in stomachs from autumn. This is probable because a part of these stomachs comes from areas with severe hypoxia.

However, comparing autumn stomachs from moderate hypoxia with autumn stomachs from severe hypoxia (bottom panels of Figure 44), it appears that the difference in feeding strategy is more complex. The stomachs from plaice in areas with moderate hypoxia suggest a more generalized feeding strategy with more prey close to the diagonal line and a generally higher frequency of occurrence. This also includes the hypoxia-resistant priapulids that are common among the stomachs (~50%) suggesting that plaice from these areas are feeding also in areas of severe hypoxia. Overall, the less hypoxic-resistant prey like amphipods and small bivalves from the moderate hypoxic areas are however more common in these stomachs than they are in those from the severely hypoxic areas. Also, the fraction comprised by the four most hypoxia-resistant prey (priapulids –> small bivalves) in the stomachs from the areas of severe hypoxia amounts to as much as 95% of the prey composition (Figure 44), which contrasts with the other areas.

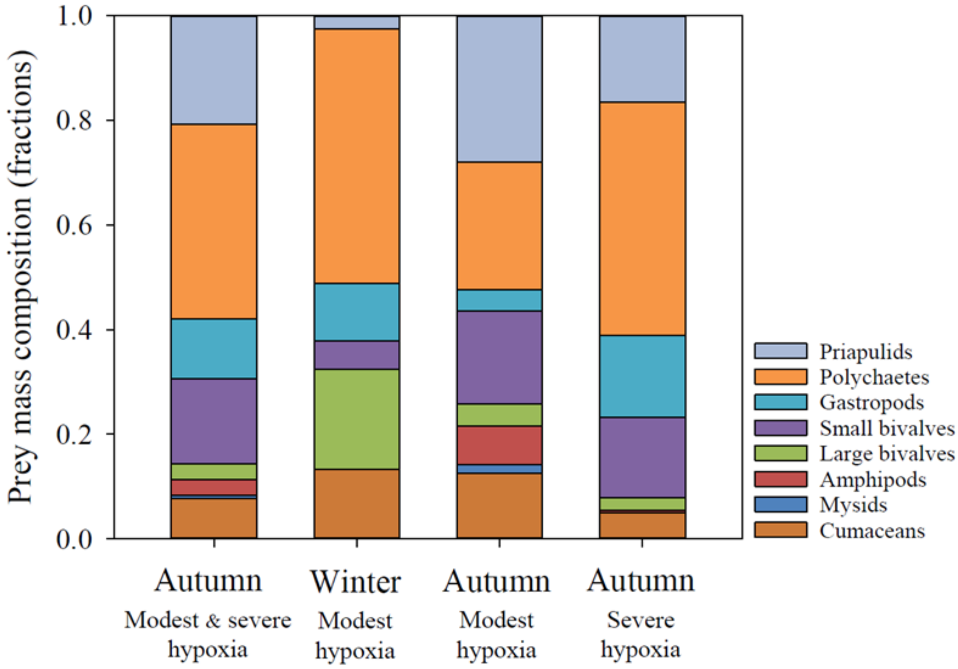

Figure 44. Average prey composition (mass fractions made up by the individual prey types) for the four groups of sampled plaice stomachs.

In accordance with the considerations provided above, the results from the bootstrapping procedure show that the prey compositions (Figure 44) obtained from all groups of stomachs are significantly different (Table 11).

Table 11. Prey composition comparisons - results from the bootstrapping procedure.

T_1^{obs}	T_1^{bst}	P_1	T_2^{obs}	T_2^{bst}	P_2

	95 % quantile			95% quantile	
Autumn (moderate & severe hypoxia) vs. winter (moderate hypoxia) (*n* = 103; *m* = 39)					
0.4523	0.2099	0.001	0.0878	0.0521	0.004
Autumn (moderate hypoxia) vs. winter (moderate hypoxia) (*n* = 36; *m* = 39)					
0.8017	0.2477	<0.001	0.1720	0.0566	<0.001
Autumn (moderate hypoxia) vs. autumn (severe hypoxia) (*n* = 36; *m* = 67)					
0.5357	0.2256	<0.001	0.1115	0.0586	0.001

So, the present data on stomach contents indicate that plaice are performing excursions between areas/depths of different levels of hypoxia. A part of them probably feeds in severe hypoxia and returns to moderate hypoxia/normoxia to digest and recover like it seems to be the case for cod in the eastern Baltic Sea (Neuenfeldt *et al.* 2009). Unfortunately, the sparse amount of data together with the poor condition of the prey in the sampled plaice stomachs did not allow a dynamic description of the temporal feeding pattern and possible shuttling between the areas. More effort in a dedicated feeding study would probably reveal these dynamics.

3.3.3. Hazard from intestinal mollusc shells

An additional variable contributing to post-catch mortality may be damage of the intestine during the catch and sorting processes due to sharp shell fragments in situations where the plaice are feeding heavily on mussels. This has for example been observed in the Skagerrak, where plaice are binge feeding on razor clam in the period after spawning. Information on the amount of shell contents in the intestine should therefore contribute to a clarification of whether there is a relationship between heavy feeding on mussels and discard survival.

The intestines of undersized (i.e., discard) plaice were therefore sampled in the winter cruise for examination of intestinal content of shells. An index of the shell content in the intestine was established for the winter cruise in the Baltic Sea to examine whether heavy feeding on mussels and snails affects the survival rate relating the index to the laboratory survival rate of discard-plaice sampled in the same hauls. The amount of shell material in the intestines was graded by the index Ishell: 0 - no shells; 1 - moderate number of shells; and 2 - the intestine is significantly expanded by shells.

There was no visible relationship between survival and I_{shell} in the winter data. It does not necessarily mean that there was no effect, but we would need additional data to observe a potentially weak effect for survival rates with little contrast and limited data points (the data needs to be pooled by day to be able to compare the stomach hauls with the survival hauls and there were only 5 days where we could do so due to logistics constraints onboard).

3.3.4. Physiological stress from capture (Case study 2)

The capture of fishes entails a cascade of events leading to disturbances of their physiological equilibrium. Initially, fishes will attempt to evade capture by an escape response, in which they attempt to swim away from the fishing gear. If captured, the fishing gear will have caught up with the fish, either because the towing speed of the gear was higher than the swimming capacity of the fish, or because the fish became exhausted and fell back. Following capture, fish will end up in the cod-end of the net along with any other catch. Here, fish will experience a secondary stressor, due to mechanical compression limiting their movement ability and possibly their ability to ventilate their gills. Depending on any capture of non-fish material (peat, rocks, crustaceans, etc.), fish may be subjected to more severe mechanical injury, such as compression or perforation. For trawling operations, the maximum duration of this secondary stressor is potentially as long as the duration of the fishing effort, while for seining, the duration will be considerably shorter. Upon retrieval of the gear, the catch is subjected, in addition to the possibility of being pulled through layers of water differing in temperature, salinity and oxygen, to air and light exposure lasting as long as the handling and sorting operations on deck.

The two main stressors in the capture process outlined here are exhaustion and reduced ability to ventilate; the latter caused either by mechanical compression of the gill operculum or air exposure. The physiological manifestation of exhaustion is elevation of blood cortisol levels as a mechanism to mobilize energy stores, depletion of energy reserves, blood and tissue acidification, and accumulation of metabolites from aerobic and anaerobic metabolism. The inability to ventilate means that the recovery process cannot be initiated, and potentially a further exacerbation of conditions.

The severity of the physiological distress caused by capture and handling will determine the ability of a fish to recover, as well as the time required to make a full recovery. The magnitude of physiological distress from capture and handling was measured in plaice captured by trawl in the early spring (March) and summer (August) immediately following capture, and after a simulated 45 min and 90 min sorting period. In addition, measurements were performed on fish that had been allowed to recover for 10 days. Measurements were also taken from fish caught from commercial vessels, one fishing with a trawl whilst another fishing with a Danish seine. Both commercial catches were conducted in October.

The overall aim of this work was to assess seasonal differences in the magnitude of physiological distress from capture, the temporal development in stress responses following retrieval of the fishing gear, and the effect of gear type.

Capture of fishes in March and August was achieved by trawling for 3 hours from R/V Havfisken (see 2.5). The cod-end of the trawl was emptied into the first pounder on-board the vessel, from where it was transported to a second pounder adjacent to the sorting table. Immediately, the first 10 fish at or below the MCRS (27 cm) were sampled for blood and skeletal muscle. A subsample of blood (March only) was analysed for plasma glucose, whole blood pH, partial pressure of CO_2 and plasma bicarbonate using a point –of-care analyser (i-stat, Abbott Laboratories, IL, USA) with EC8+ cartridges. The remaining blood sample was centrifuged for 5 min at 6.000 rpm and the plasma fraction was snap frozen in liquid nitrogen (Figure 45).

Figure 45. Taking blood sample from the fish (left) and post-processing the sample (right).

Following blood sampling, the head of each fish was frozen in liquid nitrogen for later analysis of brain levels of adrenaline (Ad), dopamine (DA), serotonin (5-HT), dopamine metabolite (DOPAC), and serotonin metabolite (5-HIAA) in the telencephalon by high-performance liquid chromatography with electrochemical detection (HPLC-EC) as described by Gesto *et al.* (2017). Brains were also assessed for the occurrence of haemorrhaging by visual scoring from 1-5, where 1 is no haemorrhaging and 5 is severe haemorrhaging.

A muscle sample (approximately 1 gram) was excised from immediately above the lateral line approximately at the level of the tip of the pectoral fin. Tissue samples were snap-frozen in liquid nitrogen. Analyses of glycogen and lactate were performed using commercial kits (Sigma Aldrich, (MAK-016 and MAK-064 respectively). Plasma levels of cortisol were analysed using a commercial cortisol kit (Neogen Life Sciences) whereas lactate and glucose levels were determined using handheld plasma analysers.

To determine to what extent the blood of plaice may sustain damage from mechanical or osmotic distress, mechanical and osmotic fragility tests were also conducted. Briefly, whole blood was subjected to mechanical distress by rotating blood samples in the presence of a stainless-steel bearing for 20 minutes, after which the amount of haemolysed blood was assessed by determination of the haemoglobin content in the plasma fraction. For osmotic fragility tests, blood was progressively diluted with distilled water and the amount of haemolysed blood was determined as for the mechanical fragility test.

Brain hormones
Dopamine (DA) levels immediately following capture (t0) in March were not significantly different from levels measured in 10 days recovered fish and showed only a tendency for reduction in response to increasing handling times (t45, t90) (Figure 46A). In contrast, DA levels for the t0 group in August showed a significant decrease compared to the same time point for March and for recovered fish and had a stronger tendency to decrease with increasing sorting times. This was also reflected in the dopamine metabolite (3,4-Dihydroxyphenylacetic acid, DOPAC) levels that were elevated for the August trawl, but not for the winter trawl or recovered fish (Figure 46B). Serotonin levels did not differ between seasons (Figure 46C) or in recovered fish (Figure 46D), and a similar response was seen for noradrenaline (Figure 46E).

Brain haemorrhaging
Visual inspection of the dissected brain showed a high degree of haemorrhaging in the outer layer of the brain. Compared against to the 10 day recovered fish (although these also had a relatively high degree of haemorrhaging - score 1,7) the t45 and t90 groups from the summer trawl showed significantly higher scores (3,8 – 3,9) than the remaining groups.

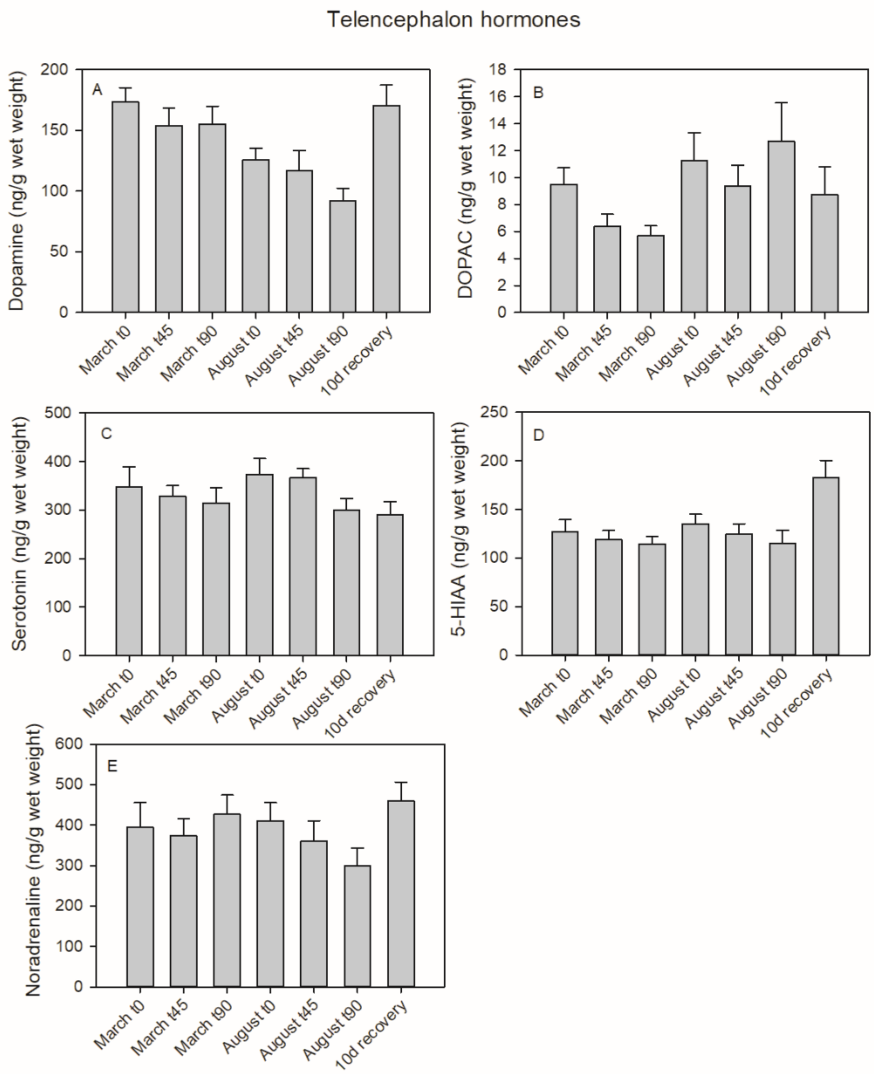

Figure 46. Telencephalon levels of dopamine (A), the dopamine metabolite, DOPAC (B), serotonin (C), the serotonin metabolite, 5-HIAA (D), and noradrenaline for plaice captured in winter (March) and summer (August) immediately following landing on deck (t0) and after 45 (t45) and 90 (t90) minutes sorting time. For comparison, values for fish that had been brought to on shore holding facilities and recovered for 10 days (10d recovery).

Blood chemistry

Upon landing, fish had already doubled their blood glucose levels compared to recovered fish, and blood glucose levels continued to increase with increasing sorting times (Figure 47A). Plasma pH levels were significantly decreased at the time of landing (on deck), compared to recovered fish, and decreased further as sorting times increased (Figure 47B). This decrease in pH was presumably in part driven by an increase in hypercapnic conditions of the blood as pCO_2 levels continued to increase with sorting times (Figure 47C), and the change in pH probably also facilitated dehydration of plasma bicarbonate as evidenced by decreasing levels of plasma HCO3 (Figure 47D).

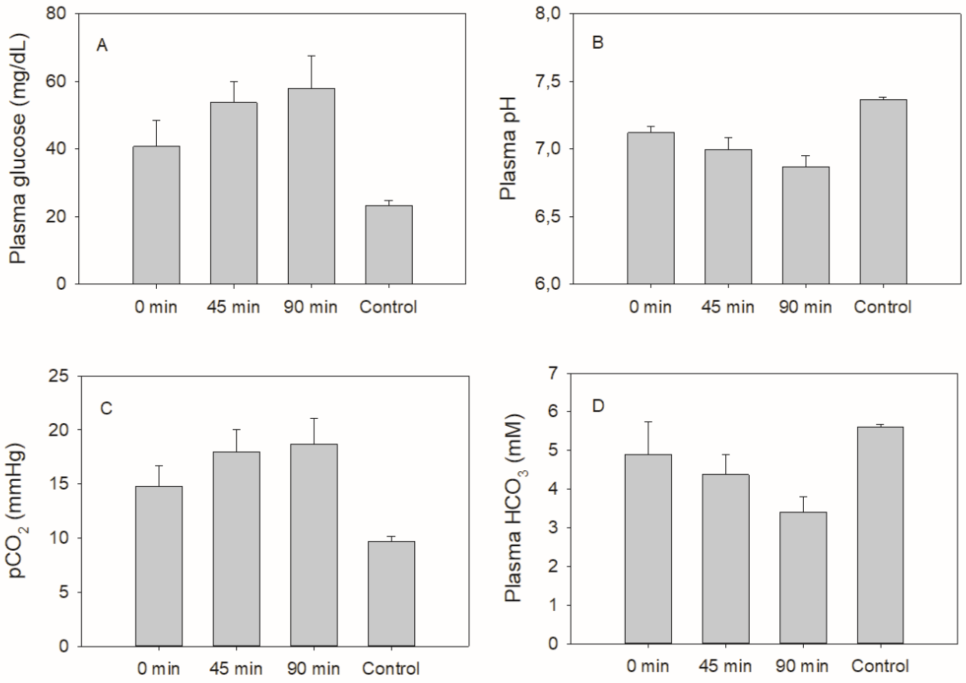

Figure 47. Data for plasma glucose (A), blood pH (B), partial pressure of CO2 in the blood, pCO2 (C) and depletion of bicarbonate (HCO3-) immediately following capture and during progressive increases in sorting times from the winter trawl (March).

Muscle glycogen

White muscle glycogen stores became progressively depleted with increasing sorting times (Figure 48A). The rate of depletion did not differ between winter and summer, but initial levels immediately following capture were lower for fish caught during warmer water temperatures in August. Data from the commercial fishing vessels showed that glycogen reserves in fish caught by trawl tended to be more depleted than for fish caught by Danish seine (Figure 48B). Surprisingly, glycogen levels in fish that had recovered on shore for 10 days had not replenished their glycogen stores.

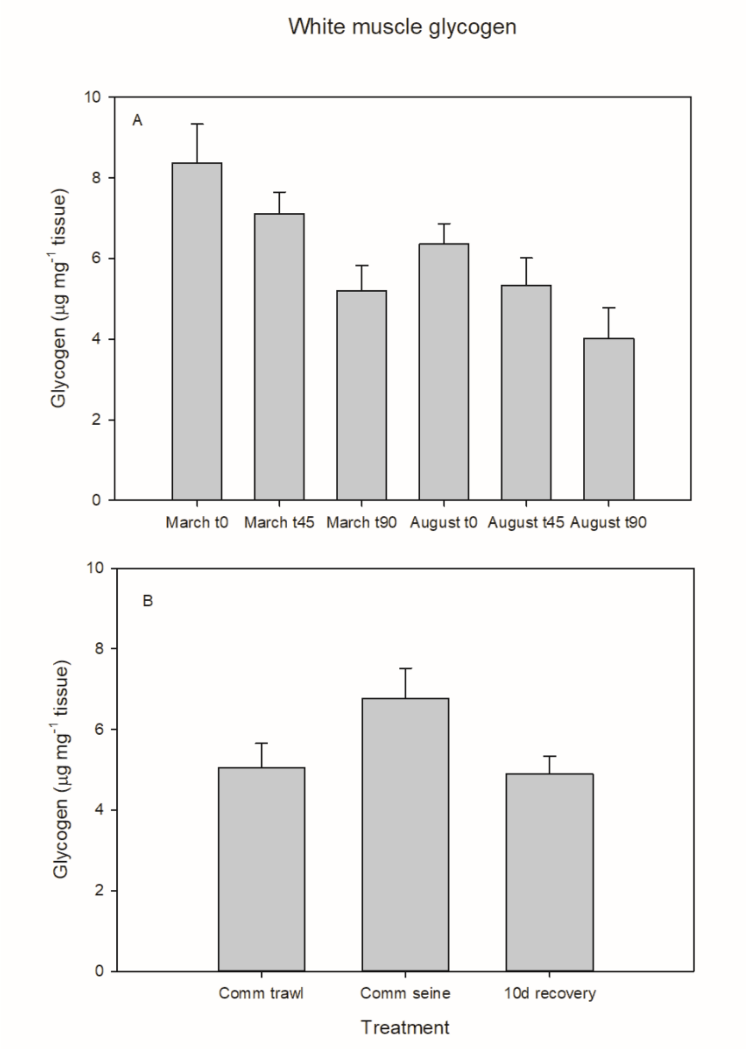

Figure 48. White muscle glycogen reserves in fish caught during winter (March) and summer (August) and during progressively increasing sorting times (A). White muscle glycogen levels from fish caught by a commercial trawler and Danish seine are shown in panel (B) along with data from fish that had recovered for 10 days on shore.

Muscle lactate
Analysis of the accumulation of muscle lactate is given in Figure 49. There was no correlation between the amount of muscle lactate in relation to either season or sorting time (Figure 49A) nor in the comparison with the commercial trawl vessel or the seine vessel. Fish that had been allowed to recover for 10 days had cleared their muscle lactate and had levels that were significantly lower than for captured fish.

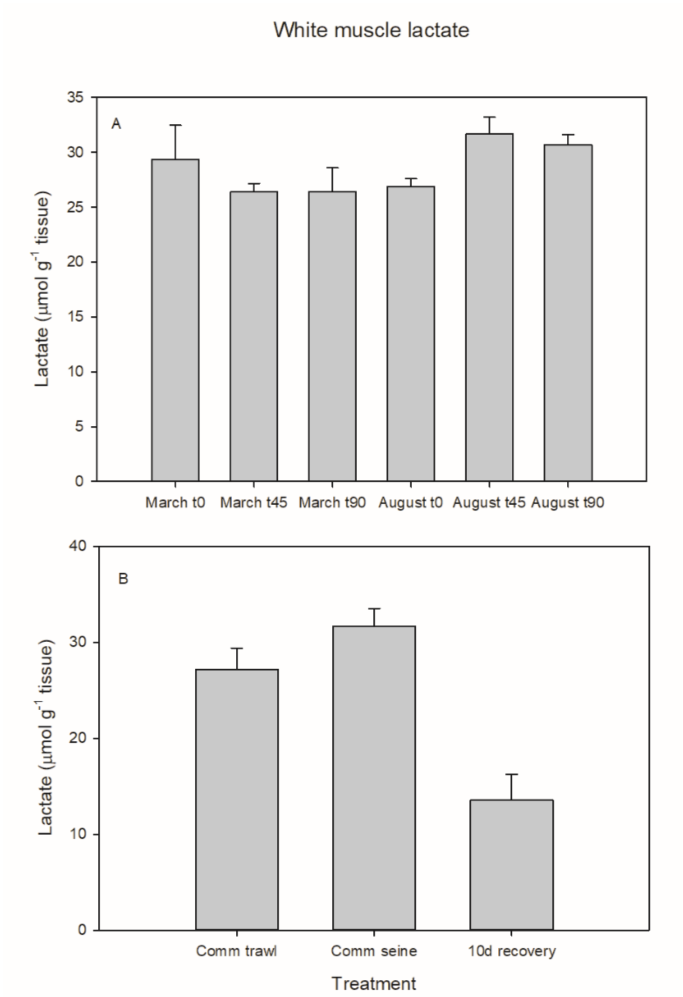

Figure 49. White muscle lactate concentrations in fish caught during winter (March) and summer (August) and during progressively increasing sorting times (A). Muscle lactate levels from fish caught by a commercial trawler and Danish seine are shown in panel (B) along with data from fish that had recovered for 10 days on shore.

Osmotic and mechanical fragility test
The osmotic fragility test showed that the onset of blood haemolysis did not occur until plasma osmolality was reduced by approximately 30% (Figure 50). This was not significantly influenced by the presence of adrenaline, although there was a tendency for adrenergically stimulated red blood cells to reach 50% haemolysation at a higher relative osmolality (0,51 vs. 0,47).

The mechanical fragility test did not indicate that handling or mechanical influence of the fish during the capture process would result in haemolysis of the blood.

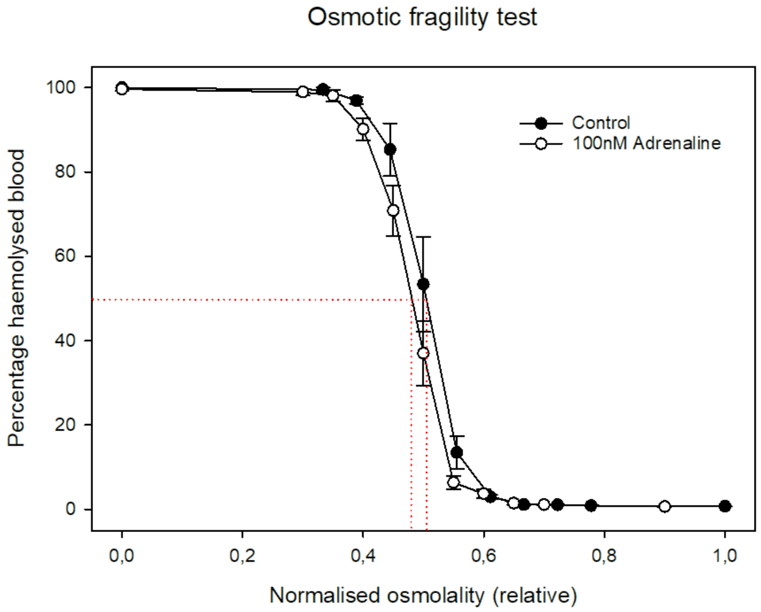

Figure 50. The percentage of haemolysed blood in relation to relative changes in plasma osmolality achieved by dilution with mixtures of distilled water and 0,9% NaCl, in the absence or presence of 100nM adrenaline. The onset of haemolysis occurs at a relative osmolality of 0,64 for both treatments, although adrenergic stimulation reveals a tendency for 50% haemolysis to occur at a higher relative osmolality, as indicated by the red drop lines in the graph.

The results reveal two main findings. The first is that the level of exhaustion based on the metabolic indicators is negatively influenced by increasing temperatures. In summary, fish that were trawled during the summer showed a depletion of dopamine. Dopamine is a hormone that is known to modulate the cortisol response, and therefore dopamine depletion can be interpreted as an increase in the overall stress of the animal. A higher rate of dopamine turnover in the summer caught fishes is supported by the general elevation of the dopamine metabolite DOPAC. Furthermore, fish that were caught during the summer months also showed a greater degree of muscle glycogen depletion, indicating that capture during warmer conditions is energetically more costly, in comparison to fish caught during the winter period. Surprisingly, the muscle lactate levels were not elevated in the fish caught during the summer. The haemorrhage scoring of fishes shows that prolonged sorting times during the summer will likely be fatal for fish.

The second main finding of the study is the effect of sorting times. In the present study, groups of fish were sampled immediately following landing, while two additional groups were sampled 45 minutes and 90 minutes after landing, to simulate the maximum amount of time that it might take to sort the catch and discard the undesired fraction of the catch. During this sorting time, fish remained out of the water and therefore had no possibility to initiate recovery. As sorting times increased, glycogen levels became progressively depleted. This was also evident from the increasing levels of glucose that were mobilised to the blood of the fish. The decrease in plasma pH and increase in CO_2 show that fish rely on anaerobic metabolism during sorting, and that they cannot rid themselves of the metabolites from this process, leading to increased distress.

The fish that served as an internal control (the 10-day recovery group) did not show complete recovery following capture after 10 days of holding in captivity. The present results do not lend evidence as to why this might be. Following arrival at the land-based holding facility, fish were not fed for the first 7 days, because previous experience in survival studies showed that fish are not particularly interested in feeding. Hypothetically, the lack of feeding might explain why, for example, fish were not able to recover the muscle glycogen to normal levels. Future studies should strive to make feed available to fish held in captivity.

Overall, dopamine levels, plasma glucose, plasma pH, plasma pCO_2, plasma bicarbonate, and muscle glycogen are all useful indicators of the magnitude of physiological distress experienced by the fish following capture and sorting. For most, these are not variables that can be employed by the fishing industry but provide insight into the response variables to trawling. Degree of brain haemorrhaging might, with proper training, serve as a useful tool or indicator for the probability of survival. Future studies should include monitoring of these variables in the recovery phase, to determine how quickly (or slowly) fish are able to recover from the capture process.

3.3.5. Effects of hypoxia on recovery of trawl-caught plaice (Case study 3)

Capture and/or discard in hypoxic conditions may impede recovery and lengthen the window in which fish are at greater risk for predation or delayed mortality due to the fishery interaction. Discard in hypoxic conditions may in addition increase the risk of a predatory encounter as the fish may attempt to seek normoxic conditions. Controlled experiments in the laboratory complement our knowledge on the possible effects of oxygen conditions on discard survival.

Fish were exposed to simulated trawl conditions consisting of mechanical chasing until unresponsive to tactical stimulation (i.e., total reflex impairment), followed by 15 minutes of air exposure. The significance of dissolved oxygen levels following discard was assessed in groups of fish using respirometric approaches to quantify oxygen uptake and biochemical analysis of muscle and blood samples. Groups of fish (n = 8) were transferred to respirometers following trawl simulation and their oxygen uptake levels were monitored during the following 24h (discarding) under either normoxic (>90% O_2 saturation), or 50 and 30% O_2 saturation (Figure 51). Fish in all treatment groups showed an increase in oxygen consumption during discarding, but fish in the 30 and 50% O_2 saturation groups were significantly impaired in their maximum oxygen uptake rates (50-65% reduction) (Figure 52).

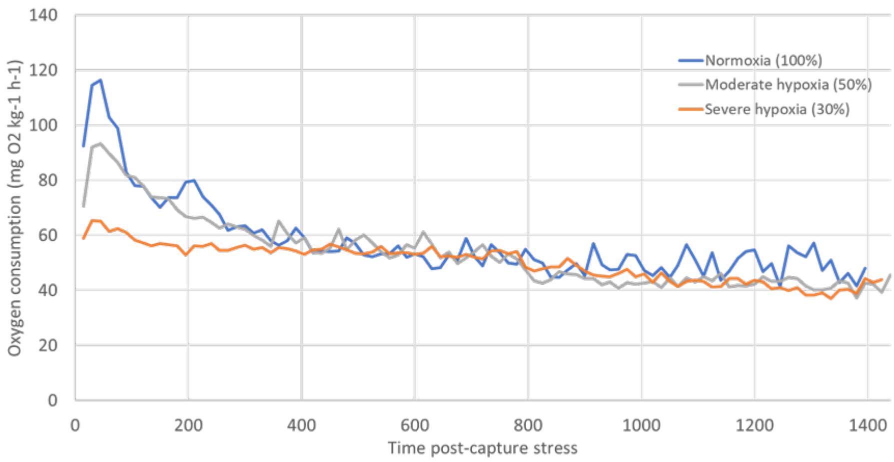

Figure 51. Oxygen consumption rates in plaice discarded to normoxic and 2 levels of hypoxic conditions following simulated trawl. Each trace is an average of measurements from 8 individuals. Hypoxia impairs the maximum amount of oxygen that fish can extract from the water to fuel their recovery.

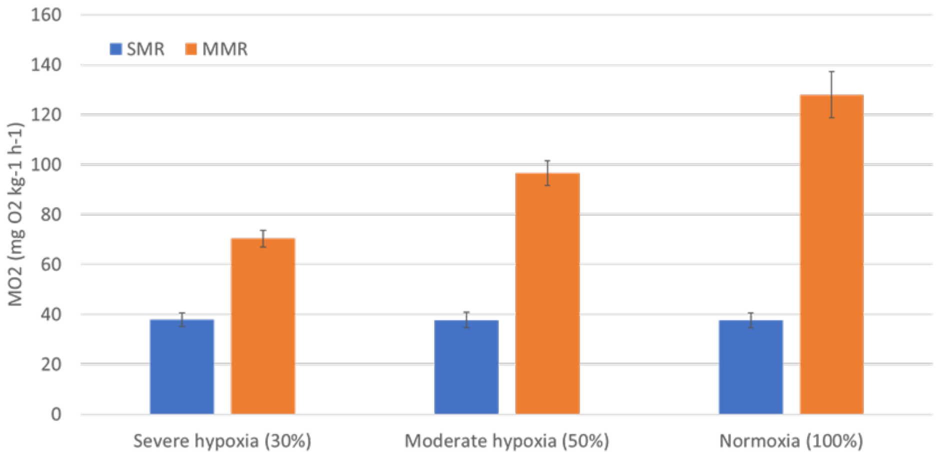

Figure 52. Baseline and maximum oxygen consumption during recovery, illustrating the reduced capacity to extract oxygen from the water during hypoxic conditions. For the most severe hypoxia treatment, this resulted in a 65% loss in metabolic scope, calculated as the difference between the maximum and standard metabolic rates.

The hypoxic groups had a significantly smaller oxygen debt following discard, indicative of an inability to fully recover from trawl during the discard period (Figure 53). This is somewhat counterintuitive since fish in hypoxia would be more likely to have a larger oxygen debt, but presumably reflects a larger utilization of anaerobic pathways not reflected in the respiration data, or that is prolonged beyond the 24h observation period.

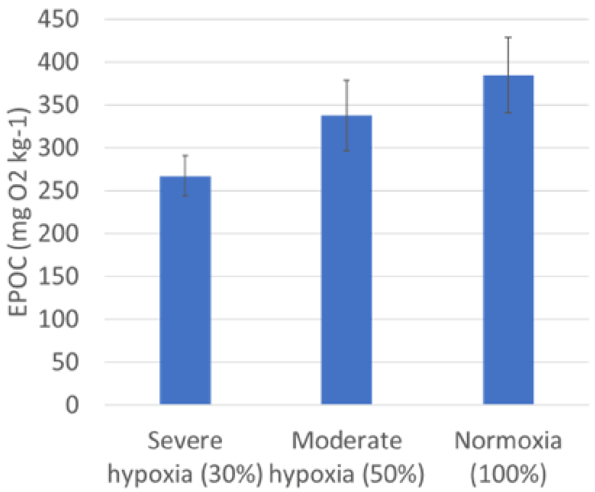

Figure 53. Total oxygen (cost of recovery) in the 24h following discard. Fish in severe hypoxia show a decrease in excess post-exercise oxygen consumption (EPOC, or oxygen debt), which is more likely to be the result of an increased reliance on anaerobic metabolic pathways or a prolonged recovery period.

Fish discarded to hypoxic conditions showed a significantly higher cortisol response indicative of a larger stress response, as well as a significantly higher lactate release rate, demonstrating an increase reliance on anaerobic metabolism when being returned to oxygen poor waters, which was further supported by a larger depletion of glucose reserves by the fish (Figure 54).

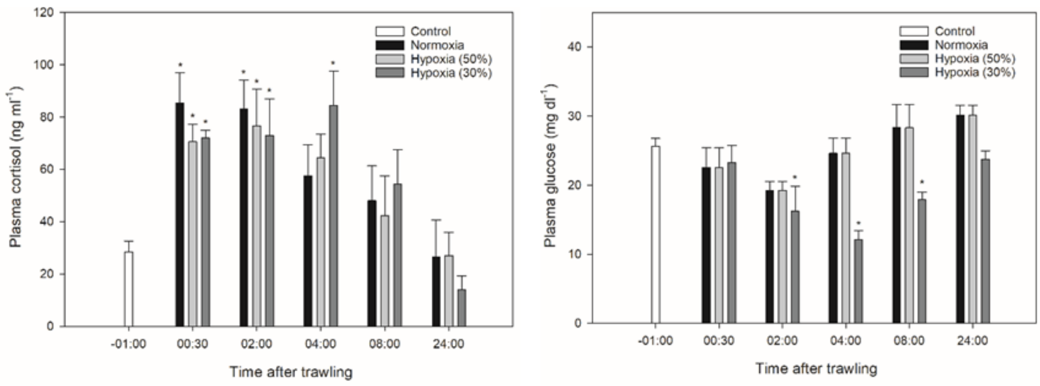

Figure 54. No differences in the maximum cortisol response were observed between hypoxic and normoxic treatments, but under the most severe hypoxic conditions, the elevated cortisol levels persisted for more than 4 hours, at which point the normoxic and intermediate hypoxia group showed recovery (left panel). Plasma glucose levels in the severe hypoxia group were significantly depleted compared to the moderate hypoxia group and the normoxic group but recovered at 24h (right panel).

Muscle creatine, a metabolic end-product of phosphocreatine degradation, was significantly elevated in both treatment groups, indicating a larger energy turnover, which was also observed for inorganic monophosphate resulting from de-phosphorylation of ATP. Measurements of ADP and AMP showed a faster rate of degradation in the hypoxic treatment groups. Overall, the results show that fish that are discarded to hypoxic waters have a more severe stress response and a prolonged recovery period. Despite this, all treatment groups recovered their measured biochemical indicators and oxygen consumption rates to pre-stress conditions within 24h. There were no stress-related mortalities in any of the treatment groups during the experiments. Fish that were exposed to trawl simulation and discarded to hypoxic conditions showed no indications of trying to escape oxygen-poor conditions, instead they all burrowed in the sediment immediately following release. It remains unequivocal whether simulated trawl exerts the same magnitude of stress as experienced during commercial fishing.

4. Predicting discard survival

The common way to estimate survival rates is to observe fish in captivity that would be discarded under commercial conditions, until the mortality levels off, i.e., approaches an asymptote (ICES, 2014). Such captive observation studies are labour-intensive, logistically challenging and financially demanding. As an alternative, the use of fish condition as a potential predictor for mortality has been discussed over the last years for different species and fisheries (e.g., Davis, 2007, 2010; Humborstad *et al.*, 2009; Barkley and Cadrin, 2012; Raby *et al.*, 2012; Uhlmann *et al.*, 2016; Methling *et al.*, 2017). Indeed, measures of impairment in fish condition can be used as an indicator for discard survival providing that they are calibrated with survival likelihood estimates from, e.g., captive observation studies.

Promising indicators of fish condition as good survival proxies are external damages and reflexes (scoring the presence or absence of pre-determined attributes), as well as vitality (ICES, 2014; Davis, 2010; Uhlmann *et al.*, 2016; van der Reijden *et al.*, 2017).

It was shown that the relationships between these proxies and mortality are species-specific (e.g., Davis, 2007), but also depend on the conditions in which the proxy-survival relation was established. A good predictor must be correlated with discard mortality over a wide range of fishing conditions (Davis, 2007). It should also be demonstrated that the chosen proxy is transferable between certain species and gears by having species and fishery-specific vitality-survival calibrations.

4.1. External damages and reflexes

Figure 55. Visual assessment of the fish for external damages and reflexes onboard the fishing vessel.

External damages account for impairments to the fish which are visually observable and known to have a direct relationship with trauma and potential infection, and thus mortality, e.g., scale loss, bruises, and injuries (Figure 55). Reflexes are innate involuntary actions or responses to a stimulus (e.g., touch) that account for impairments to the fish which are not visually observable such as internal injuries. Reflexes are initiated by the neuro-muscular response system directly related to vitality, and therefore independent of the effect of other factors such as size or sex (Uhlmann *et al.*, 2016). Relevant external damages and reflexes are identified for the species of interest by in-situ observations of the most representative attributes, together with the collection of unimpaired individuals, to define which attribute can be consistently scored.

External damages and reflexes can be further combined to a single index score, by summing the array of individual scores for each attribute (also known as aggregated vitality assessment). This approach is simple, but assumes that (i) the presence of one attribute is unrelated to the presence of the others, i.e., no multi-collinearity between attributes, (ii) attributes have an additive effect on survival, i.e., no interaction with other operational/environmental/biological factors, and (iii) attributes contribute equally to survival, i.e., no better predictors than others as the different attributes are given an equal weighting factor of one. These assumptions may not be always verified. As an alternative, WGMEDS has suggested that individual attributes should be fitted as separate parameters within a statistical model (also known as partitioned vitality assessment; Breen and Catchpole, 2021).

Aggregated and partitioned vitality assessment provides a detailed description of the health, external damages, and reflex impairment of the sampled individuals. However, this can be at the expense of a longer and more complex assessment. Indeed, a good predictor must be easy to collect at sea as one possibility to widen the conditions under which survival is assessed is to ask observers at sea or fishermen to self-sample. The chosen proxy should therefore be easy to understand and assess.

4.2. Vitality class

Vitality class (also known as categorical vitality assessment) is a more general assessment of the fish. It has various definitions from one study to another, but is usually given as a four-level ordinal index based on fish injuries and body movement (Benoît *et al.*, 2010; van Beek *et al.*, 1990).

Vitality, reflex, and damage assessment was done for plaice and lemon sole. Harmonizing methodology across study observations allows data to be pooled from a larger number of trips. Observer variation: training rather than experience of raters minimized inter-rater differences (Meeremans *et al.* 2017). Training took place together with an experienced observer and specialist in reflex assessment, Sebastian Uhlmann, ILVO, Belgium. To our knowledge, this is the first assessment of lemon sole aiming at identifying a set of relevant assessment criteria for further use as a Reflex Action Mortality Predictor (RAMP). There is no MCRS for lemon sole, even though the market size is usually above 26 cm.

4.2.1. Vitality of the caught fish (Case study 2)

Vitality assessment was conducted immediately after sorting of the catch onboard the vessel (Figure 56). Each individual was given a vitality score using the criteria in Table 12. Fish that appeared dead after sorting were included in vitality class 4, and some of these moribund individuals quickly recovered after the assessment.

A total of 151 individuals from 7 hauls were assessed onboard for external damages, reflexes, and vitality, and observed in captivity, during the research trial in the winter. A total of 820 undersized plaice from 37 hauls were assessed onboard for vitality, and observed in captivity, during four commercial trials.

Figure 56. Assessment of the fish on deck using a fish measuring board, weight and PIT tags (left). This included scoring of the fish condition (vitality, reflexes, and external injuries) in an assessment box filled with fresh sea water (right).

Table 12. Description of the four vitality classes, based on both body movements and damages.

Vitality class	Description of body movements	Description of damages
1: lively	Active	Minor damages
2: less lively	Body movement recognizable	Visible damages / hemorrhages
3: lethargic	Body does not move but mouth/operculum movement recognizable	Apparent damages / hemorrhages
4: moribund	No body movement or mouth/operculum movement	Pronounced damages / hemorrhages

The reflexes "head complex" (R3) and "evasion" (R4), and the external damages "body bruises" (D3), "intestines" (D4) and "wounds" (D5) responded most consistently from individual to individual among fit individuals, i.e., 15 min hauls (Figure 57). Among these five attributes, the most relevant for reflex impairment and damage absence occurring at three different air exposures among commercial individuals, i.e., 180 min hauls, were the reflexes "head complex" (R3) and "evasion" (R4) (Figure 58).

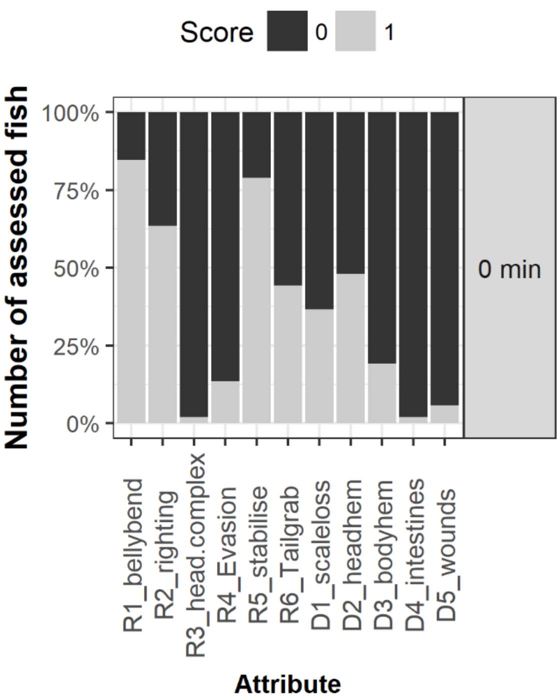

Figure 57. Number of assessed fish by score (0 = reflex unimpaired or reflex absent, 1 = reflex impaired or damage present) for each tested attribute on plaice to find which attributes respond most consistently among fit individuals (15 minutes hauls) during the research trial (bottom otter trawl).

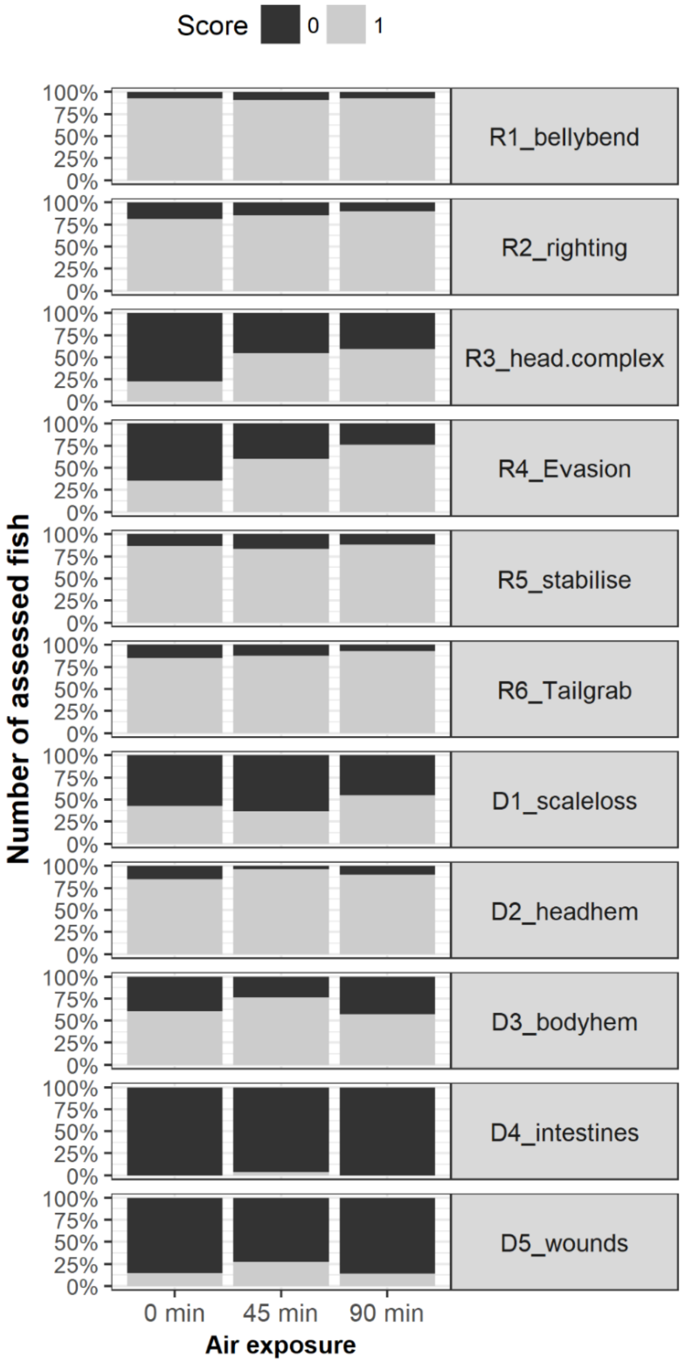

Figure 58. Number of assessed fish by score (0 = reflex unimpaired or reflex absent, 1 = reflex impaired or damage present) for each tested attribute on plaice to find the most common and relevant attributes occurring at 0-, 45- and 90-minutes air exposure among commercial individuals (180 minutes hauls) during the research trial (bottom otter trawl).

4.3. Effect of temperature on vitality/reflexes

Warning: The results presented here are based on plaice caught by Belgian beam-trawlers.

Estimating and predicting mortality of caught-and-released organisms from both recreational and commercial fishing using the reflex action mortality predictor approach requires responsiveness of innate reflexes to be independent of temperature. In this study, reflex responses and survival of beam-trawled-and-discarded plaice were registered and evaluated whether they are independent from seasonal, acclimated temperature or temperature shocks as part of the catch-and-discarding process (<10 °C from ambient water or air temperatures, with 10 min exposure times). Temperature differences (cold or warm shocks) that a fish may experience during trawling, sorting, and discarding into potentially thermocline-stratified water were induced by both manipulating (warming and cooling) air temperatures on-deck of the fishing vessel and cooling water (in summer) and warming (in winter; Figure 59). In total, 324 beam-trawled plaice (n=196 in summer and n=128 in winter) were exposed to two modified air temperature treatments and one modified (cooled in summer and warmed in winter) and one ambient water temperature treatment to represent the potential thermal shocks a fish may experience along the pathway of being beam-trawled-and-discarded (Figure 59).

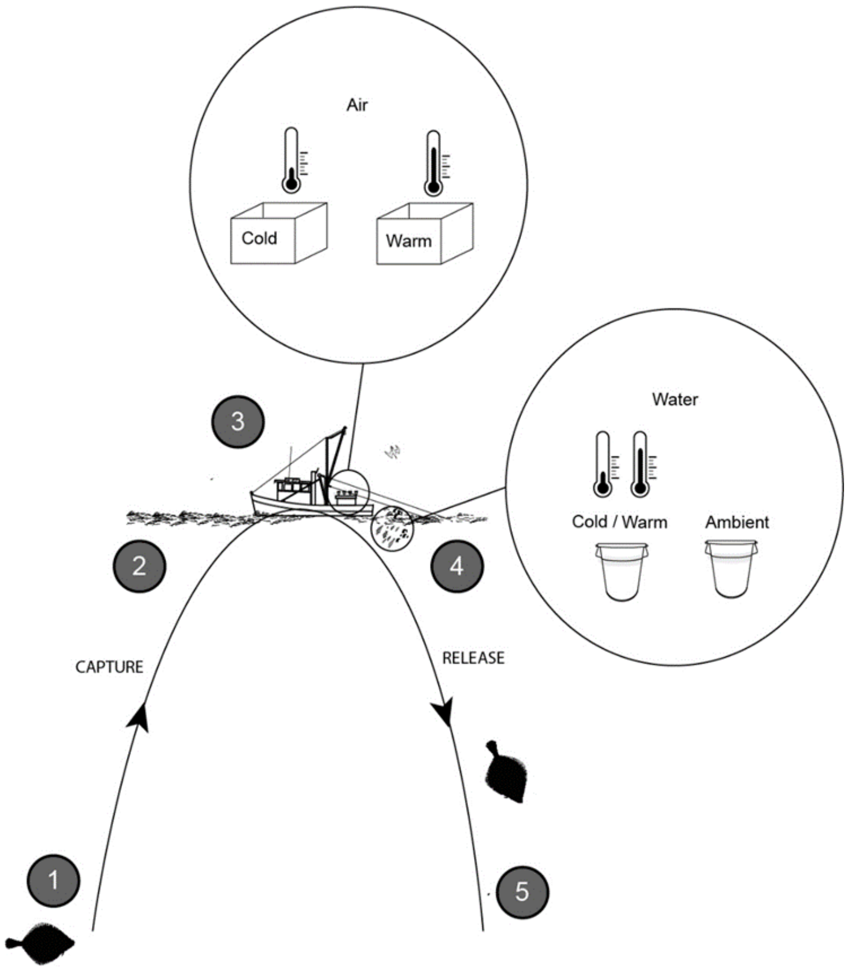

Figure 59. Schematic representation of the temperature treatments recreated to represent the potential seasonal temperature differences a plaice may experience in its pathway of being beam-trawled and discarded. From the seafloor, its acclimated environment (1), a plaice is hauled through the water column to the surface (2), lifted out of the water and sorted on deck while being exposed to air (3), and if unwanted, released at the surface (4), from which it swims back down to the seafloor to recover through potentially thermocline-stratified water (5).

It was hypothesized that both seasonality and temperature shocks were likely to affect all those reflexes which represent spontaneous behavioural responses to a stimulus, and therefore their combination, the reflex impairment index. Spontaneous reflexes were considered to include all but the head complex (i.e., body flex, righting, evasion, and tail grab). As a true reflex, the head complex reflex was expected to be affected by the acclimated temperature at the seafloor and therefore seasonality, rather than by temperature differences experienced onboard. For post-release survival, it was hypothesized that in summer fish may be more affected, and therefore less likely to survive, by any experienced temperature shock than in winter as they are closer to their temperature tolerance limit. It was also hypothesized that post-release survival may be partially predicted by the reflex impairment index.

Both spontaneous and true reflexes were affected by ambient temperature, and thus, were not independent of environmental conditions. By investigating the role of temperature in affecting vitality and probability of survival among beam-trawled and discarded plaice, it was demonstrated that the water temperature to which fish were acclimated to at the seafloor rather than the temperature differences (cold or warm shocks) that a fish may experience during trawling, sorting and discarding into potentially thermocline-stratified water columns had a greater effect on both impairment of reflexes and survival of plaice (Figure 60). In the winter compared to summer, fewer reflexes were impaired, and survival was higher among beam-trawled plaice. All reflexes showed high impairment in summer, and except for the body flex reflex, none were affected by temperature shocks alone (Figure 60).

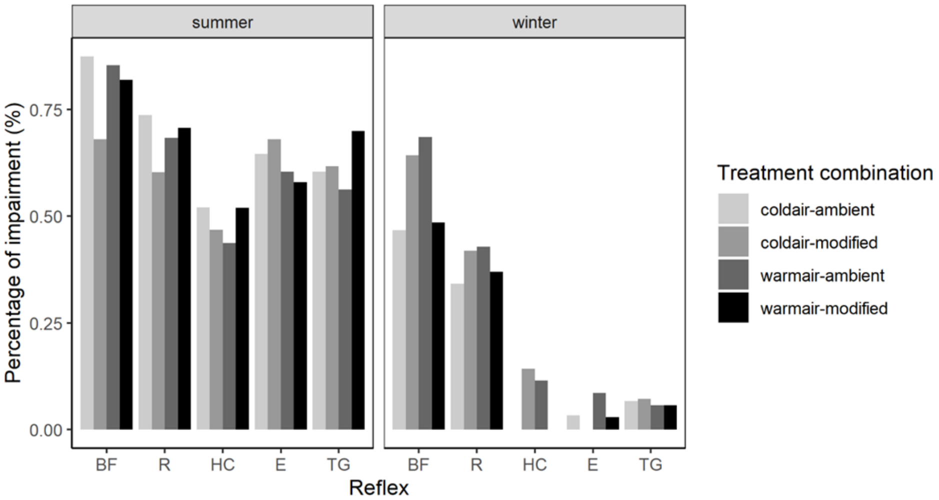

Figure 60. Percentage of impairment of each of the five reflex responses assessed among sampled plaice after exposure to each treatment combination per season (BF=body flex; E=evasion; HC=head complex; R=righting; TG=tail grab). To simulate the temperature change when plaice transition from water to a potentially variable air environment after capture and during on-board handling and sorting, plaice were exposed to an air temperature treatment, where air was both chilled (coldair-treatment) and heated (warmair-treatment) on-board (Phase 3). To simulate what discarded fish may experience when transitioning from air to water and returning to the seafloor through a potentially thermocline-stratified water column (Phase 4; previous Figure), fish were discarded into either an ambient or modified (heated in winter or chilled in summer) water temperature treatment. The ambient water treatment was meant to represent the environment the fish was acclimated to (= no temperature shock from water treatment, only from air). The modified water temperature treatments depended on the season and represented thermocline-stratified water, summarizing to the following temperature conditions: a) Summer - Modified water treatment = cold shock, presence of a thermocline when returned to the water going back to colder environment after discarding; b) summer - ambient water treatment = no shock, no thermocline; c) Winter - Modified water treatment = warm shock, presence of a thermocline when returned to the water going back to warmer environment after discarding; and d) winter - ambient water treatment = no shock, no thermocline.

Body flex was highly impaired under every exposure combination and was therefore suggested to be used to distinguish responses of captured-and-discarded from unstressed individuals. Fish size and air exposure further influenced the impairment of some reflexes. Post-release survival was low in summer (21%) and high in winter (99%; Figure 61Figure 61). Beam trawling in summer is likely to have deleterious consequences for any discarded plaice, and therefore temporal-spatial mitigation approaches should be prioritised over controlling temperatures on-board.

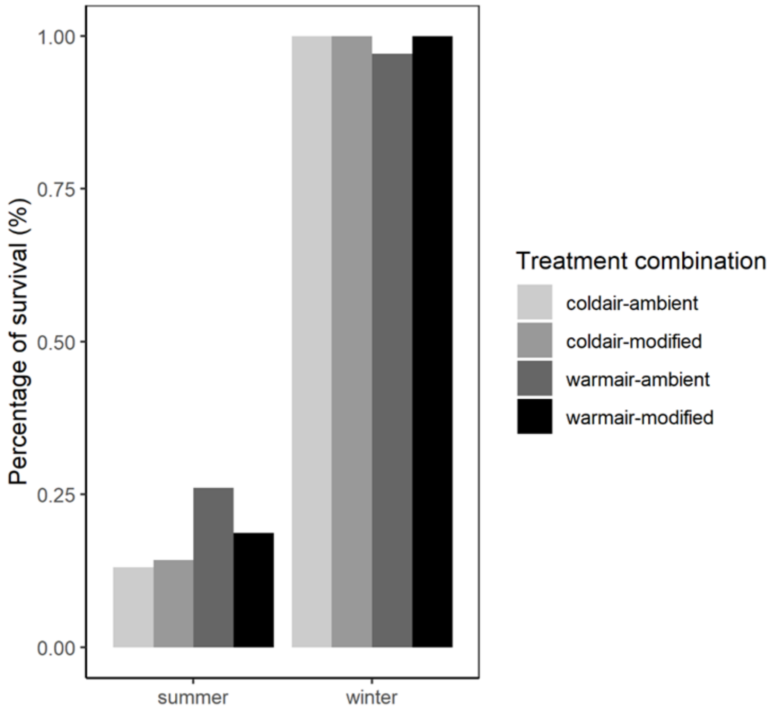

Figure 61. Survival percentage of sampled plaice after exposure to each treatment combination per season.

With decreased dissolved oxygen concentrations in summer, exercised fish might have to battle with an anoxic cycle to mobilise energy to sustain an evasion response to being herded by the demersal fishing gear. A resulting high concentration of lactic acid in the blood and in the white muscle tissue can compromise the ability of red blood cells to transport oxygen to the cells and cause asphyxiation. In this study, reflex responsiveness and survival were measured, but not physiological parameters to measure metabolic rates (such as oxygen consumption), stress (blood plasma sample, for cortisol, potassium ions, and glucose) and physical exhaustion (white muscle issue, for creatine compounds) that could possibly explain any cause-and-effect relationship. Acute decreases in temperature have been associated with loss of dorsoventral orientation in fish, which was supported by our data, but not significant in reducing the impairment of the righting reflex. However, the direction of the water shock, due to the experimental design, inherently has a seasonal feature and is therefore biased by the temperature tolerance level at which the fish was originally acclimated. Hence, the cold-water shock may have contributed to the righting impairment, but it is not possible to discern its detrimental effect from that of summer high temperatures. In summer, with 20°C water temperature, the metabolism and energy budget of plaice is most likely at the upper limit of their thermal tolerance, and they become intolerant towards any cumulative fishing capture stress.

4.4. Optimized reflexes and injuries Index (Case study 3)

A vitality indicator can be expressed as a simple proportion of impaired reflexes, or present injuries, or as an index generated from impaired reflexes and present injuries scores (Davis, 2010; Meagher, 2009). The latter implies, however, that both reflex impairment and injuries contribute with equal weights to post-capture survival and have thus been criticized in the literature for disregarding any differential contributions of individual reflexes to the observed mortality (Breen and Catchpole, 2021). To test whether some reflexes and injuries may be more relevant than others for the survival of the fish, the performance of different optimization functions can be evaluated to optimize the weightings of individual reflex and injury attributes to ideally make predictions more accurate. Even if the survival of a fish can be predicted with reasonable certainty based on the observed reflex impairment and/or injuries and/or categorical vitality scores, predicting mean survival at the trip level can become challenging. Similar mean scores may be obtained for different trips despite different scores for different vitality attributes (e.g., if one trip gives a high score for reflexes and a low for injuries and vice versa for another trip so the two effects cancel each other out, Uhlmann *et al.*, 2021). This situation is more likely if all reflexes and injuries are given equal weight. A reliable vitality indicator should therefore be optimized not only at the fish level, but also at the trip level. In this study, we aimed to optimize a reflex and injury index at both fish and trip levels (in different models). The index was tested against other vitality indicators (reflex impairment index, number of impaired reflexes, number of present injuries, number of impaired reflexes and present injuries, categorical vitality score, individual reflexes, and injuries scores) for their ability to predict discard survival of bottom-trawled plaice.

Vitality and discard survival data of undersized, trawl-caught plaice were collected following a harmonized protocol (Uhlmann *et al.*, 2016, 2021; Breen and Catchpole, 2021) from four Belgian beam trawlers and one Danish otter trawler, respectively. Each candidate model was built with mortality at asymptote (at the fish level with 0 for alive and 1 for dead) as the response variable. All models were tested with the coherent biological, environmental, technical, and operational explanatory variables (covariates), i.e., fish length, surface seawater temperature, gear type, fishing depth, gear deployment duration, total catch weight, air exposure, and two plausible interactions, one between gear type and surface seawater temperature, and the other between air exposure and surface seawater temperature. The optimization procedure aimed at finding the weighing of the reflex and injury attributes minimizes the AIC for fish-level comparisons and the absolute difference between predicted and observed trip-level comparisons. Optimization procedures were applied based on the open-source R package OptimX (Nash *et al.*, 2022).

Bruising in the head and body were the most important contributors to the survival probability of discarded plaice with 90 and 95% of the best models showing coefficients higher than 0.10 (0.25 ±0.08 and 0.36 ±0.09 at fish level and 0.20 ±0.12 and 0.37 ±0.14 at trip level, respectively). Body flex, righting, tail grab and point head were also important for the prediction of survival with weighing coefficients ranging from 0.11 to 0.26 for 40, 45, 25 and 30% of the best models, respectively. The least important reflexes and injuries were head complex, evasion, stabilise and point body with less than 5% of the best models showing coefficients higher than 0.10.

Overall, none of the individual reflex or injury indicators were independent of biological, environmental, technical, and operational covariates when predicting plaice discard survival, both at fish and trip levels. The best models (based on AIC) for each vitality indicator all included the interaction between air exposure and sea temperature.

The optimized index did not improve predictions markedly as both the reflex impairment and injury index as well as the less labour-intensive categorical vitality score were almost equally valuable proxies of plaice discard survival. Indeed, the difference in IPA between the best model (partitioned) and the easiest to assess onboard (categorical vitality score) is 3%.

When we compare observed and predicted survival ratio for each trip in the context of management purposes, i.e., assessing whether the survival ration is high, all vitality indicators could correctly predict high (>0.50) or low (<0.50) survival except for one trip. If we balance quality of the prediction and ease of assessment at sea, the categorical vitality scoring is able to correctly predict between high and low survival (0.5 as a threshold) in the (simplified) context of advice, i.e., balance between how easy the method is (in the context of collecting the data at sea and being able to assess more fish with the onboard observers for example for whom it would be easier and more precise to use the categorical vitality index than the optimized index) and how much precision is required.

4.5. Bayesian framework to include expert knowledge (Case study 3)

In contrast to traditional (frequentist) methods previously used in our survival studies, the Bayesian network model approach can integrate expert knowledge regarding life-history traits and the prevailing operational, environmental, and biological conditions of fisheries to predict survival probability after release. Bayes network models are extensively used in Artificial Intelligence applications. This expert system may be suitable as a low-cost decision support tool for fisheries managers. Such a system can also be trained by the data that are collected.

4.5.1. Discretise the data to optimise their predictive accuracy and favour interpretability

Our aim was to discretise the data to optimise their predictive accuracy and favour interpretability at the same time. We choose to measure predictive accuracy with classification error, that is, the proportion of observations for which the discretised survival probabilities are incorrectly predicted.

We considered two types of Bayesian models: causal network models whose structure is learned directly from the data, with constraints on arc directions enforcing a partial ordering of the nodes in the network, and naive Bayes network classifier models. A naive Bayes model is simpler than a data-driven causal network because its structure is fixed: we only estimate its parameters from data. At the same time, it is a network model that is explicitly designed for predictive accuracy in classification.

4.5.2. Survival probability of a new fish in an existing trip

We started with a prediction of the survival probability of a new fish in an existing trip. The training and validation sets were formed by splitting the data set at random. Therefore, both the training and the validation sets contained observations from all fishing trips, and the predictive accuracy from new fishes caught on those trips can be measured. Ideally, it would have been best to have a third, separate data set to fit the survival model and prevent any kind of information leak. Indeed, information from the training set will leak into the validation set through the survival probabilities, which are estimated from the observations in the training set even for the observations in the validation set. While undesirable, this is unavoidable given the limited available data, i.e., splitting our data into three subsets would not leave enough statistical power to learn the causal network model.

Continuous variables of the training set were jointly discretised by Hartemink’s algorithm into three levels, i.e., [0,0.25), [0.25,0.5] and [0.5,1] for the survival probability that can thus be interpreted as “low”, “average” and “high”. Discrete variables were left untouched. The validation set was then discretised using the same intervals as in the training set. Discretising both at the same time would lead to information leaking from the training set into the validation set and thus artificially inflating our accuracy estimates. The number of levels in the discretization influenced predictive accuracy: discretising all variables (response and explanatory) into three levels appeared to be a good trade-off between predictive accuracy, model complexity and predictive accuracy (Figure 62). Discretising the response variable (survival probability) into two levels was not descriptive enough, but four levels substantially increased the classification error. Discretising the explanatory variables into two levels reduced their ability to predict survival probability, but four levels increased the number of parameters of the model without a corresponding improvement in its predictive accuracy. The structure of the model was learned from the training set, and its fit parameters were used to predict the discretised survival probabilities for the observations in the validation set.

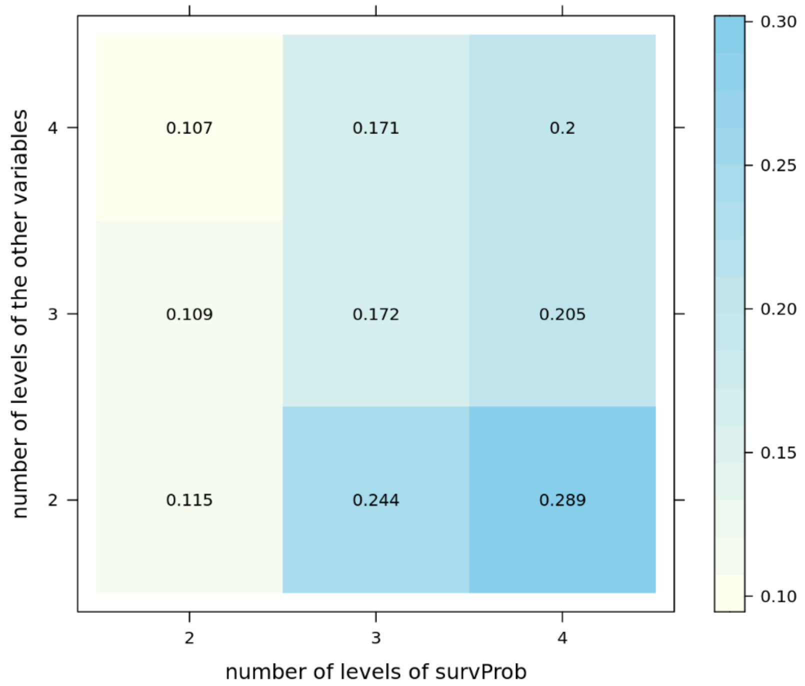

Figure 62. Classification error for different number of levels of response (survival probability “survProb”) and explanatory variables in the Bayes models.

The log-normal survival model consistently outperformed the Weibull survival model by 3-5% in terms of accuracy over different network models - note that this difference is not likely to be large enough to make a practical difference, so both models are suitable for real-world use.

The joint discretisation and learning of the causal network used 10-fold cross-validation over 20 runs for a total of 200 networks learned. The consensus causal network was computed by taking the most frequent arcs appearing in the 200 networks learned. The arcs in the causal networks did not show any causal effects between variables beyond those implied by common sense and existing literature (Figure 63 left). Introducing the individual reflexes and injuries resulted in an even more complicated network structure (Figure 63 right).

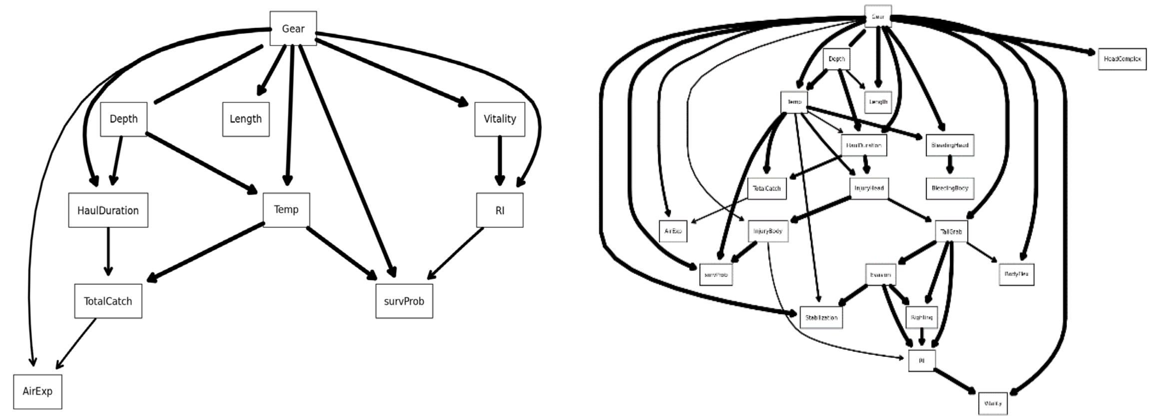

Figure 63. The consensus causal networks computed by taking the most frequent arcs appearing in the 200 networks learned, without (left) and with (right) the individual reflexes and injuries.

When predicting survival probability for a new fish, adding the individual reflexes and injuries resulted in a lower predictive accuracy (increased classification error) in both the causal and naive models. Removing the reflex and injury index in the naive models also increased predictive accuracy (Table 13). Compared to the causal network models, the naive Bayes models achieved a similar level of predictive accuracy without the added complications of learning the structure of the network from the data (Table 13).

Table 13. Classification errors for the different models (the lower the better).

Model type	**Without RI index**	**Without reflex and injuries**	**With reflex and injuries**
Causal for new fish	-	0.125	0.135
Causal for new trip	-	0.404	-
Naive for new fish	0.170	0.172	0.222
Naive for new trip with single approach	-	0.516	
Naive for new trip with ensemble approach	-	0.364	-

4.5.3. Prediction of the survival probability of a new fishing trip

We started with a prediction of the survival probability of a new fish in an existing trip, but of course, predicting survival probability of a new fishing trip is more relevant in the context of fisheries management. However, predicting fish survival in an entirely new fishing trip, i.e., that has not been used to learn the models, is more difficult than predicting fish survival in observed fishing trips because of the heterogeneity between different trips.

When predicting a new trip, one trip constituted the validation set, and all the remaining trips the training set. Continuous variables in the training set were jointly discretised by Hartemink's algorithm into three levels ("low", "average" and "high" as above); discrete variables were left untouched. We discretised the validation set using the same intervals as in the training set. When predicting a new trip, the classification error was much higher in the naive than in the causal models (Table 13). We attribute this to how heterogeneous the fishing trips are: the causal network can adapt to different subsets of trips because we learn its structure from data, which we do not for the naive Bayes network.

For the naive Bayes models, an alternative approach (ensemble approach) allows to use the fixed structure to construct an ensemble of naive Bayes models that can be used for prediction. In this case, one trip constituted the training set, and all the remaining trips the validation set.

The classification error of the ensemble approach was much lower than in single naive Bayes or causal models. We observed that it was rare (7.9%) for a low survival probability (<25%) to be incorrectly predicted as a high survival probability (50-100%) or vice versa. 4.3% of the fish with a high probability of survival (>50%) were predicted to have an average probability of survival (25-50%) and 3.5% to have a low probability of survival (<25%).

4.5.4. Bayesian Belief Network model to estimate post-release survival potential

The objective of this work is to build an operational Bayesian Belief Network (BBN) model to estimate post-release survival potential of discarded plaice. The BBN model was constructed from a combination of historical data and subject matter expert knowledge. The typical user case would be to identify species-fisheries for which it would be meaningful to collect scientific documentation for a high survival exemption in the context of the CFP.

The addition of edges to the model was based on the Bayesian Information Criterion (BIC) score (a score that combines model complexity and how well the model represents the data in terms of log-likelihood) as well as the Area-Under-Curve (AUC) measure (how well – or not, does the model classify each deployment as having a higher than 50% survival rate). The score of the initial model was computed. Until no improvement in the score, each candidate edge to the model was added and the score of the extended model was computed. The edge that improved the score the most in the model was then included.

The model output indicates the probability of a survival rate above 50%. It can be used as a relative score to compare different scenarios but should not be interpreted as an absolute probability of a survival rate above 50%.

Our expert and data driven BNN is available online: http://demo.hugin.com/example/cope2.

5. Conclusions and future perspectives

The opportunity in the CFP to obtain exemptions from the landing obligation has driven an intensive research activity on discard survival on species expected to have high resilience to the capture and handling processes. Conducting discard survival studies are logistically demanding and scientifically challenging as true controls cannot be obtained and observing discarded fish in their natural environment without study-related burdens (e.g., tagging) that can influence survival is difficult. The large variability in discard survival estimates between and sometimes within studies, may reflect that each study is conducted using one or a few fishing vessels, and under a limited range of fishing conditions and seasons while there is a large range of operational, environmental, and biological factors that affects discard survival. Some ecosystems require specific investigations such as for example the Baltic Sea due to areas and periods with hypoxic conditions. The use of prey types in the stomach content of plaice as an indication of the oxygen levels in the feeding habitat of place in addition to the mechanical impact of hard-shelled prey in the stomach were new to discard survival studies. More effort in a dedicated feeding study would allow a dynamic description of the temporal feeding pattern and possible shuttling between areas.

Improving gear design for selectivity and survival
To reduce the discard amounts in fisheries, the CFP highlights the importance of developing new, more selective gear designs. In line with this, gear designs should also be developed to improve discard survival as illustrated with the catch separation in a codend with different compartments for fish and *Nephrops* (Savina *et al.*, 2019).

Improving fishing operations
New technologies such as electronic monitoring (van Helmond *et al.*, 2019) and real-time catch monitoring (Sokolova *et al.*, 2021) would allow for collecting additional data useful for estimating discard survival, e.g., sorting time, and improving fishing operations, e.g., by targeting catch compositions that give optimal discard survival.

Temporal and spatial mitigation approaches, granting exemptions in those seasons when release survival can be maximized, are currently prioritised over controlling temperatures on-board. However, controlling temperatures in the space where the sorting takes place to match with the ambient, acclimated, environmental temperature (cool in winter, ambient in summer) would make sense to minimize any artefact temperature shocks and promote animal welfare-conscious fishing.

Improving captive observation studies
Future discard survival studies using captive observation should strive to make feed available to fish held in the tanks as the lack of feeding in the first week of captive observation might explain why fish were not able to recover the muscle glycogen to normal levels.

Improving our understanding of drivers of discard survival
While obtaining discard survival estimates have been a main aim of most studies for advisory purposes, investigations on factors affecting the survival rates have been made in parallel to reduce the need for demanding capture observation studies, and at the same time achieve more robust discard survival estimates and to inform how fishing operations can be changed to improve survival rates.

Investigations on how various factors influence discard survival could to a higher degree be performed under controlled conditions in the laboratory. The overlap index for fishery and oxygen presented in this report could be further used to enable the application of laboratory results on differential discard survival at different oxygen concentrations to calculate an estimated average discard mortality in the field.

Proxies for discard survival, such as vitality, including reflex impairment and external damages, are simple to measure onboard and could be included as self-sampling programs to collect data onboard a wider range of vessels and fishing conditions. With an increased number of studies aiming at using vitality as a measure of discard survival, it has become evident that the various types of proxies are not always able to sufficiently predict discard survival (Kraak *et al.*, 2018). This indicates that the link between observed vitality, reflex impairment, and external damages and survival, as well as how operational and environmental factors are reflected in the different proxies is not well understood. This calls for a review of the assumptions and achievements when using proxies and an evaluation of how the use of proxies has evolved over time.

Our results open for additional work to determine how quickly (or slowly) fish are able to recover from the capture process. Physiological variables such as dopamine levels, plasma glucose, plasma pH, plasma pCO_2, plasma bicarbonate, and muscle glycogen are all useful indicators of the magnitude of physiological distress experienced by the fish following capture and sorting. For most, these are not variables that can be employed by the fishing industry but provide insight into the response variables to trawling. Degree of brain haemorrhaging might, with proper training, serve as a useful tool or indicator for the probability of survival.

6. References

Amundsen, P. A., Gabler, H. M. and Staldvik, F. J. (1996). A new approach to graphical analysis of feeding strategy from stomach contents data—modification of the Costello (1990) method. J. Fish Biol., 48, 607–614.

Bailey, N., Rihan, D., Doerner, H. (2018). Reports of the Scientific, Technical and Economic Committee for Fisheries (STECF): evaluation of the landing obligation joint recommendations (STECF-18-06), Publications Office. https://data.europa.eu/doi/10.2760/999971

Barkley, A. S., and Cadrin, S. X. (2012). Discard mortality estimation of yellowtail flounder using reflex action mortality predictors. Transactions of the American Fisheries Society, 141(3), 638-644.

Benoît, H. P., Hurlbut, T., Chassé, J. (2010). Assessing the factors influencing discard mortality of demersal fishes using a semi-quantitative indicator of survival potential, Fisheries Research, Volume 106, Issue 3, Pages 436-447, ISSN 0165-7836. https://doi.org/10.1016/j.fishres.2010.09.018.

Benoît, H. P., Hurlbut T., Chassé J., Jonsen, I. D. (2012). Estimating fishery-scale rates of discard mortality using conditional reasoning. Fish. Res. 125–126, 318–330. Doi: 10.1016/j.fishres.2011.12.004.

Benoît, H. P., Plante S., Kroiz, M., Hurlbut, T. (2013). A comparative analysis of marine fish species' susceptibilities to discard mortality: effects of environmental factors, individual traits, and phylogeny. ICES J. Mar. Sci. 70:99–113. Doi:10.1093/icesjms/fss132.

Boussarie, G., Kopp, D., Méhault, S., Morfin, M. (2020). High survivability of discarded invertebrates from bottom trawling fisheries, Regional Studies in Marine Science, Volume 40, 101543, ISSN 2352-4855. https://doi.org/10.1016/j.rsma.2020.101543.

Breen, M. and Catchpole, T. (2021). ICES Guidelines on Methods for Estimating Discard Survival. ICES Cooperative Research Reports No. 351. 219 pp. Doi: 10.17895/ices.pub.8006.

Davis, M. W. (2007). Simulated fishing experiments for predicting delayed mortality rates using reflex impairment in restrained fish. ICES Journal of Marine Science, 64(8), 1535-1542.

Davis, M. W. (2010). Fish stress and mortality can be predicted using reflex impairment. Fish and Fisheries, 11: 1–11.

DFPO (2018). Fiskeri i tal – TAC og Kvoter 2018 og statistik fra dansk erhvervsfiskeri. Danmarks Fiskeriforening Producent Organisation. https://fiskeriforening.dk/media/1789/fiskeri_i_tal_2018.pdf.

DFPO (2023). Fiskeri i tal – TAC og Kvoter 2023 og statistik fra dansk erhvervsfiskeri. Danmarks Fiskeriforening Producent Organisation. https://fiskeriforening.dk/media/9703/fiskeri_i_tal_2023.pdf.

Eigaard, O. R., Bastardie, F., Breen, M., Dinesen, G. E., Hintzen, N. T., Laffargue, P., Mortensen, L. O., Nielsen, J. R., Nilsson, H. C., O'Neill, F. G., Polet, H., Reid, D. G., Sala, A., Sköld, M., Smith, C., Sørensen, T. K., Tully,O., Zengin, M., Rijnsdorp, A. D. (2016). Estimating seabed pressure from demersal trawls, seines, and dredges based on gear design and dimensions, ICES Journal of Marine Science, Volume 73, Issue suppl_1, January 2016, Pages i27–i43, https://doi.org/10.1093/icesjms/fsv099.

EU (2013). Commission Delegated Regulation (EU) 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy. Official Journal of the European Union, L 354/22-60.

EU (2018). Commission Delegated Regulation (EU) 2018/2035 of 18 October 2018 specifying details of implementation of the landing obligation for certain demersal fisheries in the North Sea for the period 2019-2021. Official Journal of the European Union, L 327/17.

EU (2019a). Commission Delegated Regulation (EU) 2019/906 of 13 March 2019 amending Delegated Regulation (EU) 2018/2035 specifying details of implementation of the landing obligation for certain demersal fisheries in the North Sea for the period 2019-2021. Official Journal of the European Union, L 145/4.

EU (2019b). Commission Delegated Regulation (EU) 2019/2238 of 1 October 2019 specifying details of implementation of the landing obligation for certain demersal fisheries in the North Sea for the period 2020-2021. Official Journal of the European Union, L 336/34.

EU (2020). Commission Delegated Regulation (EU) 2020/2014 of 21 August 2020 specifying details of implementation of the landing obligation for certain fisheries in the North Sea for the period 2021-2023. Official Journal of the European Union, L 415/10.

EU (2021). Commission Delegated Regulation (EU). 2021/2062 of 23 August 2021 amending Delegated Regulation (EU) 2020/2014 specifying details of implementation of the landing obligation for certain fisheries in the North Sea for the period 2021-2023. Official Journal of the European Union, L 421/4.

Fry, F. E. J. (1971). The Effect of Environmental Factors on the Physiology of Fish, in: Hoar, W.S., 432 Randall, D. J. (Eds.), Fish Physiology. Academic Press, pp. 1–98.

Fox, C. J., Albalat, A., Valentinsson, D., Nilsson, H. C., Armstrong, F., Randall, P., Catchpole, T. (2020). Survival rates for *Nephrops norvegicus* discarded from Northern European trawl fisheries, ICES Journal of Marine Science, Volume 77, Issue 5, Pages 1698–1710, https://doi.org/10.1093/icesjms/fsaa037.

Gesto M., Skov P.V., Jokumsen A. (2017). Emergence Time and Skin Melanin Spot Patterns Do Not Correlate with Growth Performance, Social Competitive Ability or Stress Response in Farmed Rainbow Trout. Frontiers in Neuroscience 11, 319doi: 10.3389/fnins.2017.00319

Gogina, M., Nygård, H., Blomqvist, M., Daunys, D., Josefson, A. B., Kotta, J., Maximov, A, *et al.* (2016). The Baltic Sea scale inventory of benthic faunal communities. ICES J. Mar. Sci., 73, 1196–1213.

Haase, K., Orio, A., Pawlak, J., Pachur, M. and Casini, M. (2020). Diet of dominant demersal fish species in the Baltic Sea: Is flounder stealing benthic food from cod? Mar. Ecol. Prog. Ser., 645, 159–170.

HELCOM (2023). State of the Baltic Sea. Third HELCOM holistic assessment 2016-2021. Baltic Sea Environment Proceedings n°194. https://helcom.fi/post_type_publ/holas3_sobs.

Herrmann, B., Sistiaga, M., Nielsen, K. N., and Larsen, R. B. (2012). Understanding the size selectivity of redfish (*Sebastes* spp.) in North Atlantic trawl codends. J. Northwest Atl. Fish. Sci. 44: 1–13. doi:10.2960/J.v44.m680.

Hoffman, J. I. E. (2015). Biostatistics for medical and biomedical practitioners. Chap. 36 Meta-analysis. Elsevier. p. 645-653.

Humborstad, O., Davis, M. W., Løkkeborg, S. (2009). Reflex impairment as a measure of vitality and survival potential of Atlantic cod (*Gadus morhua*).

Hutchinson, M., Siders, Z., Stahl, J., and Bigelow, K. (2021). Quantitative estimates of post-release survival rates of sharks captured in Pacific tuna longline fisheries reveal handling and discard practices that improve survivorship. United States. National Marine Fisheries Service;Pacific Islands Fisheries Science Center (U.S.). https://doi.org/10.25923/0m3c-2577.

ICES (2014). Report of the Workshop on Methods for Estimating Discard Survival (WKMEDS), 17–21 February 2014, ICES HQ, Copenhagen, Denmark. ICES CM 2014/ACOM:51. 114 pp.

ICES (2015). Report of the Workshop on Methods for Estimating Discard Survival 3 (WKMEDS 3), 20-24 April 2015, London, UK. ICES CM 2015\ACOM:39. 47 pp.

ICES (2018). Plaice (*Pleuronectes platessa*) in subdivisions 21–23 (Kattegat, Belt Seas, and the Sound). IICES Advice 2018, ple.27.21–23. https://doi.org/10.17895/ices.pub.4385

ICES (2019). Guidelines on Methods for Estimating Discard Survival – ICES Cooperative Research Report. M. Breen and T. Catchpole (eds). 199 pp.

ICES (2023a). Plaice (*Pleuronectes platessa*) in Subarea 4 (North Sea) and Subdivision 20 (Skagerrak). Replacing advice provided in 2022. ICES Advice: Recurrent Advice. Report. https://doi.org/10.17895/ices.advice.22548568.v1.

ICES (2023b). Plaice (*Pleuronectes platessa*) in subdivisions 21–23 (Kattegat, Belt Seas, and the Sound). ICES Advice: Recurrent Advice. Report. https://doi.org/10.17895/ices.advice.19453550.v6.

ICES (2023c). Plaice (*Pleuronectes platessa*) in subdivisions 24–32 (Baltic Sea, excluding the Sound and Belt Seas). Replacing advice provided in 2022. ICES Advice: Recurrent Advice. Report. https://doi.org/10.17895/ices.advice.23144228.v1.

Kaplan, E. L. and Meier, P. (1958). Nonparametric Estimation from Incomplete Observations. J. Am. Stat. Assoc. 53, 457–481. doi:10.1080/01621459.1958.10501452.

Karlsen, J. D., Krag, L. A., ALbertsen, C. M., Frandsen, R. P. (2015). From fishing to fish processing: separation of fish from crustaceans in the Norway lobster-directed multispecies trawl fishery improves seafood quality. PLoS ONE 10(11): e0140864. doi: 10.1371/journal.pone.0140864.

Kraak, S. B. M., Velasco, A., Fröse, U., Krumme, U. (2018). Prediction of delayed mortality using vitality scores and reflexes, as well as catch, processing, and post-release conditions: evidence from discarded flatfish in the Western Baltic trawl fishery, ICES Journal of Marine Science, Volume 76, Issue 1, Pages 330–341, https://doi.org/10.1093/icesjms/fsy129.

Meagher, R. K. (2009). Observer ratings: Validity and value as a tool for animal welfare research, Applied Animal Behaviour Science, Volume 119, Issues 1–2, Pages 1-14, ISSN 0168-1591, https://doi.org/10.1016/j.applanim.2009.02.026.

Methling, C., Skov, P. V., and Madsen, N. (2017). Reflex impairment, physiological stress, and discard mortality of European plaice Pleuronectes platessa in an otter trawl fishery. ICES Journal of Marine Science, 74(6), 1660-1671.

Morfin, M., Méhault, S., Benoît, H. P., Kopp, D. (2017a). Narrowing down the number of species requiring detailed study as candidates for the EU Common Fisheries Policy discard ban. Mar. Policy 77: 23–29. Doi: 10.1016/j.marpol.2016.12.003.

Morfin, M., Kopp, D., Benoît, H. P., Méhault, S., Randall, P., Foster, R., Catchpole, T. (2017b). Survival of European plaice discarded from coastal otter trawl fisheries in the English Channel. J. Environ. Manage. 204, 404–412. Doi: 10.1016/j.jenvman.2017.08.046.

Morfin, M., Simon, J., Morandeau, F., Baulier, L., Méhault, S., and Kopp, D. (2019). Using acoustic telemetry to estimate post-release survival of undulate ray Raja undulata (Rajidae) in northeast Altantic. Ocean & Coastal Management, 178, 104848.

Nash, J. C. (2022). Function minimization and nonlinear least squares in R. Wiley Interdisciplinary Reviews: Computational Statistics, 14(6), e1580. https://doi.org/10.1002/wics.1580

Neuenfeldt, S., Andersen, K. H. and Hinrichsen, H. H. (2009). Some Atlantic cod Gadus morhua in the Baltic Sea visit hypoxic water briefly but often. J. Fish Biol., 75, 290–294.

Noack, T., Frandsen, R. P., Krag, L. A., Mieske, B., and Madsen, N. (2017). Codend selectivity in a commercial Danish anchor seine. Fisheries Research 186:283–291. Doi: 10.1016/j.fishres.2016.10.006.

Noack, T., Stepputtis, D., Madsen, N., Wieland, K., Haase, S., Krag, L. A. (2019). Gear performance and catch process of a commercial Danish anchor seine. Fish. Res. 211: 204–211.

Noack, T., Savina, E., Karlsen, J. (2020). Survival of undersized plaice (*Pleuronectes platessa*) discarded in the bottom otter trawl and Danish seine mixed fisheries in Skagerrak. Mar. Pol. 115: 103852. doi: 10.1016/j.marpol.2020.103852.

Oliver, M., McHugh, M., Murphy, S., Minto, C., Browne, D., Cosgrove. R. (2019). Sole survivability in the Irish otter trawl fishery. BIM Report, December 2019.

Oliver, M. O'Neill, R., McHugh, M., Browne, D., Murphy, S., Murphy, S., Minto, C., Cosgrove. R. (2022). Assessment of cod survival in the Irish seine-net fishery using pop-up satellite archival tags. Fisheries Conservation Report. BIM, November 2022.

Raby, G. D., Donaldson, M. R., Hinch, S. G., Patterson, D. A., Lotto, A. G., Robichaud, D., English, K. K., Willmore, W. G., Farrell, A. P., Davis, M. W. and Cooke, S. J. (2012). Validation of reflex indicators for measuring vitality and predicting the delayed mortality of wild coho salmon bycatch released from fishing gears. Journal of Applied Ecology, 49(1), 90-98.

Randall, P., Lamb, P., Ives, M., Bendall, V., Lambert, G., Fronkova, L., and Hyder, K. (2021). The Potential Survival of Sea Bass Discarded by Commercial Fisheries in UK Waters. CEFAS Tech. Rep., 128.

Revill, A. S., Broadhurst, M. K., Millar, R. B. (2013). Mortality of adult plaice, Pleuronectes platessa and sole, Solea solea discarded from English Channel beam trawlers, Fish. Res. 147, 320–326, https://doi.org/10.1016/j.fishres.2013.07.005.

Rihan, D., Uhlmann, S. S., Ulrich, C., Breen, M., and Catchpole, T. (2019). Requirements for documentation, data collection and scientific evaluations. In: Uhlmann *et al.* (eds) The European Landing Obligation: Reducing Discards in Complex, Multi-Species and Multi-Jurisdictional Fisheries, p. 49-68.

Rodrigues, E., Bell, M., and Mesquita, C. (2015). Discard survival and condition in Orkney brown crabs (*Cancer pagurus*). Fishing Industry Science Alliance (FISA), 648-665.

Rosenberg, R., Hellman, B. and Johansson, B. (1991). Hypoxic tolerance of marine benthic fauna. Mar. Ecol. Prog. Ser., 79, 12–131.

Schram, E., Molenaar, P., Goedhart, P. W., Poos, J. J. (2023). Effects of environmental conditions and catch processing on survival probability of plaice discards in the North Sea pulse trawl fishery. PLoS ONE 18(6): e0287020. https://doi.org/10.1371/journal.pone.0287020.

Sokolova, M., Mompó Alepuz, A., Thompson, F., Mariani, P., Galeazzi, R., & Krag, L. A. (2021). A Deep Learning Approach to Assist Sustainability of Demersal Trawling Operations. *Sustainability*, *13*(22), 12362. https://doi.org/10.3390/su132212362

STECF (2015). Reports of the Scientific, Technical and Economic Committee for Fisheries (STECF) – assessment of balance indicators for key fleet segments and review of national reports on Member States efforts to achieve balance between fleet capacity and fishing opportunities (STECF-15-02). Publications Office. https://data.europa.eu/doi/10.2788/92692.

STECF (2017). Reports of the Scientific, Technical and Economic Committee for Fisheries (STECF) – 55th plenary meeting report (PLEN-17-02). Publications Office. https://data.europa.eu/doi/10.2760/53335.

Savina, E., Noack, T., and Karlsen, J. D. (2019). Effects of season, target species and codend design on the survival of undersized plaice (*Pleuronectes platessa*) discarded in the bottom otter trawl mixed fisheries in Skagerrak. Fish. Res. 219 (June): 105311. Elsevier. Doi: 10.1016/j.fishres.2019.105311.

Uhlmann, S. S., Theunynck, R., Ampe, B., Desender, M., Soetaert, M., and Depestele, J. (2016). Injury, reflex impairment, and survival of beam-trawled flatfish. ICES Journal of Marine Science, 73: 578–589. doi:10.1093/icesjms/fst048.

Uhlmann, S. S., Ampe, B., Goley, J. M., Savina, E., Broadhurst, M. K. (2023). Effects of catch composition on the fate of European plaice (*Pleuronectes platessa*) discarded from Belgian beam trawlers, Fisheries Research, Volume 261, 106616, ISSN 0165-7836, https://doi.org/10.1016/j.fishres.2023.106616.

van der Reijden, K. J., Molenaar, P., Chen, C., Uhlmann, S. S., Goudswaard, P. C., and van Marlen, B. (2017). Survival of undersized plaice (*Pleuronectes platessa*), sole (*Solea solea*), and dab (*Limanda limanda*) in North Sea pulse-trawl fisheries. ICES Journal of Marine Science, 74(6): 1672–1680. Doi: 10.1093/icesjms/fsx019.

van Helmond, A. T. M., Mortensen, L. O., Plet-Hansen, K. S., *et al.* (2020). Electronic monitoring in fisheries: Lessons from global experiences and future opportunities. Fish Fish. 2020; 21: 162–189. https://doi.org/10.1111/faf.12425

Viva., C, Ligas, A., Sartor, P., Sbrana., M, Breen, M., Erzini, K., Campos, A., Costantini, M., Martin, P., Maynou, F., Stefánsson, G., Sturludottir, E. (2016) Science, Technology, and Society Initiative to Minimize Unwanted Catches in European Fisheries. MINOW report SFS-09-2014, RIA 634495.

Wienbeck, H., Herrmann, B., Feekings, J. P., Stepputtis, D., and Moderhak, W. (2014). A comparative analysis of legislated and modified Baltic Sea trawl codends for simultaneously improving the size selection of cod (*Gadus morhua*) and plaice (*Pleuronectes platessa*). Fish. Res. 150(2187): 28–37. Elsevier B.V. doi: 10.1016/j.fishres.2013.10.007.

Yochum, N., Rose, C. S., and Hammond, C. F. (2015). Evaluating the flexibility of a reflex action mortality predictor to determine bycatch mortality rates: A case study of Tanner crab (*Chionoecetes bairdi*) bycaught in Alaska bottom trawls. Fish. Res. 161: 226–234. Elsevier B.V. Doi: 10.1016/j.fishres.2014.07.012.

7. Supplementary material

A. Survival catalogue

About the dataset

The dataset used for the analysis represents the years 2011-2016 and is extracted from the Danish database of the observer at sea data collection program (EU Data Collection Framework, DCF; EEC, 2000). Data is collected during commercial fishing trips. Total landings and discard fraction of the catch is presented by métier, i.e., a combination of fishing gear, target species, mesh, and potential use of selectivity devices (Table A.1). “OTB_CRU_70-89_2_35”, for instance, encodes bottom otter trawls targeting crustaceans with a codend mesh size of 70-89 mm using a fixed grid (35 mm) as selectivity device. The observer program covers less than 1 % of the fishery (Table A.2). Nevertheless, collected discard data at the trip level is raised to the fleet level. The dataset is therefore representative of the whole Danish fishery. Additional information on the observer at sea sampling program is detailed in Storr-Paulsen *et al.* (2010).

The discard database served for estimating average annual landings (kg) as well as average annual discards (kg), which are presented in the document by species, area and fishery (gear, target and mesh size). Annual landings and discards have further been used to estimate discard ratios (discard/total catch). Mean values averaged over the years as well as minimum and maximum values are presented within the document.

Table A.1. Codes and abbreviations used throughout the whole document, based on metier-approach as used within the discard database.

Gear code	
FPN	Fixed pound nets
FPO	Pots
GNS	Set gillnets
LHP	Handlines and pole-lines
LLS	Longlines set
OTB	Otter trawls bottom
OTM	Otter trawls midwater
PTB	Pair trawls bottom
PTM	Pair trawls midwater
SDN	Anchored seines
SSC	Scottish seines
TBB	Beam trawls

Target species assemblage code	
CAT	Catadromous species
CRU	Crustaceans
DEF	Demersal fish
FIF	Finfish
MCD	Mixed crustaceans and demersal fish
SPF	Small pelagic species

Selection device code	
0	No selection device
2	Fixed grid

Table A.2. Sampling effort in the period 2011-2016. Number of total fishing trips and number of observed fishing trips separated by gear, target species assemblage and area (Ministry of Environment and Food of Denmark, Danish Agrifish Agency; observer program).

Gear	Target species assemblage	Kattegat		North Sea		Skagerrak	
		total	observed	total	observed	total	observed
FPN	CAT	123	0	1163	0	0	0
FPO	CRU	8	0	447	0	0	0
GNS	CRU	600	1	1512	0	367	0
	DEF	3541	11	16938	51	12994	170
	SPF	107	0	8	0	13	0
LHP	FIF	8	0	135	0	295	0
LLS	FIF	0	0	420	1	59	0
No logbook	-	24978	0	37952	0	25597	0
No matrix	-	1103	0	5546	0	481	0
OTB	CRU	273	1	364	3	4264	33
	DEF	227	1	4524	0	2342	0
	MCD	41458	279	11154	88	41765	264
	SPF	2	0	1663	0	178	0
OTM	DEF	20	0	3	0	6	0
	SPF	3525	0	15	0	415	0
PTB	DEF	1	0	0	0	0	0
	MCD	0	0	1	0	30	0
	SPF	0	0	0	0	2	0
PTM	SPF	493	0	4832	0	100	0
SDN	DEF	86	2	1313	12	9477	42
SSC	DEF	0	0	652	6	245	1
TBB	CRU	0	0	11130	66	0	0
	DEF	0	0	370	0	192	0

Note: Vessels <10 m are not obliged to fill in logbook information, i.e., category "no logbook" mainly consists of small trawlers and other small vessels using passive gears. No matrix: recorded information by vessel leads to a non-defined métier (e.g., mesh size outside the defined ranges).

Information is shown on a species-by-species base in the following chapter of the document. After introducing each species with general information including economic importance for the Danish fishery and a subjective estimation of discard survivability based on experiences by fishermen and scientists, figures are shown for all considered areas (Kattegat, North Sea, Skagerrak) summarizing the results for each fishing gear. If available, results of previous survival studies (excluding control hauls) are included in those considerations based on estimates from studies investigating commercial gears (excluding pulse trawl). Those facilitate comparing differences in catches, discards, and survivability between fisheries for each species in each area. Ensuing tables show detailed information about average annual landings and raised discards of the Danish fleet as well as the resulting discard ratios (discard/total catch) including minimum and maximum values. Those are presented as heatmaps, i.e., colors reflect the size of a value (landing, discard, or discard ratio) in relation to all other observation (low values are given in green, medium values in yellow and high values in red).

Survival probabilities are given based on results of previously conducted survival studies on relevant species and relevant fishing gears. As estimates of survival probability estimates can be highly variable between different studies, specific conditions under which the studies were conducted (area, season, haul duration, study period, fish size) are given. Estimates for commercially used gears are highlighted in bold and summarized by area for studies which used commercial gears (excluding pulse

trawls). For simplicity, survival estimates are only shown as mean values for individual studies and as mean values (minimum-maximum) for area summaries, but no confidence intervals are provided within this document. In case confidence intervals are of interest, readers are kindly referred to the respective original document (references are provided).
The following part presents, based on the discard information presented before, an overview of fisheries discarding in particularly high numbers – either in absolute terms (>10 t per year), in relative terms (>40% of the catch) or combining both.

The final section of the document summarizes all information presented within the document by translating those to a more subjective, but simple scale which is easy to read and allows to get an overview of a) a species' robustness, i.e., the likelihood to survive stressful experiences, b) their importance for the Danish market, and c) if they are discarded in particularly high numbers.

Species catalogue

Brill (*Scophthalmus rhombus*)

Although brill is no common target species within Danish waters, it is considered a valuable species on the market and is subject to TAC regulations within the North Sea (together with turbot). Generally, brill is considered to be a relatively robust species, *i.e.*, the chance of surviving discarding is potentially high. As this on experiences-based assumption does not allow to give a profound estimation of the survivability of brill, future studies are required assessing this.

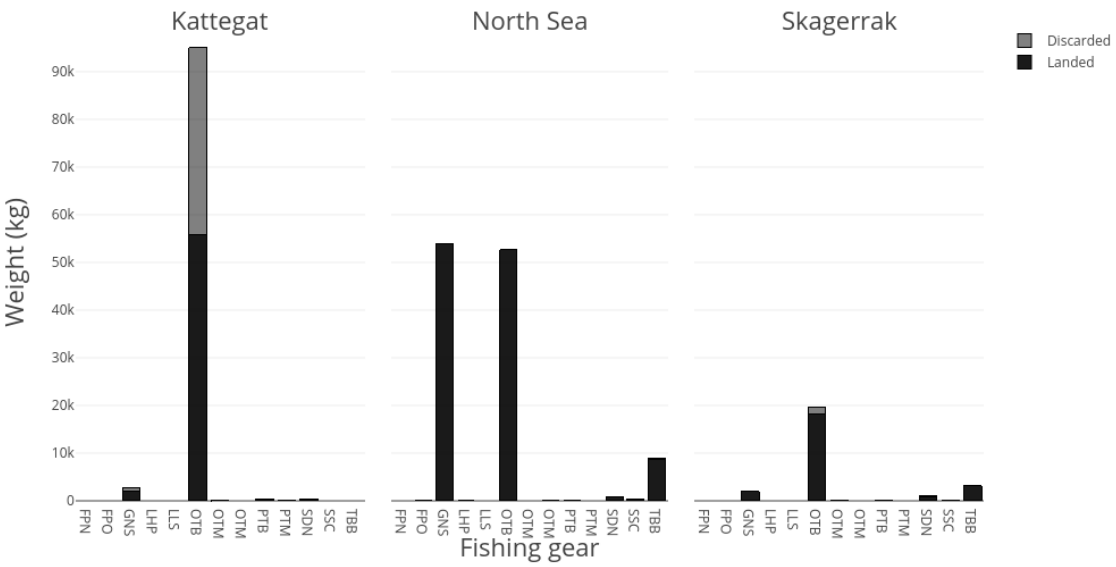

Figure A.1. Average annual landings (kg) and raised discards (kg) of brill by Danish vessels for the years 2011-2016 separated by area and fishing gear.

Table A.3. Total landings (kg), raised discards (kg) and average discard ratio (discard/total catch including Min and Max) for brill, separated by area and metier including potential estimates on discard survival probability from previous studies (estimates for commercially used gears in bold). Cells are shaded according to their value (low: green, medium: yellow, high: red).

Area	Gear	Target	Mesh size (mm)	Sel. dev.	Annual Landings (kg)	Annual Discards (kg)	Discard ratio	Survival probability
Kattegat	GNS	CRU	>0	0	11	0	0 (0-0)	- no estimates
		DEF	50-70	0	29	NA	NA	
			90-99	0	228	185	0.37 (0.37-0.37)	
			100-119	0	295	618	0.54 (0.49-0.59)	
			120-219	0	1357	255	0.25 (0-0.5)	
			≥220	0	171	0	0 (0-0)	
	OTB	CRU	32-69	0	25	NA	NA	
			70-89	2 (35 mm)	304	NA	NA	
		DEF	<16	0	34	NA	NA	
			32-69	0	49	NA	NA	
			70-89	2 (35 mm)	73	NA	NA	
		MCD	90-119	0	54908	38966	0.4 (0.17-0.6)	
			≥120	0	639	446	0.28 (0-0.55)	
	OTM	DEF	16-31	2 (35 mm)	7	NA	NA	
			90-119	0	16	NA	NA	
		SPF	16-31	2 (35 mm)	8	NA	NA	
			32-69	0	5	NA	NA	
	PTB	MCD	90-119	0	261	57	0.18 (0.18-0.18)	
	PTM	SPF	16-31	0	7	NA	NA	
	SDN	DEF	90-119	0	108	316	0.64 (0.64-0.64)	
			≥120	0	7	NA	NA	
North Sea	FPO	CRU	>0	0	8	NA	NA	**16.5% (0.0% - 33.0%)** <u>Schram and Molenaar (2018):</u> 0% (July, September, December); 33% (May, October) • season: mix • gear: pulse trawl (~2h) • depth: 18-52 m • study period: 15-18 days • observations: 90
	GNS	CRU	>0	0	134	NA	NA	
		DEF	90-99	0	2912	NA	NA	
			100-119	0	3055	NA	NA	
			120-219	0	38462	62	0 (0-0.01)	
			≥220	0	9313	0	0 (0-0)	
	LHP	FIF	-	0	2	NA	NA	
	LLS	FIF	-	0	NA	0	NA	
	OTB	CRU	32-69	0	5	0	0 (0-0)	
		DEF	<16	0	8	NA	NA	
			16-31	2 (35 mm)	2	NA	NA	
		MCD	70-99	0	3506	0	0 (0-0)	
			100-119	0	2946	2	0 (0-0)	
			≥120	0	46173	52	0 (0-0)	
	OTM	DEF	16-31	0	20	NA	NA	
				2 (35 mm)	11	NA	NA	
		MCD	100-119	0	6	NA	NA	
	PTB	MCD	100-119	0	8	NA	NA	

			≥120	0	NA	0	NA	
	SDN	DEF	100-119	0	60	0	0 (0-0)	
			≥120	0	851	20	0.02 (0-0.07)	
	SSC	DEF	≥120	0	402	0	0 (0-0)	
	TBB	CRU	16-31	0	2	71	1 (1-1)	
		DEF	100-119	0	141	NA	NA	
			≥120	0	8751	NA	NA	
Skagerrak	GNS	CRU	>0	0	15	NA	NA	- no estimates
		DEF	50-70	0	15	0	0 (0-0)	
			100-119	0	55	0	0 (0-0)	
			120-219	0	1596	3	0 (0-0.01)	
			≥220	0	231	0	0 (0-0)	
	OTB	CRU	32-69	0	10	0	0 (0-0)	
			70-89	2 (35 mm)	7	NA	NA	
		DEF	<16	0	30	NA	NA	
			70-89	2 (35 mm)	12	NA	NA	
		MCD	90-119	0	11084	627	0.06 (0-0.19)	
			≥120	0	7204	670	0.09 (0.03-0.21)	
	OTM	DEF	<16	0	5	NA	NA	
			16-31	0	56	NA	NA	
			90-119	0	3	NA	NA	
		SPF	16-31	0	1	NA	NA	
	PTB	MCD	90-119	0	2	0	0 (0-0)	
			≥120	0	3	0	0 (0-0)	
	SDN	DEF	90-119	0	179	33	0.2 (0-0.74)	
			≥120	0	733	44	0.09 (0-0.2)	
	SSC	DEF	≥120	0	30	0	0 (0-0)	
	TBB	DEF	90-119	0	475	NA	NA	
			≥120	0	3086	NA	NA	

Dab (*Limanda limanda*)

Dab is no common target species in the Danish fishery and the economic value is low in comparison to other flatfish. Although quotas do only exist in the North Sea (managed together with flounder), discard levels are comparatively high in all areas. In terms of survivability, experiences showed that dab seems to be relatively sensitive compared to other fish. At this point it needs to be stated, however, that very high levels of discards in combination with very low levels of discard survival might increase the total fishing mortality in times of the landing obligation. Additional studies to those conducted in the North Sea (Table A.4), were conducted by Kaiser and Spencer (1995) in the Irish Sea (survival rate: 24%; season: spring; gear: beam trawl (30 min); study period: 120h; observations: 22) and by Kraak *et al.* (2018) in the Baltic sea (survival rate: ~35.0-100%; season: whole year; gear: otter trawl (3 h); depth: 20-30 m; study period: 5-8 d; observations: 772) reporting variable survival rates over the year.

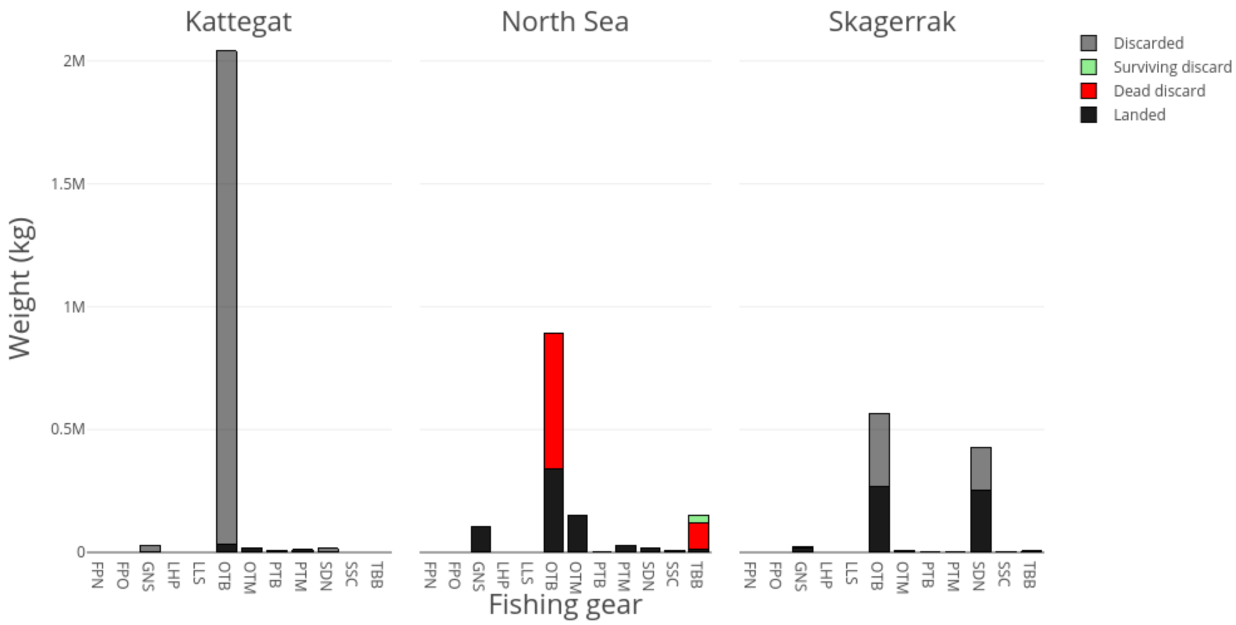

Figure A.2. Average annual landings (kg) and raised discards (kg) of dab by Danish vessels for the years 2011-2016 separated by area and fishing gear including information about discard survival based on estimates from studies investigating commercial gears.

Table A.4. Total landings (kg), raised discards (kg) and average discard ratio (discard/total catch including Min and Max) for dab, separated by area and metier including potential estimates on discard survival probability from previous studies (estimates for commercially used gears in bold). Cells are colour-coded according to their value (low: green, medium: yellow, high: red).

Area	Gear	Target	Mesh size (mm)	Sel. dev.	Annual Landings (kg)	Annual Discards (kg)	Discard ratio	Survival probability
Kattegat	GNS	CRU	>0	0	33	0	0 (0-0)	- no estimates
		DEF	50-70	0	192	NA	NA	
			90-99	0	69	4409	0.98 (0.98-0.98)	
			100-119	0	1017	34223	0.95 (0.94-0.95)	
			120-219	0	1008	1886	0.59 (0.46-0.72)	
			≥220	0	56	0	0 (0-0)	
		SPF	100-119	0	7	NA	NA	
	OTB	CRU	70-89	2 (35 mm)	43	NA	NA	
		DEF	<16	0	471	NA	NA	
			32-69	0	45	NA	NA	
			70-89	2 (35 mm)	191	NA	NA	
		MCD	90-119	0	26468	1971801	0.99 (0.98-0.99)	
			≥120	0	1790	103491	0.87 (0.77-0.97)	
		SPF	16-31	0	4677	NA	NA	
	OTM	DEF	16-31	2 (35 mm)	1	NA	NA	
		SPF	16-31	0	20207	NA	NA	
			32-69	0	1	NA	NA	
	PTB	MCD	90-119	0	1	2796	1 (1-1)	
		SPF	16-31	0	3911	NA	NA	
	PTM	SPF	16-31	0	10243	NA	NA	
			32-69	0	4448	NA	NA	
	SDN	DEF	90-119	0	1211	14809	0.93 (0.93-0.93)	
			≥120	0	468	NA	NA	
North Sea	GNS	CRU	>0	0	122	NA	NA	**19.2% (0.0% - 67.4%)** Kelle (1976): **1.4%** (grid sorting) - 58.4% (no grid sorting) • season: mix • gear: beam trawl (15-120 min) • depth: 2-25 m • study period: 7 days • observations: 449 (4-20 cm) Berghahn *et al.* (1992): **67.4%** (grid sorting) - 88.1% (no grid sorting) • season: autumn • gear: beam trawl (1h) • depth: 2-25 m • study period: 5 days • observations: 511 (7-27 cm) Evans *et al.* (1994): **0.0%** • season: mix • gear: otter trawl van Marlen *et al.* (2015): **8.0%** (twinrig) – 15.0% (pulse) • season: mix • gear: beam trawl (2h) • study period: 21 days van der Reijden *et al.* (2017): **16.0%** • season: mix • gear: pulse trawl (60 min) • study period: 25 days • observations: 187 (~20 cm)
		DEF	90-99	0	4150	NA	NA	
			100-119	0	9272	NA	NA	
			120-219	0	88498	40416	0.31 (0.04-0.57)	
			≥220	0	508	25	0.08 (0-0.3)	
	LHP	FIF	-	0	3	NA	NA	
	LLS	FIF	-	0	1	0	0 (0-0)	
	OTB	CRU	32-69	0	13	69	0.94 (0.94-0.94)	
		DEF	<16	0	14114	NA	NA	
			16-31	2 (35 mm)	5733	NA	NA	
		MCD	70-99	0	6295	504495	0.99 (0.97-0.99)	
			100-119	0	39187	2623	0.08 (0.05-0.12)	
			≥120	0	192913	128195	0.3 (0.12-0.61)	
		SPF	<16	0	19648	NA	NA	
			16-31	0	81280	NA	NA	
	OTM	DEF	<16	0	2119	NA	NA	
			16-31	0	123	NA	NA	
				2 (35 mm)	1685	NA	NA	
			100-119	0	111	NA	NA	
		SPF	<16	0	92	NA	NA	
			16-31	0	148043	NA	NA	
			32-69	0	1709	NA	NA	
	PTB	DEF	<16	0	89	NA	NA	

			16-31	0	1	NA	NA
		MCD	100-119	0	554	NA	NA
			≥120	0	NA	19	NA
		SPF	16-31	0	166	NA	NA
	PTM	DEF	<16	0	147	NA	NA
			16-31	0	3	NA	NA
		SPF	16-31	0	28398	NA	NA
			32-69	0	65	NA	NA
	SDN	DEF	100-119	0	1985	1311	0.15 (0.15-0.15)
		DEF	≥120	0	17831	7489	0.16 (0-0.44)
	SSC	DEF	≥120	0	8665	15	0 (0-0.01)
	TBB	CRU	16-31	0	28	136986	1 (1-1)
		DEF	100-119	0	32	NA	NA
			≥120	0	14285	NA	NA
Skagerrak	GNS	CRU	>0	0	40	NA	NA
		DEF	50-70	0	225	111	0.38 (0.38-0.38)
			90-99	0	14	NA	NA
			100-119	0	839	351	0.42 (0.09-0.87)
			120-219	0	17774	3447	0.15 (0.01-0.29)
			≥220	0	141	0	0 (0-0)
		SPF	120-219	0	144	NA	NA
	LHP	FIF	-	0	1	NA	NA
	LLS	FIF	-	0	1	NA	NA
	OTB	CRU	32-69	0	16	616	0.25 (0-1)
			70-89	2 (35 mm)	7	NA	NA
		DEF	<16	0	447	NA	NA
			16-31	2 (35 mm)	214	NA	NA
			32-69	0	5	NA	NA
			70-89	2 (35 mm)	19	NA	NA
		MCD	90-119	0	110970	235812	0.67 (0.49-0.79)
			≥120	0	157831	59963	0.24 (0.1-0.44)
		SPF	16-31	0	962	NA	NA
	OTM	DEF	<16	0	69	NA	NA
			16-31	2 (35 mm)	346	NA	NA
			90-119	0	5	NA	NA
		SPF	16-31	0	7715	NA	NA
	PTB	DEF	<16	0	54	NA	NA
		MCD	90-119	0	42	295	0.84 (0.78-0.9)
			≥120	0	56	4	0.07 (0.07-0.07)
		SPF	16-31	0	43	NA	NA
	PTM	SPF	16-31	0	720	NA	NA
	SDN	DEF	90-119	0	56283	55067	0.28 (0.11-0.58)
			≥120	0	194453	132294	0.4 (0.11-0.68)
	SSC	DEF	≥120	0	4605	0	0 (0-0)
	TBB	DEF	90-119	0	1673	NA	NA
			≥120	0	5931	NA	NA

- no estimates

Flounder (*Platichthys flesus*)

Flounder is a species that is not targeted in the Danish fisheries and the economic value of the species is low. Quotas do exist for flounder only in the North Sea where it is managed together with dab. Contrary to dab, flounder is a relatively robust species, which makes it a potential candidate for being exempted from the landing obligation. Further studies are, however, needed to prove this assumption. Only two studies about survival of flounder are published so far – one conducted in the North Sea (see Table A.5) and another one by Kraak *et al.* (2018) in the Baltic Sea (survival rate: 0.0-~95%; season: whole year; gear: otter trawl (3 h); depth: 20-30 m; study period: 5-8 d; observations: 702) reporting highly variable survival rates over the year.

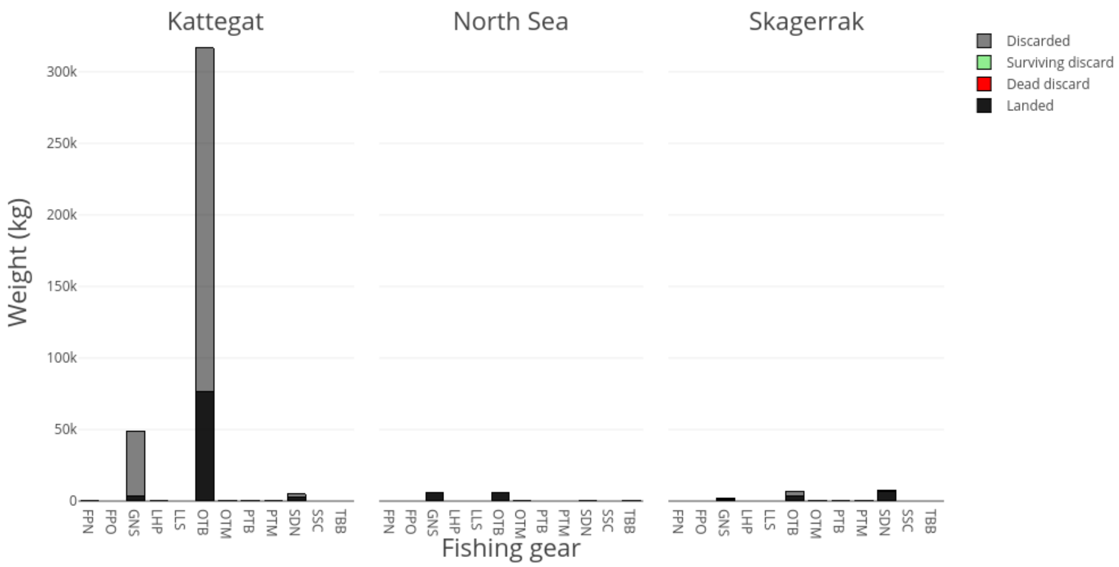

Figure A.3. Average annual landings (kg) and raised discards (kg) of flounder by Danish vessels for the years 2011-2016 separated by area and fishing gear including information about discard survival based on estimates from studies investigating commercial gears.

Table A.5. Total landings (kg), raised discards (kg) and average discard ratio (discard/total catch including Min and Max) for flounder, separated by area and metier including potential estimates on discard survival probability from previous studies (estimates for commercially used gears in bold). Cells are shaded according to their value (low: green, medium: yellow, high: red).

Area	Gear	Target	Mesh size (mm)	Sel. dev.	Annual Landings (kg)	Annual Discards (kg)	Discard ratio	Survival probability
Kattegat	FPN	CAT	>0	0	6	NA	NA	- no estimates
	GNS	CRU	>0	0	7	116	0.94 (0.94-0.94)	
		DEF	50-70	0	192	NA	NA	
			90-99	0	42	0	0 (0-0)	
			100-119	0	890	17987	0.93 (0.93-0.93)	
			120-219	0	2392	49831	0.59 (0.21-0.97)	
			≥220	0	85	236	0.45 (0-0.89)	
		SPF	100-119	0	6	NA	NA	
			120-219	0	2	NA	NA	
	LHP	FIF	-	0	14	NA	NA	
	OTB	CRU	32-69	0	175	NA	NA	
			70-89	2 (35 mm)	612	NA	NA	
		DEF	<16	0	8	NA	NA	
			32-69	0	318	NA	NA	
			70-89	2 (35 mm)	59	NA	NA	
		MCD	90-119	0	74343	238502	0.68 (0.43-0.93)	
			≥120	0	1874	3920	0.39 (0-0.77)	
		SPF	16-31	0	119	NA	NA	
	OTM	DEF	16-31	2 (35 mm)	5	NA	NA	
		SPF	16-31	0	393	NA	NA	
			32-69	0	3	NA	NA	
	PTB	MCD	90-119	0	49	227	0.82 (0.82-0.82)	
		SPF	16-31	0	32	NA	NA	
	PTM	SPF	16-31	0	219	NA	NA	
	SDN	DEF	90-119	0	4219	2020	0.23 (0.23-0.23)	
			≥120	0	12	NA	NA	

North Sea	GNS	CRU	>0	0	19	NA	NA	**72.0%**
		DEF	90-99	0	484	NA	NA	
			100-119	0	1469	NA	NA	Berghahn *et al.* (1992):
			120-219	0	4041	0	0 (0-0)	**72.0%** (after grid sorting)
			≥220	0	21	0	0 (0-0)	• season: autumn
	LLS	FIF	-	0	NA	0	NA	• gear: beam trawl (1h)
	OTB	CRU	32-69	0	NA	0	NA	• depth: 2-25 m
		DEF	<16	0	5	NA	NA	• study period: 5 days
		MCD	70-99	0	115	0	0 (0-0)	• observations: 32 (12-31 cm)
			100-119	0	1044	2	0.02 (0-0.08)	
			≥120	0	5204	38	0.01 (0-0.02)	
	OTM	DEF	16-31	0	93	NA	NA	
				2 (35 mm)	5	NA	NA	
			100-119	0	29	NA	NA	
	PTB	MCD	≥120	0	NA	0	NA	
	SDN	DEF	100-119	0	120	0	0 (0-0)	
			≥120	0	88	4	0.02 (0-0.08)	
	SSC	DEF	≥120	0	NA	0	NA	
	TBB	CRU	16-31	0	36	420	0.93 (0.93-0.93)	
		DEF	≥120	0	28	NA	NA	
Skagerrak	GNS	CRU	>0	0	5	NA	NA	- no estimates
		DEF	50-70	0	59	0	0 (0-0)	
			90-99	0	1	NA	NA	
			100-119	0	30	9	0.19 (0-0.56)	
			120-219	0	1435	301	0.09 (0-0.43)	
			≥220	0	22	0	0 (0-0)	
		SPF	120-219	0	2	NA	NA	
	OTB	CRU	32-69	0	4	0	0 (0-0)	
		DEF	<16	0	12	NA	NA	
			70-89	2 (35 mm)	1	NA	NA	
		MCD	90-119	0	1803	1827	0.45 (0.07-0.78)	
			≥120	0	1883	1214	0.26 (0-0.68)	
		SPF	16-31	0	163	NA	NA	
	OTM	DEF	**16-31**	0	6	NA	NA	
			90-119	0	2	NA	NA	
		SPF	16-31	0	1250	NA	NA	
	PTB	MCD	90-119	0	2	0	0.13 (0.13-0.13)	
			≥120	0	4	4	0.51 (0.51-0.51)	
	PTM	SPF	16-31	0	289	NA	NA	
	SDN	DEF	90-119	0	1942	165	0.22 (0.04-0.53)	
			≥120	0	4755	573	0.13 (0.02-0.26)	
	SSC	DEF	≥120	0	NA	0	NA	

Lemon sole (*Microsomus kitt*)

Lemon sole is a valuable species that is occasionally targeted by Danish fishing vessels. Together with flounder, it is quota-regulated in the North Sea. Experiences showed that lemon sole is a relatively sensitive species, but more survival experiments are necessary before an assessment in terms of a potential exclusion from the landing obligation is possible.

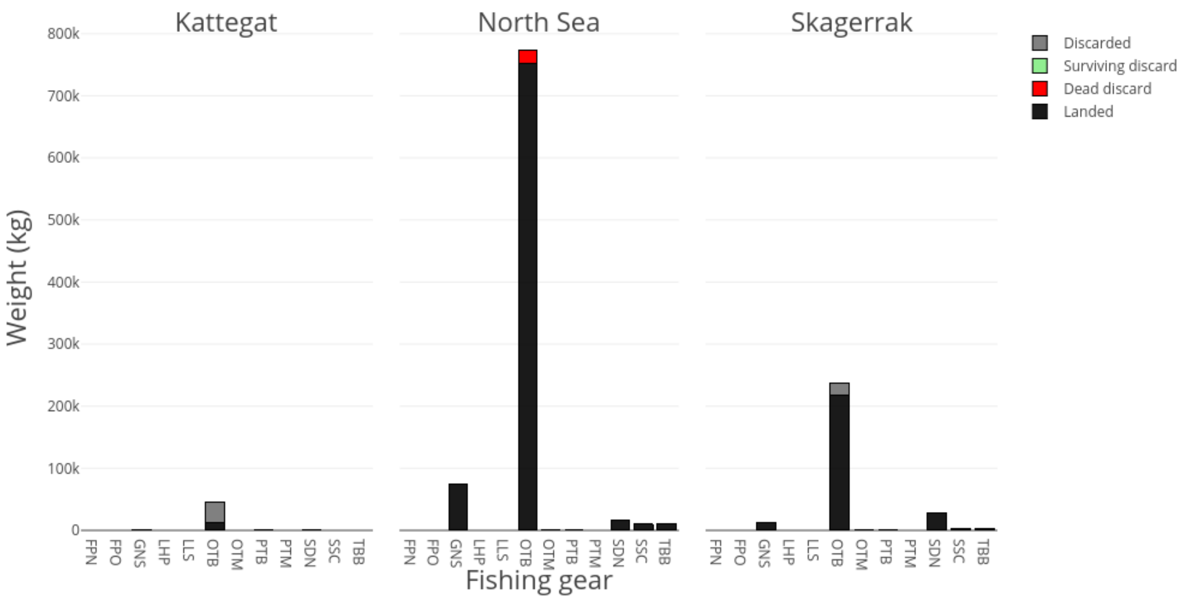

Figure A.4. Average annual landings (kg) and raised discards (kg) of lemon sole by Danish vessels for the years 2011-2016 separated by area and fishing gear including information about discard survival based on estimates from studies investigating commercial gears.

Table A.6. Total landings (kg), raised discards (kg) and average discard ratio (discard/total catch including Min and Max) for lemon sole, separated by area and metier including potential estimates on discard survival probability from previous studies (estimates for commercially used gears in bold). Cells are shaded according to their value (low: green, medium: yellow, high: red).

Area	Gear	Target	Mesh size (mm)	Sel. dev.	Annual Landings (kg)	Annual Discards (kg)	Discard ratio	Survival probability
Kattegat	GNS	CRU	>0	0	2	0	0 (0-0)	- no estimates
		DEF	50-70	0	2	NA	NA	
			90-99	0	143	1144	0.78 (0.78-0.78)	
			100-119	0	101	102	0.21 (0-0.41)	
			120-219	0	205	0	0 (0-0)	
			≥220	0	3	0	0 (0-0)	
	OTB	CRU	32-69	0	4	NA	NA	
			70-89	2 (35 mm)	50	NA	NA	
		DEF	<16	0	1	NA	NA	
			32-69	0	5	NA	NA	
			70-89	2 (35 mm)	3	NA	NA	
		MCD	90-119	0	12371	33567	0.71 (0.61-0.84)	
			≥120	0	254	465	0.34 (0-0.69)	
	OTM	DEF	16-31	2 (35 mm)	1	NA	NA	
		SPF	16-31	0	1	NA	NA	
			32-69	0	6	NA	NA	
	PTB	MCD	90-119	0	48	59	0.55 (0.55-0.55)	
	SDN	DEF	90-119	0	76	12	0.12 (0.12-0.12)	
			≥120	0	11	NA	NA	
North Sea	GNS	CRU	>0	0	40	NA	NA	**45.5% (0.0% - 91.0%)** Berghahn *et al.* (1992): **91.0%** (grid sorting) • season: autumn • gear: beam trawl (1h) • depth: 2-25 m • study period: 5 days • observations: 11 (7-9 cm) Evans *et al.* (1994): **0.0%** • season: mix • gear: otter trawl
		DEF	90-99	0	43	NA	NA	
			100-119	0	55	NA	NA	
			120-219	0	74508	40	0 (0-0)	
			≥220	0	321	0	0 (0-0)	
	LHP	FIF	-	0	2	NA	NA	
	LLS	FIF	-	0	2	0	NA	
	OTB	CRU	32-69	0	12	0	0 (0-0)	
		DEF	<16	0	92	NA	NA	
			16-31	2 (35 mm)	415	NA	NA	
		MCD	70-99	0	12340	7932	0.32 (0.04-0.65)	
			100-119	0	35091	269	0 (0-0.01)	
			≥120	0	704356	13655	0.02 (0-0.08)	
	OTM	DEF	16-31	2 (35 mm)	284	NA	NA	
			100-119	0	1	NA	NA	
	PTB	MCD	100-119	0	127	NA	NA	
			≥120	0	45	5	0.09 (0.09-0.09)	
	SDN	DEF	100-119	0	66	0	0 (0-0)	
			≥120	0	15438	33	0 (0-0)	
	SSC	DEF	≥120	0	9869	0	0 (0-0)	
	TBB	CRU	16-31	0	1	441	0 (0-0)	
		DEF	100-119	0	122	NA	NA	
			≥120	0	10084	NA	NA	

Skagerrak	GNS	CRU	>0	0	40	NA	NA	- no estimates
		DEF	50-70	0	18	0	0 (0-0)	
			90-99	0	1	NA	NA	
			100-119	0	160	63	0.32 (0.07-0.64)	
			120-219	0	12333	120	0.01 (0-0.02)	
			≥220	0	173	0	0 (0-0)	
		SPF	120-219	0	19	NA	NA	
	LHP	FIF	-	0	1	NA	NA	
	OTB	CRU	32-69	0	26	21	0.16 (0-0.95)	
			70-89	2 (35 mm)	148	NA	NA	
		DEF	<16	0	14	NA	NA	
			16-31	2 (35 mm)	22	NA	NA	
			32-69	0	22	NA	NA	
			70-89	2 (35 mm)	137	NA	NA	
		MCD	90-119	0	111403	19558	0.15 (0.09-0.29)	
			≥120	0	105553	1373	0.01 (0-0.06)	
	OTM	DEF	<16	0	3	NA	NA	
			16-31	0	18	NA	NA	
			90-119	0	35	NA	NA	
		SPF	16-31	0	1	NA	NA	
	PTB	MCD	90-119	0	109	43	0.31 (0.15-0.48)	
			≥120	0	7	0	0 (0-0)	
	SDN	DEF	90-119	0	11682	206	0.01 (0-0.03)	
			≥120	0	15966	301	0.02 (0-0.06)	
	SSC	DEF	≥120	0	2107	0	0 (0-0)	
	TBB	DEF	90-119	0	285	NA	NA	
			≥120	0	3161	NA	NA	

Plaice (*Pleurneces platessa*)

Plaice belongs to the main species in the Danish fishery and is targeted frequently by different vessel types. Quotas exist for all three considered areas. The number of survival studies on this species is relatively high, which is most likely due to its commercial importance. The general conclusions of the studies are that survivability is comparatively high but decreases with haul duration and air exposure. Furthermore, larger specimens show higher survival rates. Individual results of the studies conducted in Kattegat, North Sea or Skagerrak are given below in Table A.7. Further survival studies on plaice were conducted by Kraak *et al.* (2018) in the Baltic Sea (survival rate: ~5.0-100%; season: whole year; gear: otter trawl (3 h); depth: 20-30 m; study period: 5-8 d; observations: 738) finding highly variable survival rates over the year, by Kaiser and Spencer (1995) in the Irish sea (survival rate: 39.0-40.0%; season: spring; gear: beam trawl (30 min); depth: ~35 m; study period: 120-144 h; observations: 122), in the English Channel by Millner *et al.* (1993; survival rate: 63.0-94.0%; season: mix; gear: otter trawl (60-120 min); depth: 5-20 m; study period: >216 h; observations: 75 (19-31 cm)), Revill *et al.* (2013; survival rate: 20.4-62.7%; season: spring; gear: beam trawl (60-120 min); depth: 60-80 m; study period: 3 days; observations: 120 (23-62 cm)) and Morfin *et al.* (2017; survival rate: 45.2-66.6%; season: January-November; gear: otter trawl (93-270 min)); depth: 19-36 m; study period: 66-133 hours; observations: 1111 (24.127.7 cm)) and by Catchpole *et al.* (2015) in the North West Waters. Catchpole *et al.* (2015) conducted trials for different fishing gears: otter trawl (survival rate: 64.4%; season: winter; haul duration: 2h; depth: ~36 m; study period: 66-133 h; observations: 348 (~27.6 cm)); beam trawl (survival rate: 37.3%; season: winter; haul duration: 5h; depth: ~65 m; study period: 38-72 h; observations: 275 (~32.3 cm)); and trammel net (survival rate: 72.9%; season: spring; soaking time: 24-28h; study period: 168-342 h; observations: 168 (~33.5 cm)). An additional study that has been carried out by Savina *et al.* (2016) in the Skagerrak area concluded that damages (and thus likely also survivability) of fish caught in trammel nets depend on soaking time and individual length.

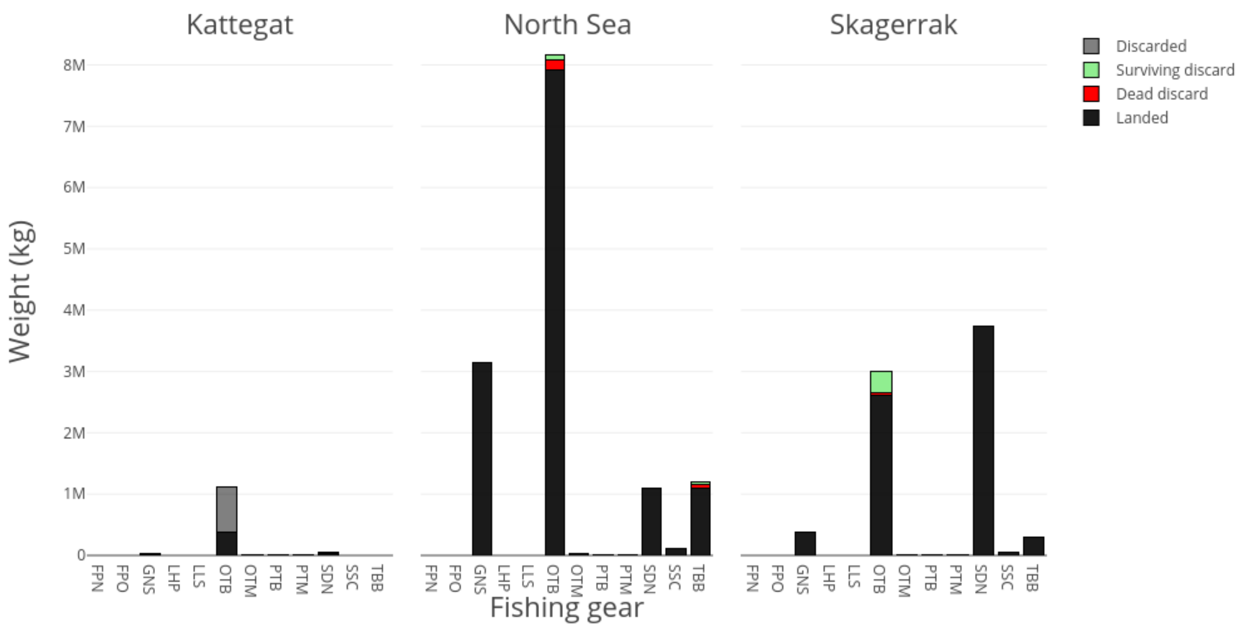

Figure A.5. Average annual landings (kg) and raised discards (kg) of plaice by Danish vessels for the years 2011-2016 separated by area and fishing gear including information about discard survival based on estimates from studies investigating commercial gears.

Table A.7. Total landings (kg), raised discards (kg) and average discard ratio (discard/total catch including Min and Max) for plaice, separated by area and métier including potential estimates on discard survival probability from previous studies (estimates for commercially used gears in bold). Cells are shaded according to their value (low: green, medium: yellow, high: red).

Area	Gear	Target	Mesh size (mm)	Sel. dev.	Annual Landings (kg)	Annual Discards (kg)	Discard ratio	Survival probability
Kattegat	GNS	CRU	>0	0	48	0	0 (0-0)	- no estimates
		DEF	50-70	0	1223	NA	NA	
			90-99	0	686	456	0.31 (0.31-0.31)	
			100-119	0	2200	8327	0.54 (0.34-0.74)	
			120-219	0	12052	0	0 (0-0)	
			≥220	0	113	0	0 (0-0)	
	OTB	CRU	32-69	0	13	NA	NA	
			70-89	2 (35 mm)	594	NA	NA	
		DEF	<16	0	400	NA	NA	
			32-69	0	870	NA	NA	
			70-89	2 (35 mm)	349	NA	NA	
		MCD	90-119	0	337355	737995	0.69 (0.45-0.85)	
			≥120	0	31896	29519	0.21 (0.07-0.34)	
		SPF	16-31	0	502	NA	NA	
	OTM	DEF	16-31	2 (35 mm)	28	NA	NA	
			90-119	0	1	NA	NA	
		SPF	16-31	0	1566	NA	NA	
			32-69	0	24	NA	NA	
	PTB	MCD	90-119	0	462	656	0.59 (0.59-0.59)	
		SPF	16-31	0	81	NA	NA	
	PTM	SPF	16-31	0	246	NA	NA	
	SDN	DEF	90-119	0	33307	23877	0.3 (0.3-0.3)	
			≥120	0	17756	NA	NA	

North Sea	GNS	CRU	>0	0	1381	NA	NA
		DEF	90-99	0	24768	NA	NA
			100-119	0	22028	NA	NA
			120-219	0	3055282	8719	0 (0-0.01)
			≥220	0	46415	0	0 (0-0)
	LHP	FIF	-	0	28	NA	NA
	LLS	FIF	-	0	79	0	0 (0-0)
	OTB	CRU	32-69	0	23	0	0 (0-0)
		DEF	<16	0	3939	NA	NA
			16-31	2 (35 mm)	2308	NA	NA
		MCD	70-99	0	361696	247868	0.37 (0.15-0.58)
			100-119	0	432407	1541	0 (0-0.01)
			≥120	0	7119271	37812	0.01 (0-0.01)
		SPF	<16	0	2643	NA	NA
			16-31	0	14552	NA	NA
	OTM	DEF	<16	0	596	NA	NA
			16-31	0	1449	NA	NA
				2 (35 mm)	4793	NA	NA
			100-119	0	1910	NA	NA
		SPF	16-31	0	19436	NA	NA
			32-69	0	60	NA	NA
	PTB	DEF	<16	0	182	NA	NA
		MCD	100-119	0	1047	NA	NA
			≥120	0	82	3	0.04 (0.04-0.04)
		SPF	16-31	0	18	NA	NA
	PTM	DEF	<16	0	34	NA	NA
		SPF	16-31	0	1337	NA	NA
	SDN	DEF	100-119	0	39046	2198	0.02 (0.02-0.02)
			≥120	0	1063416	11124	0.01 (0-0.03)
	SSC	DEF	≥120	0	103077	0	0 (0-0)
	TBB	CRU	16-31	0	2	95678	1 (1-1)
		DEF	<16	0	63	NA	NA
			100-119	0	802	NA	NA
			≥120	0	1099322	NA	NA

35.3% (10.0% - 58.8%)

Kelle (1976):
28.3% (grid sorting) - 52.9% (no grid sorting)
- season: mix
- gear: beam trawl (15-120 min)
- depth: 2-25 m
- study period: 7 days
- observations: 1705 (4-25 cm)

van Beek *et al.* (1990):
17.9% (beam trawl) - **24.5%** (otter trawl)
- season: mix
- gear: beam trawl (60-120 min); otter trawl (20-105min
- depth: 23-40 m
- study period: 1-4 days
- observations: 2331 (20-30 cm)

Berghahn *et al.* (1992):
9.0-83.0% (grid sorting); 30.0-100.0% (no grid sorting)
- season: autumn
- gear: beam trawl (1h)
- depth: 2-25 m
- study period: 5 days
- observations: 1008 (4-16 cm)

Depestele *et al.* (2014):
48.0-69.0%
- season: mix
- gear: beam trawl (84-97 min)
- depth: 10-50 m
- study period: 57-77 h
- observations: 185 (15-32 cm)

Catchpole *et al.* (2015):
42.0%
- season: mix
- gear: otter trawl (3h)
- depth: 69 m
- study period: 105-120 h
- observations: 292 (~28 cm)

van Marlen *et al.* (2015):
10.0 (twinrig) - 28.0% (pulse)
- season: mix
- gear: beam trawl (1-2h)
- study period: 21 days

Uhlmann *et al.* (2016):
85.5 (haul duration: <20 min) - **54.8%** (haul duration: 60 min)
- season: mix
- gear: beam trawl (≤60 min)
- depth: 8-16 m
- study period: 15-35 days
- observations: >316 (12-24 cm)

van der Reijden *et al.* (2017):
14.6%
- season: mix
- gear: pulse trawl (1 h)
- study period: 25 days
- observations: 349 (~22 cm)

Schram and Molenaar (2018):
1% (September); 22% (October)
- season: mix
- gear: pulse trawl (~2h)
- depth: 18-52 m
- study period: 15-18 days
- observations: 558

Skagerrak	GNS	CRU	>0	0	456	NA	NA	**88.9% (76.0% - 96.0%)** Methling *et al.* (2017): **96.0%** (0 min air exposure); **98.0%** (30 min air exposure); **85.5%** (60min air exposure); **76%** (90min air exposure) • season: mix • gear: otter trawl (3h) • depth: 11-66 m • study period: 10 days • observations: 200 (~33 cm)
		DEF	50-70	0	2528	95	0.15 (0.15-0.15)	
			90-99	0	56	NA	NA	
			100-119	0	4940	1677	0.21 (0.02-0.52)	
			120-219	0	366652	8938	0.03 (0-0.06)	
			≥220	0	6415	23	0 (0-0.01)	
		SPF	120-219	0	27	NA	NA	
	LHP	FIF	-	0	8	NA	NA	
	LLS	FIF	-	0	3	NA	NA	
	OTB	CRU	32-69	0	1378	48	0.03 (0-0.15)	
			70-89	2 (35 mm)	2435	NA	NA	
		DEF	<16	0	1127	NA	NA	
			16-31	2 (35 mm)	51	NA	NA	
			32-69	0	148	NA	NA	
			70-89	2 (35 mm)	3072	NA	NA	
		MCD	90-119	0	1066281	305199	0.24 (0.11-0.4)	
			≥120	0	1531458	99318	0.06 (0.05-0.12)	
		SPF	16-31	0	438	NA	NA	
	OTM	DEF	<16	0	86	NA	NA	
			16-31	0	1513	NA	NA	
			90-119	0	893	NA	NA	
		SPF	16-31	0	3902	NA	NA	
	PTB	DEF	<16	0	80	NA	NA	
		MCD	90-119	0	2722	502	0.33 (0.06-0.6)	
			≥120	0	1212	17	0.01 (0.01-0.01)	
		SPF	16-31	0	378	NA	NA	
	PTM	DEF	<16	0	89	NA	NA	
			16-31	0	2	NA	NA	
		SPF	16-31	0	1664	NA	NA	
	SDN	DEF	90-119	0	737797	101374	0.08 (0.04-0.14)	
			≥120	0	2998684	256568	0.08 (0.04-0.13)	
	SSC	DEF	≥120	0	50193	65	0 (0-0)	
	TBB	DEF	100-119	0	62088	NA	NA	
			≥120	0	289681	NA	NA	

Sole (*Solea solea*)

Sole is a very valuable quota-regulated species, which is also reflected in low discard rates in most métiers. An experience-based assessment of sole in terms of discard survivability categorizes the species as being relatively robust. As results of survival studies in the North Sea (see Table A.8 for details) concluded survival rates to bel relatively high, there is a request for a high survivability exemption for sole for inshore trawlers in the North Sea operating within six nautical miles of the coast. However, STECF (2016) concluded that it may be appropriate to await the outcome of further studies within the North Sea area before taking a decision. Besides studies in the North Sea, Cabral *et al.* (2002) conducted survival experiments on sole in the Tagus estuary (survival rate: 90-100%; season: mix; gear: beam trawl; depth: 10 m; study period: 30 min; observations: 71) and (Revill *et al.*, 2013) in the English channel (survival rate: 23.6-46.9%; season: spring; gear: beam trawl (60-120 min); depth: 60-80 m; study period: 3 days; observations: 90 (23-52 cm)).

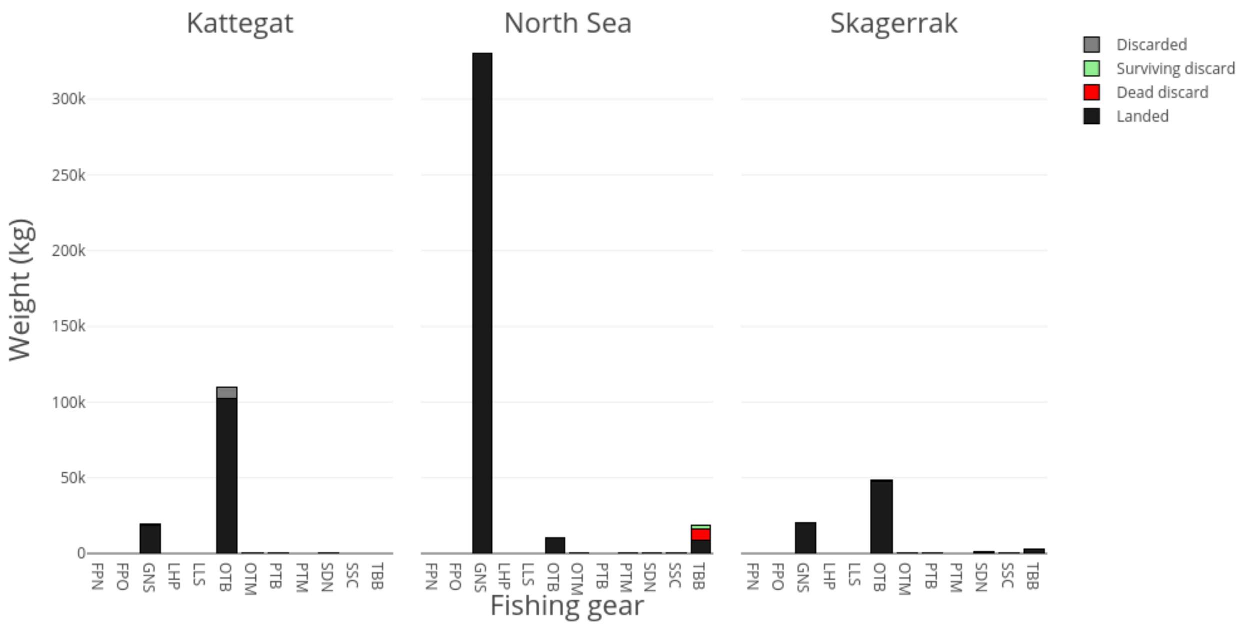

Figure A.6. Average annual landings (kg) and raised discards (kg) of sole by Danish vessels for the years 2011-2016 separated by area and fishing gear including information about discard survival based on estimates from studies investigating commercial gears.

Table A.8. Total landings (kg), raised discards (kg) and average discard ratio (discard/total catch including Min and Max) for sole, separated by area and metier including potential estimates on discard survival probability from previous studies (estimates for commercially used gears in bold). Cells are shaded according to their value (low: green, medium: yellow, high: red).

Area	Gear	Target	Mesh size (mm)	Sel. dev.	Annual Landings (kg)	Annual Discards (kg)	Discard ratio	Survival probability
Kattegat	GNS	CRU	>0	0	22	0	0 (0-0)	- no estimates
		DEF	50-70	0	228	NA	NA	
			90-99	0	5541	1740	0.14 (0.14-0.14)	
			100-119	0	9952	209	0.01 (0.01-0.01)	
			120-219	0	2843	0	0 (0-0)	
			≥220	0	122	0	0 (0-0)	
		SPF	50-70	0	2	NA	NA	
			100-119	0	8	NA	NA	
	LHP	FIF	-	0	2	NA	NA	
	OTB	CRU	32-69	0	17	NA	NA	
			70-89	2 (35 mm)	358	NA	NA	
		DEF	32-69	0	274	NA	NA	
			70-89	2 (35 mm)	125	NA	NA	
		MCD	90-119	0	101040	7203	0.06 (0.02-0.13)	
			≥120	0	584	423	0.51 (0.22-0.8)	
	OTM	DEF	16-31	2 (35 mm)	9	NA	NA	
			90-119	0	3	NA	NA	
		SPF	16-31	0	7	NA	NA	
	PTB	MCD	90-119	0	184	5	0.02 (0.02-0.02)	
	SDN	DEF	90-119	0	8	0	0 (0-0)	
			≥120	0	1	NA	NA	
North Sea	GNS	CRU	>0	0	11	NA	NA	**37.8% (6.7% - 74.0%)** Kelle (1976): **40.6%** (grid sorting) - 57.6% (no grid sorting) • season: mix • gear: beam trawl (15-120 min) • depth: 2-25 m • study period: 7 days • observations: 1685 (8-24 cm) van Beek *et al.* (1990): 41.0% (haul duration: <30 min), 21.2% (haul duration: 60 min), **6.7%** (haul duration: 120min) • season: mix • gear: beam trawl (15-120 min) • depth: 18-30 m • study period: 3-4 days • observations: 778 (20-28 cm) Berghahn *et al.* (1992): **74.0%** (grid sorting) • season: autumn • gear: beam trawl (1h) • depth: 2-25 m • study period: 5 days • observations: 89 (7-22 cm) Depestele *et al.* (2014): **14.0-29.0%** • season: mix • gear: beam trawl (84-97 min) • depth: 10-50 m
		DEF	90-99	0	110845	NA	NA	
			100-119	0	158248	NA	NA	
			120-219	0	60986	27	0 (0-0)	
			≥220	0	557	0	0 (0-0)	
	LHP	FIF	-	0	1	NA	NA	
	LLS	FIF	-	0	NA	0	NA	
	OTB	CRU	32-69	0	NA	0	NA	
		DEF	<16	0	86	NA	NA	
			16-31	2 (35 mm)	1	NA	NA	
		MCD	70-99	0	2627	198	0.05 (0-0.26)	
			100-119	0	2664	0	0 (0-0)	
			≥120	0	5096	0	0 (0-0)	
		SPF	16-31	0	522	NA	NA	
	OTM	DEF	16-31	2 (35 mm)	7	NA	NA	
			100-119	0	1	NA	NA	
		SPF	16-31	0	451	NA	NA	
	PTB	MCD	100-119	0	1	NA	NA	

			≥120	0	NA	0	NA	• study period: 64-91 h • observations: 454 (13-35 cm) van Marlen *et al.* (2015): 31.0 (haul duration: 1h) - 41.0% (haul duration: 2h) • season: mix • gear: pulse trawl (1-2h) • study period: 21 days Ribeiro Santos *et al.* (2016): **46.0** (<MLS) - 51.0% (all sizes) • season: autumn • gear: otter trawl (2 h) • depth: 16 m • study period: 360 h • observations: 357 (~21.6 cm) van der Reijden *et al.* (2017): 29.1% • season: mix • gear: pulse trawl (1 h) • study period: 25 days • observations: 226 (~22 cm) Schram and Molenaar (2018): 0% (December, January); 50% (May) • season: mix • gear: pulse trawl (~2h) • depth: 18-52 m • study period: 15-18 days • observations: 274
	PTM	SPF	16-31	0	205	NA	NA	
	SDN	DEF	100-119	0	6	0	0 (0-0)	
			≥120	0	46	0	0 (0-0)	
	SSC	DEF	≥120	0	4	0	0 (0-0)	
	TBB	CRU	16-31	0	1	7748	1 (1-1)	
			100-119	0	465	NA	NA	
		DEF	≥120	0	8324	NA	NA	
Skagerrak	GNS	CRU	>0	0	10	NA	NA	- no estimates
		DEF	50-70	0	138	0	0 (0-0)	
			90-99	0	801	NA	NA	
			100-119	0	13368	52	0 (0-0.01)	
			120-219	0	8541	2	0 (0-0)	
			≥220	0	31	0	0 (0-0)	
		SPF	120-219	0	2	NA	NA	
	LHP	FIF	-	0	2	NA	NA	
	OTB	CRU	32-69	0	5	0	0 (0-0)	
			70-89	2 (35 mm)	17	NA	NA	
		DEF	<16	0	6	NA	NA	
			32-69	0	3	NA	NA	
			70-89	2 (35 mm)	151	NA	NA	
		MCD	90-119	0	41083	135	0 (0-0.01)	
			≥120	0	6475	917	0.1 (0-0.62)	
	OTM	DEF	16-31	2 (35 mm)	61	NA	NA	
			90-119	0	2	NA	NA	
	PTB	MCD	90-119	0	112	0	0.01 (0.01-0.01)	
			≥120	0	5	0	0 (0-0)	
	SDN	DEF	90-119	0	110	0	0 (0-0)	
			≥120	0	719	34	0.02 (0-0.09)	
	SSC	DEF	≥120	0	17	0	0 (0-0)	
	TBB	DEF	90-119		1292	NA	NA	
			≥120	0	2579	NA	NA	

Turbot (*Scophthalmus maximus*)

Turbot belongs to the most valuable species in the Danish fishery and is targeted by different fisheries. Quotas exist for turbot in the North Sea area, where it is managed together with brill. A subjective assessment of the species categorizes it as relatively robust species, which makes it a potential candidate for being excluded from the landing obligation. A study by Basaran and Samsun (2004) investigated survivability of the sub species *Psetta maxima maeotica* caught with gillnets in the Black Sea (survival rates 25-92%). Nevertheless, further studies in Danish waters are necessary to perform a proper survivability-assessment of turbot.

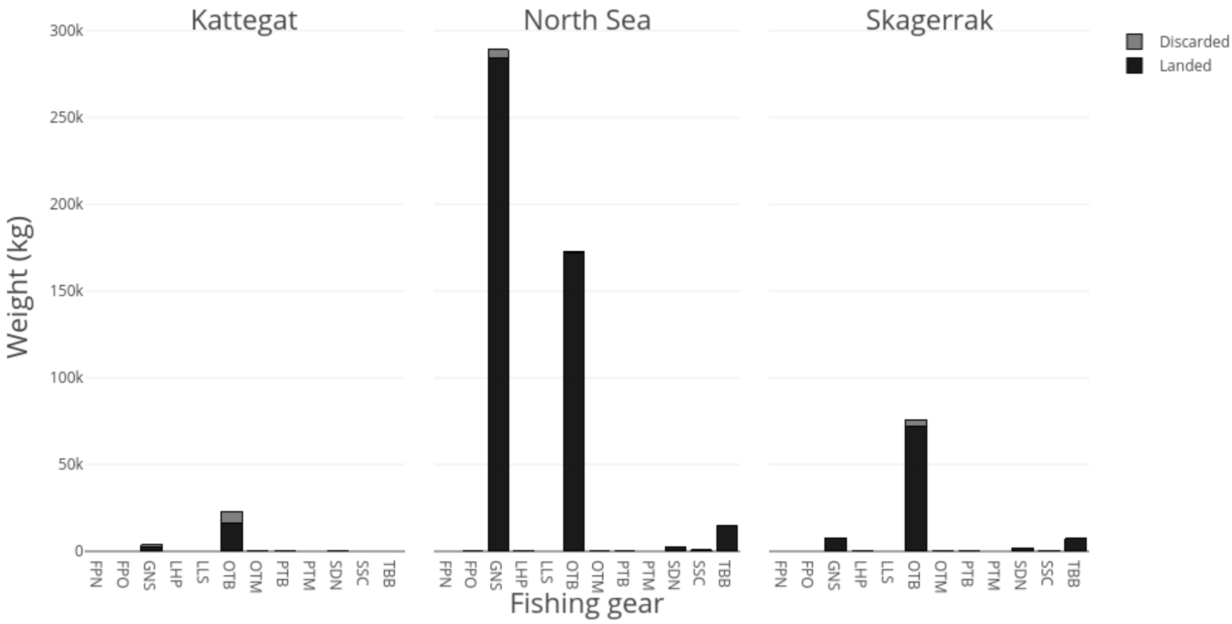

Figure A.7. Average annual landings (kg) and raised discards (kg) of turbot by Danish vessels for the years 2011-2016 separated by area and fishing gear.

Table A.9. Total landings (kg), raised discards (kg) and average discard ratio (discard/total catch including Min and Max) for turbot, separated by area and metier including potential estimates on discard survival probability from previous studies (estimates for commercially used gears in bold). Cells are shaded according to their value (low: green, medium: yellow, high: red).

Area	Gear	Target	Mesh size (mm)	Sel. dev.	Annual Landings (kg)	Annual Discards (kg)	Discard ratio	Survival probability
Kattegat	GNS	CRU	>0	0	26	76	0.88 (0.88-0.88)	- no estimates
		DEF	50-70	0	17	NA	NA	
			90-99	0	169	26	0.15 (0.15-0.15)	
			100-119	0	409	876	0.58 (0.42-0.74)	
			120-219	0	993	825	0.38 (0-0.75)	
			≥220	0	852	0	0 (0-0)	
		SPF	100-119	0	1	NA	NA	
			120-219	0	3	NA	NA	
	OTB	CRU	32-69	0	3	NA	NA	
			70-89	2 (35 mm)	69	NA	NA	
		DEF	<16	0	2	NA	NA	
			32-69	0	16	NA	NA	
			70-89	2 (35 mm)	32	NA	NA	
		MCD	90-119	0	16128	6529	0.29 (0.13-0.41)	
			≥120	0	222	233	0.27 (0-0.53)	
	OTM	DEF	16-31	2 (35 mm)	8	NA	NA	
			90-119	0	1	NA	NA	
		SPF	16-31	0	2	NA	NA	
	PTB	MCD	90-119	0	48	13	0.22 (0.22-0.22)	
	SDN	DEF	90-119	0	33	58	0.54 (0.54-0.54)	
			≥120	0	2	NA	NA	
North Sea	FPO	CRU	>0	0	17	NA	NA	Schram and Molenaar (2018): 0% (January, February); 63% (July) • season: mix • gear: pulse trawl (~2h) • depth: 18-52 m • study period: 15-18 days • observations: 111
	GNS	CRU	>0	0	1312	NA	NA	
		DEF	90-99	0	2952	NA	NA	
			100-119	0	3165	NA	NA	
			120-219	0	90733	2809	0.03 (0-0.08)	
			≥220	0	186424	2489	0.01 (0-0.04)	
	LHP	FIF	-	0	8	NA	NA	
	LLS	FIF	-	0	1	0	NA	
	OTB	CRU	32-69	0	4	0	NA	
		DEF	<16	0	9	NA	NA	
			16-31	2 (35 mm)	2	NA	NA	
		MCD	70-99	0	12598	0	0 (0-0)	
			100-119	0	8829	5	0 (0-0.01)	
			≥120	0	150824	555	0 (0-0.01)	
	OTM	DEF	16-31	0	2	NA	NA	
				2 (35 mm)	41	NA	NA	
			100-119	0	4	NA	NA	
	PTB	MCD	100-119	0	26	NA	NA	

			≥120	0	38	0	0 (0-0)	
	SDN	DEF	100-119	0	57	39	0.19 (0.19-0.19)	
			≥120	0	2125	155	0.05 (0-0.14)	
	SSC	DEF	≥120	0	871	0	0 (0-0)	
	TBB	CRU	16-31	0	4	48	0 (0-0)	
		DEF	≥120	0	14801	NA	NA	
Skagerrak	GNS	CRU	>0	0	229	NA	NA	- no estimates
		DEF	50-70	0	9	55	0.98 (0.98-0.98)	
			90-99	0	10	NA	NA	
			100-119	0	55	0	0 (0-0)	
			120-219	0	2963	262	0.08 (0-0.18)	
			≥220	0	4076	0	0 (0-0)	
	LHP	FIF	-	0	5	NA	NA	
	OTB	CRU	32-69	0	13	283	0.19 (0-0.97)	
			70-89	2 (35 mm)	80	NA	NA	
		DEF	<16	0	48	NA	NA	
			32-69	0	1	NA	NA	
			70-89	2 (35 mm)	243	NA	NA	
		MCD	90-119	0	28619	1283	0.06 (0.01-0.11)	
			≥120	0	43599	1959	0.04 (0.01-0.11)	
	OTM	DEF	<16	0	4	NA	NA	
			16-31	2 (35 mm)	47	NA	NA	
			90-119	0	3	NA	NA	
	PTB	MCD	90-119	0	4	6	0.54 (0.17-0.92)	
			≥120	0	3	0	0 (0-0)	
	SDN	DEF	90-119	0	384	3	0.02 (0-0.09)	
			≥120	0	1611	33	0.03 (0-0.18)	
	SSC	DEF	≥120	0	189	0	0 (0-0)	
	TBB	DEF	90-119	0	1570	NA	NA	
			≥120	0	7245	NA	NA	

Witch flounder (*Glyptocephalus cynoglossus*)

Witch flounder is a valuable species that is occasionally targeted by several types of vessels. It is quota-regulated in the North Sea together with lemon sole. Based on experience, survivability of witch flounder is expected to be low, but survival studies are needed to test for this.

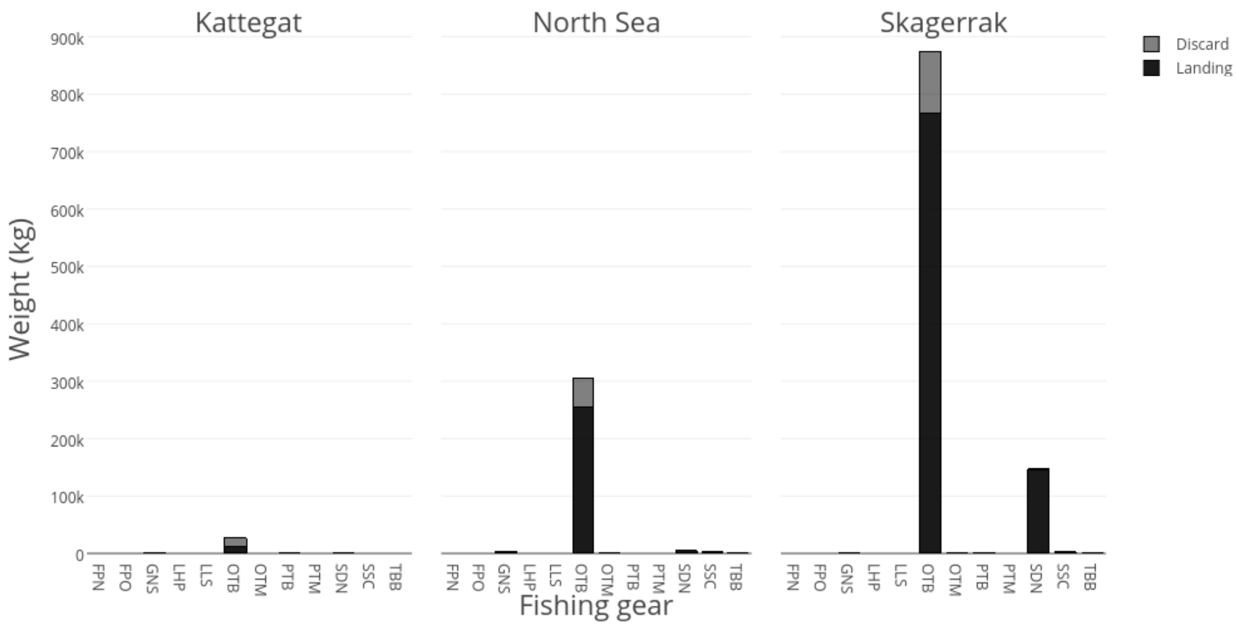

Figure A.8. Average annual landings (kg) and raised discards (kg) of witch flounder by Danish vessels for the years 2011-2016 separated by area and fishing gear.

Table A.10. Total landings (kg) raised discards (kg) and average discard ratio (discard/total catch including Min and Max) for witch flounder, separated by area and metier including potential estimates on discard survival probability from previous studies (estimates for commercially used gears in bold). Cells are shaded according to their value (low: green, medium: yellow, high: red).

Area	Gear	Target	Mesh size (mm)	Sel. dev.	Annual Landings (kg)	Annual Discards (kg)	Discard ratio	Survival probability
Kattegat	GNS	CRU	>0	0	2	0	0 (0-0)	- no estimates
		DEF	90-99	0	37	0	NA	
			100-119	0	4	0	0 (0-0)	
			120-219	0	457	0	0 (0-0)	
			≥220	0	NA	0	NA	
	OTB	CRU	70-89	2 (35 mm)	26	NA	NA	
		DEF	32-69	0	12	NA	NA	
			70-89	2 (35 mm)	12	NA	NA	
		MCD	90-119	0	13778	16779	0.54 (0.48-0.58)	
			≥120	0	112	1052	0.9 (0.81-0.99)	
	OTM	DEF	16-31	2 (35 mm)	2	NA	NA	
		SPF	32-69	0	4	NA	NA	
	PTB	MCD	90-119	0	24	12	0.34 (0.34-0.34)	
	SDN	DEF	90-119	0	24	0	0 (0-0)	
			≥120	0	2	NA	NA	
North Sea	GNS	DEF	90-99	0	3	NA	NA	- no estimates
			100-119	0	16	NA	NA	
			120-219	0	3990	11	0.01 (0-0.04)	
			≥220	0	186	17	0.14 (0-0.56)	
	LLS	FIF	-	0	NA	0	NA	
	OTB	CRU	32-69	0	616	289	0.2 (0-0.59)	
		DEF	16-31	2 (35 mm)	8473	NA	NA	
		MCD	70-99	0	11463	4151	0.18 (0.01-0.49)	
			100-119	0	2488	59	0.02 (0-0.06)	
			≥120	0	275547	44824	0.13 (0-0.33)	
		SPF	16-31	0	5644	NA	NA	
	OTM	DEF	16-31	2 (35 mm)	2522	NA	NA	
		SPF	16-31	0	9318	NA	NA	
	PTB	MCD	≥120	0	471	91	0.16 (0.16-0.16)	
	PTM	SPF	16-31	0	2	NA	NA	
	SDN	DEF	100-119	0	1624	0	0 (0-0)	
			≥120	0	5619	3	0 (0-0)	
	SSC	DEF	≥120	0	3025	1957	0.23 (0-0.47)	
	TBB	CRU	16-31	0	NA	25	NA	
		DEF	100-119	0	18	NA	NA	
			≥120	0	721	NA	NA	
Skagerrak	GNS	CRU	>0	0	4	NA	NA	- no estimates
		DEF	50-70	0	1	0	NA	
			100-119	0	4	0	0 (0-0)	
			120-219	0	113	0	0 (0-0)	
			≥220	0	9	0	0 (0-0)	
	OTB	CRU	32-69	0	25935	13601	0.34 (0.15-0.6)	
			70-89	2 (35 mm)	623	NA	NA	

		DEF	<16	0	127	NA	NA	
			16-31	2 (35 mm)	481	NA	NA	
			32-69	0	928	NA	NA	
			70-89	2 (35 mm)	88	NA	NA	
		MCD	90-119	0	708000	77480	0.1 (0.02-0.25)	
			≥120	0	42739	955	0.02 (0-0.08)	
	OTM	DEF	<16	0	15	NA	NA	
			16-31	0	316	NA	NA	
			90-119	0	149	NA	NA	
	PTB	MCD	90-119	0	308	103	0.25 (0.11-0.39)	
			≥120	0	NA	0	NA	
	SDN	DEF	90-119	0	73366	409	0 (0-0.02)	
			≥120	0	74678	509	0.01 (0-0.05)	
	SSC	DEF	≥120	0	2379	351	0.06 (0.06-0.06)	
	TBB	DEF	100-119	0	16	NA	NA	
			≥120	0	29	NA	NA	

Most hazardous fisheries

Within this section, most hazardous fisheries in terms of discards have been identified and extracted from the species catalogue. The identification followed an absolute (discard ≥ 10 t; Table 15), a relative (discard ratios ≥ 40%, Table A.11) as well as a combined approach (discard ≥ 10 t and discard ratios ≥ 40%; Table A.12).

Table A.11. Overview of fisheries with discards ≥10000 kg. Cells shaded according to value (low: green, medium: yellow, high: red).

Species	Area	Fishing gear	Target	Mesh size	Sel. Dev.	Annual landings (kg)	Annual Discards (kg)	Discard ratio
Brill	Kattegat	OTB	MCD	90-119	0	54908	38966	0.40
Dab	Kattegat	GNS	DEF	100-119	0	1017	34223	0.95
		OTB	MCD	90-119	0	26468	1971801	0.99
				≥120	0	1790	103491	0.87
		SDN	DEF	90-119	0	1211	14809	0.93
	North Sea	GNS	DEF	120-219	0	88498	40416	0.31
		OTB	MCD	70-99	0	6295	504495	0.99
				≥120	0	192913	128195	0.30
		TBB	CRU	16-31	0	28	136986	1.00
	Skagerrak	OTB	MCD	90-119	0	110970	235812	0.67
				≥120	0	157831	59963	0.24
		SDN	DEF	90-119	0	56283	55067	0.28
				≥120	0	194453	132294	0.40
Flounder	Kattegat	GNS	DEF	100-119	0	890	17987	0.93
				120-219	0	2392	49831	0.59
		OTB	MCD	90-119	0	74343	238502	0.68
Lemon sole	Kattegat	OTB	MCD	90-119	0	12371	33567	0.71
	North Sea	OTB	MCD	≥120	0	704356	13655	0.02
	Skagerrak	OTB	MCD	90-119	0	111403	19558	0.15
Plaice	Kattegat	OTB	MCD	90-119	0	337355	737995	0.69
				≥120	0	31896	29519	0.21
		SDN	DEF	90-119	0	33307	23877	0.30
	North Sea	OTB	MCD	70-99	0	361696	247868	0.37
				≥120	0	7119271	37812	0.01
		SDN	DEF	≥120	0	1063416	11124	0.01
		TBB	CRU	16-31	0	2	95678	1.00
	Skagerrak	OTB	MCD	90-119	0	1066281	305199	0.24
				≥120	0	1531458	99318	0.06
		SDN	DEF	90-119	0	737797	101374	0.08
				≥120	0	2998684	256568	0.08
Witch flounder	Kattegat	OTB	MCD	90-119	0	13778	16779	0.54
	North Sea	OTB	MCD	≥120	0	275547	44824	0.13
	Skagerrak	OTB	CRU	32-69	0	25935	13601	0.34
			MCD	90-119	0	708000	77480	0.10

Table A.12. Overview of fisheries with discard ratios ≥40%. Cells shaded according to value (low: green, medium: yellow, high: red).

Species	Area	Fishing gear	Target	Mesh size	Sel. Dev.	Annual landings (kg)	Annual Discards (kg)	Discard ratio
Brill	Kattegat	GNS	DEF	100-119	0	295	618	0.54
		OTB	MCD	90-119	0	54908	38966	0.40
		SDN	DEF	90-119	0	108	316	0.64
	North Sea	TBB	CRU	16-31	0	2	71	1.00
Dab	Kattegat	GNS	DEF	90-99	0	69	4409	0.98
				100-119	0	1017	34223	0.95
				120-219	0	1008	1886	0.59
		OTB	MCD	90-119	0	26468	1971801	0.99
				≥120	0	1790	103491	0.87
		PTB	**MCD**	**90-119**	0	1	2796	1.00
		SDN	DEF	90-119	0	1211	14809	0.93
	North Sea	**OTB**	**CRU**	**32-69**	0	13	69	0.94
			MCD	70-99	0	6295	504495	0.99
		TBB	**CRU**	**16-31**	0	28	136986	1.00
	Skagerrak	**GNS**	**DEF**	**100-119**	**0**	839	351	0.42
		OTB	**MCD**	**90-119**	0	110970	235812	0.67
		PTB	**MCD**	**90-119**	0	42	295	0.84
		SDN	DEF	≥120	0	194453	132294	0.40
Flounder	Kattegat	GNS	CRU	>0	0	7	116	0.94
			DEF	100-119	0	890	17987	0.93
				120-219	0	2392	49831	0.59
				≥220	0	85	236	0.45
		OTB	MCD	90-119	0	74343	238502	0.68
		PTB	**MCD**	**90-119**	0	49	227	0.82
	North Sea	**TBB**	**CRU**	16-31	0	36	420	0.93
	Skagerrak	OTB	MCD	**90-119**	0	1803	1827	0.45
		PTB	**MCD**	**≥120**	0	4	4	0.51
Lemon sole	Kattegat	GNS	DEF	90-99	0	143	1144	0.78
		OTB	MCD	90-119	0	12371	33567	0.71
		PTB	**MCD**	**90-119**	0	48	59	0.55
Plaice	Kattegat	GNS	DEF	100-119	0	2200	8327	0.54
		OTB	MCD	90-119	0	337355	737995	0.69
		PTB	MCD	90-119	0	462	656	0.59
	North Sea	TBB	CRU	16-31	0	2	95678	1.00
Sole	Kattegat	OTB	MCD	≥120	0	584	423	0.51
	North Sea	TBB	CRU	16-31	0	1	7748	1.00
Turbot	Kattegat	GNS	CRU	>0	0	26	76	0.88
			DEF	100-119	0	409	876	0.58
		SDN	DEF	90-119	0	33	58	0.54
	Skagerrak	**GNS**	**DEF**	**50-70**	0	9	55	0.98
		PTB	**MCD**	**90-119**	**0**	4	6	0.54
Witch flounder	Kattegat	OTB	MCD	90-119	0	13778	16779	0.54
				≥120	0	112	1052	0.90

Table A.13. Overview of fisheries with discards ≥10 t and discard ratios ≥40%. Cells shaded according to value (low: green, medium: yellow, high: red).

Species	Area	Fishing gear	Target	Mesh size	Sel. Dev.	Annual landings (kg)	Annual Discards (kg)	Discard ratio
Brill	Kattegat	OTB	MCD	90-119	0	54,908	38,966	0.40
Dab	Kattegat	GNS	DEF	100-119	0	1,017	34,223	0.95
		OTB	MCD	≥120	0	1,790	103,491	0.87
				90-119	0	26,468	1,971,801	0.99
		SDN	DEF	90-119	0	1,211	14,809	0.93
	North Sea	OTB	MCD	70-99	0	6,295	504,495	0.99
		TBB	CRU	16-31	0	28	136,986	1.00
	Skagerrak	OTB	MCD	90-119	0	110,970	235,812	0.67
		SDN	DEF	≥120	0	194,453	132,294	0.40
Flounder	Kattegat	GNS	DEF	100-119	0	890	17,987	0.93
				120-219	0	2,392	49,831	0.59
		OTB	MCD	90-119	0	74,343	238,502	0.68
Lemon sole	Kattegat	OTB	MCD	90-119	0	12,371	33,567	0.71
Plaice	Kattegat	OTB	MCD	90-119	0	337,355	737,995	0.69
	North Sea	TBB	CRU	16-31	0	2	95,678	1.00
Witch flounder	Kattegat	OTB	MCD	90-119	0	13,778	16,779	0.54

Species ranking and final remarks

This document presented Danish fisheries targeting flatfish and provided information about flatfish species, which are of economic interest in Denmark including information about catches and discards from 2011-2016. It highlighted fisheries with high discard ratios of quota regulated species that will fall under the regulations of the landing obligation, likely becoming problematic as fish that are discarded by now need to be landed under the landing obligation, but earnings for those will be low. As one possibility to reduce these potential issues are exemptions for species (in specific fisheries) where chances to survive the process of discarding are "high", the robustness of each single species has been described within the document. Higher robustness likely means a higher chance to survive the process of being discarded. Table A.14 summarizes the information about species´ robustness, economic importance, and extent of discards for the Danish fishery as well as discard levels in a qualitative way. It shows that it is the right approach to focus on plaice as a) plaice is a species that has good chances of surviving being discarded, b) it is caught in high amounts and c) is depending on the fishery discarded in relatively high numbers. All other species either have a likely low chance of surviving, are of low economic value, thus not caught in high numbers, or are not discarded in high numbers.

Table A.14. Qualitative ranking of flatfish species presented within the document. Symbols encode accuracy of statement about respective species (++: true, +: partly true, -: not true).

Species	High robustness	High importance for Danish fishery	Discarded in high numbers
Brill	+	+	-
Dab	-	-	++
Flounder	+	-	+
Lemon sole	-	+	+
Plaice	+	++	+
Sole	+	+	-
Turbot	+	+	-
Witch flounder	-	+	+

Although estimates for catches and discards exist for each species and survival studies have been conducted for most of them, a final quantification of the results or a provision of a ranking order of these species in terms of survivability is not possible at this point because a) the number of studies that investigated survival of discarded fish is relatively low, b) the variability between and within studies is high and c) outcomes of studies for same species show that survival estimates depend to a large extent on the applied fishing method and other technical and environmental conditions (see Table 2). For instance, survival chances of fish discarded from a Danish seiner are likely higher than from a trawler because fish enter the net very late during the fishing process (Noack *et al.*, , but both gears belong to the same legislative category. Fish caught in a trawl spend longer time inside the net, thus are more stressed, get more squeezed and more exhausted, which reduces their chances to survive the following process of being brought onboard and discarded. Sound conclusions that can be drawn from previous studies and apply to all investigated species and all fisheries are so far that survivability decreases with longer fishing durations and longer handling times. Longer fishing durations mean longer times of stress and stronger exhaustion for the fish, which again leads to reduced chances of surviving. Longer handling times, which can be caused by larger catches or suboptimal handling procedures, mean longer air exposures for the fish, which eventually result in lower survivability. Furthermore, survival of plaice has been shown to depend on individual length, indicating lower survival rates for small than for large individuals (Uhlmann *et al.*, 2016).

As a general summary of the present study, it can be said that available data does not allow to apply exemption from the landing obligation in terms of high survival on specific species or fisheries because the available data basis is very low, used methodologies are very different and results are very variable and case specific. Therefore, more survival studies on different species, fisheries and conditions in question are necessary to provide more data that can allow for an assessment if an exemption from the landing obligation is meaningful.

B. Pre-capture oxygen and feeding environment from stomach data analysis

Additional details on the data analysis

The relative contributions of the individual prey groups with each stomach standardized to 100% were used for the statistical analyses testing for differences in prey compositions between two groups of hauls from two areas or two contrasting oxygen conditions at the bottom are tested for statistical differences.

It was tested if it could be rejected that the prey compositions of the two groups are similar. The null hypothesis was therefore that the compositions are similar, and the alternative hypothesis thus that they are dissimilar:

H_0 : Prey composition 1 = Prey composition 2

H_A : Prey composition 1 ≠ Prey composition 2

A significance level of *P* = 0.05 is adopted here.

Bootstrapping is used for this purpose (Kaspersen, 2008). It is assumed that the prey composition is the same in the two groups. For two group the mean compositions $\overline{p}_1^1,\ldots,\overline{p}_A^1$ and $\overline{p}_1^2,\ldots,\overline{p}_A^2$ are calculated, where $\overline{p}_j^g$ is the mean fraction constituted by prey category *j* in group *g* (*j* = 1,…*A* and *g* = 1,2). The mean composition $\overline{p}_1,\ldots,\overline{p}_A$ for all stomachs combined is calculated as well.

Two test sizes are used. They are defined for the observed stomach contents by:

$$T_1^{obs} = \sum_{j=1}^{A} \frac{\left(\bar{p}_j^1 - \bar{p}_j\right)^2}{\bar{p}_j} + \sum_{j=1}^{A} \frac{\left(\bar{p}_j^2 - \bar{p}_j\right)^2}{\bar{p}_j} \quad (1)$$

$$T_2^{obs} = \sum_{j=1}^{A}\left(\bar{p}_j^1 - \bar{p}_j^2\right)^2 \quad (2)$$

The test size T_1^{obs} corresponds to the χ^2 distribution. Let *n* and *m* denote the number of stomachs in the first and second group, respectively. The bootstrapping procedure then goes as follows:

1. Among the combined stomachs (*n+m* stomachs), *n* stomachs are randomly sampled and then placed in the first group. The remaining *m* stomachs are placed in the second group

2. Use equations (1) and (2) to calculate $T_1^{bootstrap}$ and $T_2^{bootstrap}$

3. This procedure is repeated 1000 times to establish the empirical distributions of $T_1^{bootstrap}$ and $T_2^{bootstrap}$

Test probabilities P_1 and P_2 for the two tests are calculated as the fraction of $T_k^{bootstrap}$ values larger than T_k^{obs}, *k* = 1,2. The H_0-hypothesis about similar prey composition can be rejected if P_k < 0.05, which leads to acceptance of the alternative hypothesis. If the P_k values are higher, it cannot be excluded that the two prey compositions are similar and the difference between the observed value and those obtained by bootstrapping is considered random.

Table B.1. Number of analysed stomachs by haul together with temperature, salinity, and oxygen content (average ± SD) as well as % oxygen saturation at the bottom.

Date	Haul (No.)	Stomachs (*n*)	Temperature (°C)	Salinity (ppt)	Oxygen (mg l^{-1})	% sat.†	Depth (m)
Autumn (eastern Baltic Sea)							
13-10-2020	9	2	7.44 ± 0.19	7.4*	6.27 ± 0.16	52	41
13-10-2020	10	4	7.35 ± 0.07	7.4*	6.14 ± 0.13	51	42
13-10-2020	11	7	7.33 ± 0.07	7.4*	6.48 ± 0.10	54	40
13-10-2020	12	12	7.31 ± 0.07	7.4*	6.31 ± 0.14	52	41
13-10-2020	13	11	7.88 ± 0.08	7.4*	5.91 ± 0.20	50	41
20-10-2020	16	10	n/a	6.86 ± 0.27	n/a	36‡	65
21-10-2020	18	31	15.33 ± 0.20	7.84 ± 0.21	3.59 ± 0.27	36	68
24-10-2020	21	4	15.20 ± 0.16	5.75 ± 0.29	3.44 ± 0.20	34	65
25-10-2020	22	9	15.43 ± 0.07	6.69 ± 0.29	3.56 ± 0.26	36	64
25-10-2020	23	13	15.49 ± 0.12	5.85 ± 0.19	3.92 ± 0.10	39	63
Winter (western Baltic Sea)							
27-01-2021	1	3	8.13 ± 0.13	7.4*	7.62 ± 0.11	64	45
29-01-2021	6	10	7.85 ± 0.21	6.64 ± 0.10	8.19 ± 0.50	69	42
31-01-2021	11	0	n/a	n/a	n/a	n/a	n/a
31-01-2021	12	3	7.39 ± 0.16	8.13 ± 0.03	7.56 ± 0.09	63	43
31-01-2021	13	14	7.45 ± 0.04	7.86 ± 0.03	7.55 ± 0.03	63	43
01-02-2021	14	0	n/a	n/a	n/a	n/a	n/a
02-02-2021	17	0	n/a	n/a	n/a	n/a	n/a
02-02-2021	18	7	6.12 ± 0.52	7.18 ± 0.21	10.17 ± 0.85	82	45
03-02-2021	20	2	6.72 ± 0.10	7.24 ± 0.18	8.81 ± 0.24	72	42

*The salinity was not measured here. The value is the average obtained from hauls at similar depths

†The percent oxygen saturation was obtained from https://water.usgs.gov/water-resources/software/DOTABLES/ using the values of temperature, salinity, and oxygen content

‡Temperature and oxygen content measurements were erroneous, so the oxygen saturation was calculated as the average of the values from hauls 18–23 of similar depths.

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