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Ecosystem based management of fish stocks in the North Sea (ECOMAN)

Mikael van Deurs, Alexandros Kokkalis, Anna Rindorf, Vanessa Trijoulet, Morten Vinther, Mollie E. Brooks, Nis Sand Jacobsen, Ole Henriksen, Jane Behrens and Kirsten Birch Håkansson

DTU Aqua Report no. 415-2022

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Colophon

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Preface

This report is based on the project "Ecosystem management of fish stocks in the North Sea (ECOMAN) journal no. 33113-B-19-150 and funded by the European Maritime and Fisheries Fund and the Danish Fisheries Agency.

European Union
European Maritime and Fisheries Fund

HAV & FISK

We thank all the scientists who participated during the course of the project and contributed to discussing the results.

DTU Aqua, Kgs. Lyngby
November 2022

Mikael van Deurs
Senior Researcher

Content

Summary

The ecosystem approach to fisheries management is a key element in the Common Fisheries Policy (CFP). In light of the importance of the North Sea to the Danish fisheries, Denmark needs to take a leading role in the development of best practice and methods for the implementation of the ecosystem approach to fisheries management. The ECOMAN project consisted of five separate work packages.

WP1: Sampling designs should ensure the provision of accurate data on biological parameters and stock information to be used as input to single-species assessments and multi-species models. Via this project, we were able to engage in discussions and thereby influence the development of data collection approaches.

WP2: The productivity of fish stocks in the North Sea has undergone substantial changes in recent decades, with some species increasing in numbers, while other species have shown prolonged recruitment failure with a resulting decline in stock size. Here we investigated multiple aspects of stock productivity in order to identify important drivers, such as density dependent regulation and spawner quality; all of which are ecological processes not accounted for conventional stock-by-stock fisheries management. Also methods for estimating biomass reference points were scrutinized and changes over time in the environmental conditions were visited. The latter results provided a basis for improving how reference points are defined and which processes needs further attention (i.e. in management strategy evaluations).

WP3: Natural mortality is a key component of estimation of historical stock development and the setting of reference points such as Bescapement, MSY Btrigger, FMSY and Fcap. The natural mortality varies considerably over time, and particularly the mortality introduced by grey seal and mackerel has increased for North Sea fish stocks in the most recent decades. The present project was used to built an application that allow scientists and stakeholders to view (interactively) the results produced by the complex SMS multispecies model applied by ICES; who-eats-who? And how much?.

WP4: The landing obligation (LO) reform of the CFP is a major challenge to a successful implementation of an ecosystem approach to fisheries management, and the ultimate aim should be to avoid bycatch species while maximizing the catch of target species. One way to address this issue is to make informed decisions in management based on the consequences for both the target stocks, bycatch species, and fisheries. The ECOMAN project contributed significantly to the development of mixed fisheries modeling by considering the potential effects of controlling the selectivity patterns in the fisheries.

WP5: Lastly, we acknowledge the importance, for the subsequent uptake of results, of involving stakeholders and international experts in the process. A major output of the ECOMAN project is therefore the web site https://sites.dtu.dk/ecoman. The purpose of this web site is to provide an easy way to access complex data, analysis and information relevant to scientists as well as stakeholders interested in ecosystem based fisheries management.

The ECOMAN project has also served as a precursor to the Horizon 2020 project SEAWISE.

The report itself provides a quick walk through the contributions coming from ECOMAN. A full overview of results and tools is available on https://sites.dtu.dk/ecoman. The technical details are available in scientific articles (mentioned in the text) and appendices.

Introduction

Quantifying the size of a fish stocks in hind side and as predictions of “tomorrow” is key in fisheries management. Fish stock size is a combination between productivity and mortality (incl. fishing). Traditionally, fisheries management have taken a stock-by-stock approach, treating each stock in isolation without considering interactions with other stocks and the environment.

In order to begin the transition from a single-stock approach to an ecosystem approach, we first of all need to combine information across stocks to gain sufficient overview, secondly, we need to consider the many processes that impact productivity, both the internally driven (i.e. intra-specific density dependence) and the externally driven (i.e. the environment). Thirdly, we need to understand inter-linkages between stocks; for example who each who and what species are caught together in the same fisheries.

Productivity can be the growth of the individual fish or the number of young fish entering the stock (the recruitment; R). Productivity and fishing varies over time, which leads to fluctuations in stock size. Productivity is not only affected by fishing (when fished below certain thresholds, i.e. Blim), but also density dependent processes, spawner quality, and the environment may impact productivity and lead to fluctuations in stock size as well as high and low productivity regimes. Here we present a series of simple web-applications that can help understand the many aspects of stock productivity. The stock specific examples mainly focus on 11 selected data rich North Sea Stocks.

Mortality in fish stocks can be divided into fishing mortality and natural mortality. Natural mortality is primarily driven by predation. Natural mortality is in general difficult to estimate, but the multispecies SMS model is an advanced attempt to do exactly so. Here we present an application that enables the user to test the model and explore who eats who and how changes in fishing mortality on predatory stocks affects the natural mortality of prey species. The last web application to visit addresses fishing mortality in mixed fisheries and shows biological and economical projections (and choke species) given different fishing scenarios.

The web site and its applications is introduced here in the report, but you can also go directly to https://sites.dtu.dk/ecoman, where you can either work your way through the different applications by scrolling down on this web page from top to bottom or you can jump to selected topics by clicking on the headers above.

1. Work package 1 – Data collection and optimization

The ECOMAN project has supported participation in ICES working groups working towards reliable commercial catch data, from sampling thereof, over data formats, to estimation. During the last couple of years ICES has developed a new database and estimation framework for commercial catch data, the Regional Database and Estimation System (RDBES). Commercial fishery sampling is in most cases complex in nature and the main purpose of the RDBES data format is to convey information about e.g. the sampling hierarchy, stratification and selection methods to the users and estimators. The increased knowledge will lead to more reliable estimates of biological parameters relevant for stock assessment in the future. The RDBES core group supports ICES in developing the RDBES and solving issues encountered by user, see https://github.com/ices-tools-dev/RDBES, and through active participation, it has been possible to include fields, so Danish commercial catch data can be stored in the RDBES format in a meaningful manner. Beside the database, the RDBES also have an estimation system, where inputs, estimation scripts and outputs are stored (much like the present ICES Transparent Assessment Framework (TAF)). In the future, this will enable end-users of the estimates, e.g., catch at age and mean weight at age, to see the estimation scripts. This should increase the knowledge of estimators in use, threshold for including samples and assumptions being made e.g., simple random sampling and how different metiers are grouped into the fleets used in e.g., WGMIXFISH.

The RDEBS may enable users to read the estimations script, but for most a simpler overview is preferable. The ICES WGCATCH group has among other tasks developed templates to get a faster overview of sampling and estimation. The templates are still under development, but they were used to get an overview of different countries discard estimation (ICES, 2020a), and seems like a good way of documenting sampling and estimation.

The ICES WKRDBES-EST group, and preceding WKRDB-EST, aims to develop an R-package with documented estimators with the RDBES data as input (ICES 2020b, ICES 2021), see https://github.com/ices-tools-dev/RDBEScore. As a start the focus is on design-based estimators, bootstrapping methods for cases where an analytical variance becomes tricky and ratio estimators that take the sampling design into account e.g., unequal probability sampling. Another aim is to develop overview of landings and sampling to support the knowledge before estimation. Further, an R markdown script is developed to encourage the same workflow in estimation, so it becomes easier for the end-user to actually see what is going on in the estimation.

Meeting participation with relevance to this work:

- ICES WKBIOPTIM (2019, 2021*) – Mollie Elizabeth Brooks and Kirsten Birch Håkansson attended ICES WKRATIO (2021) – Kirsten Birch Håkansson attended
- ICES WGCATCH (2019, 2020, 2021) – Kirsten Birch Håkansson attended
- ICES WKRDB-EST (2019, 2020) – Kirsten Birch Håkansson was co-chairing
- ICES WGRDBES-EST (2021-present) – Kirsten Birch Håkansson is co-chairing
- RDBES core group (2019-present) – Kirsten Birch Håkansson is a part of this group

*The working document in Appendix 6.1 was presented at the ICES WKBIOPTIM 2021 meeting

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ICES. 2019. Workshop on Optimization of Biological Sampling (WKBIOPTIM 3). ICES Scientific Reports. 1:78. 219 pp. http://doi.org/10.17895/ices.pub.56478

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ICES. 2020b. Workshop on Estimation with the RDBES data model (WKRDB-EST; outputs from 2019 meeting). ICES Scientific Reports. 2:5. 106 pp. http://doi.org/10.17895/ices.pub.5956

ICES. 2021. Second Workshop on Estimation with the RDBES data model (WKRDB-EST2; outputs from 2020 meeting). ICES Scientific Reports. 3:15. 128 pp. https://doi.org/10.17895/ices.pub.7915

ICES.2022. Fourth Workshop on Optimization of Biological Sampling (WKBIOPTIM4; Outputs from 2021 meeting). ICES Scientific Reports. 4:69. 80pp. http://doi.org/10.17895/ices.pub.21103000

2. Work package 2 – Stock productivity

The size of a fish stock is a combination between productivity and mortality (incl. fishing). Productivity can be the growth of the individual fish or the number of young fish entering the stock (recruitment; R). Productivity and fishing varies over time, which leads to fluctuations in stock size. Below, we describe some high lights and example. **The full amount of results and descriptions methods can be found here: https://sites.dtu.dk/ecoman and in two publications plus a manuscript being prepared for submission:**

See also publication: van Deurs, M., Brooks, M. E., Lindegren, M., Henriksen, O., & Rindorf, A. (2021). Biomass limit reference points are sensitive to estimation method, time-series length and stock development. Fish and Fisheries, 22(1), 18-30. (ECOMAN is specifically highlighted in acknowledgement)

Scientific Manuscript is being prepared for submission to Ices Journal of Marine Science, tentative title: Are older fish key to getting abundant surviving offspring? (ECOMAN is specifically highlighted in acknowledgement) (contact mvd@aqua.dtu.dk for latest version)

See also publication: Rindorf, A., van Deurs, M., Howell, D., Andonegi, E., Berger, A., Bogstad, B., ... & Collie, J. (2022). Strength and consistency of density dependence in marine fish productivity. Fish and Fisheries. (ECOMAN is specifically highlighted in acknowledgement)

The examples mentioned below and on **https://sites.dtu.dk/ecoman** mainly focus on 11 selected data rich North Sea Stocks (see Fig. 1).

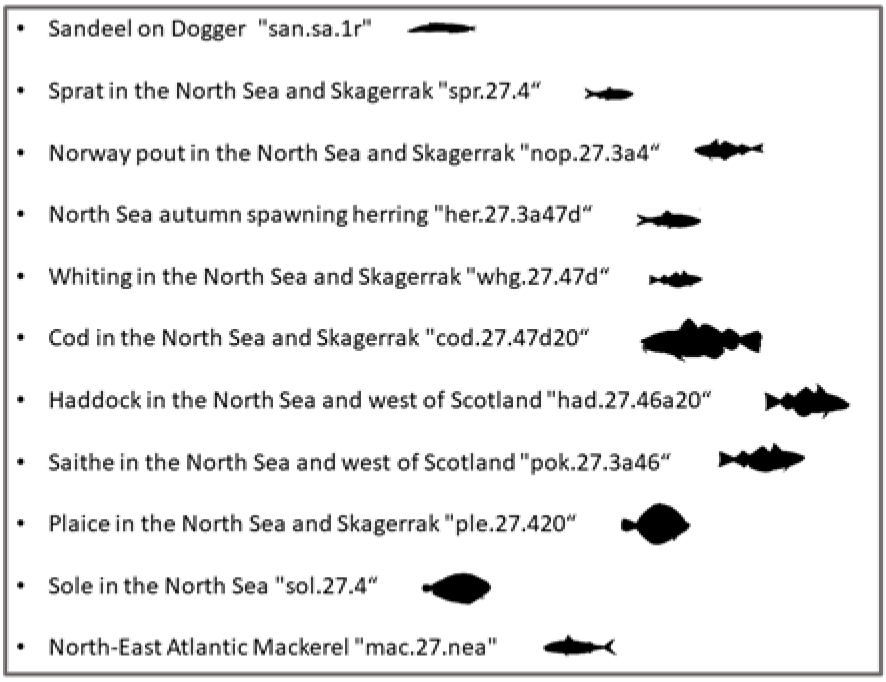

Figure 1. List of data-rich North Sea stocks. The main focus in the analysis was on these stocks due to the data richness.

As mentioned above, recruitment (R) is the result of SSB. A measure of productivity can therefore be the number of recruits produced per spawner biomass (R/S). Below (Fig 2) you can see that for example stocks such as cod, herring, haddock and sprat produced many recruits per spawner in the 70s, 80s, and 90s, whereas, whiting, sandeel, and mackerel shows a different temporal pattern. Choose other measures of stock productivity at https://sites.dtu.dk/ecoman

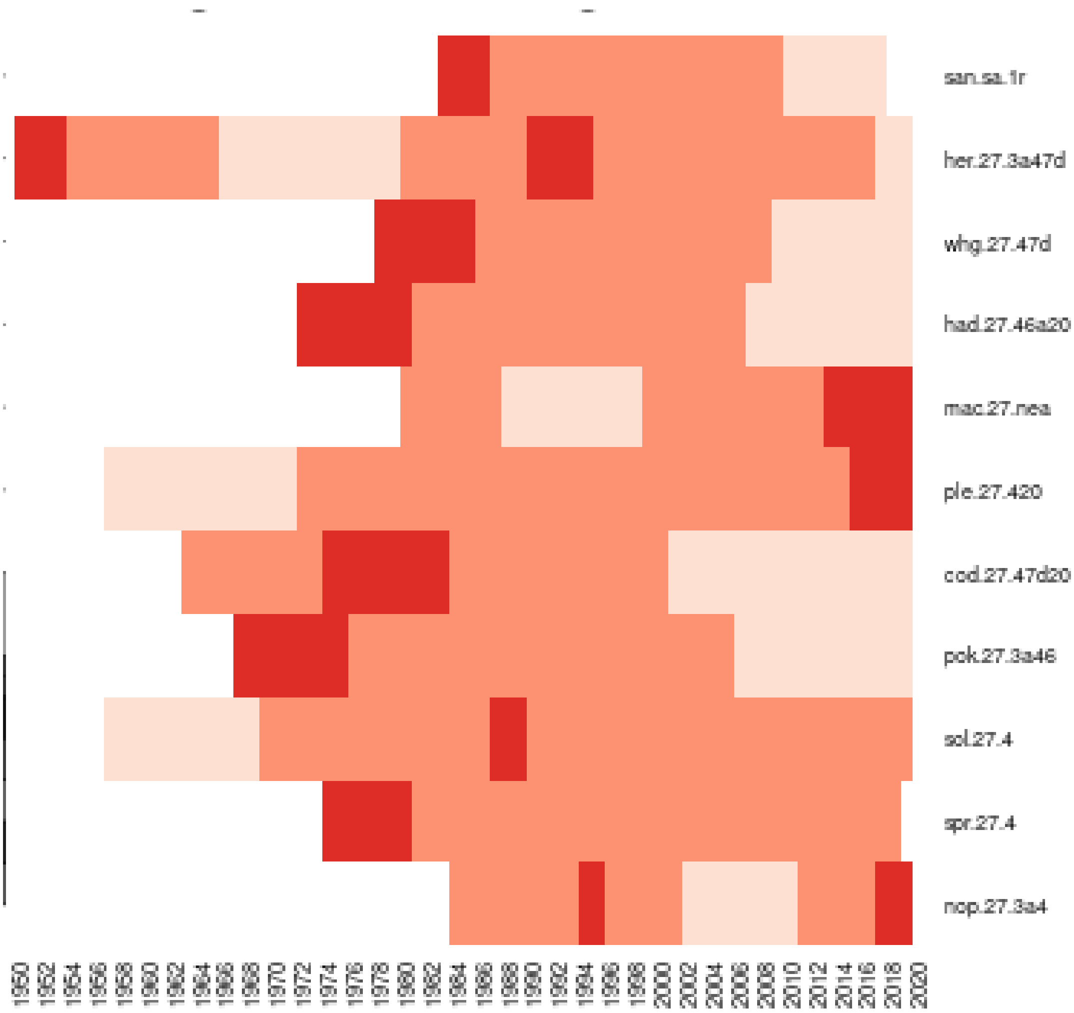

Figure 2. Changes in productivity (recruits per spawner biomass) for 11 data rich North Sea stocks (dark red is high productivity and light red is low productivity).

If SSB is pressed below a critical lower level (Blim), R is expected to be inhibited. Hence, it is essential that SSB is kept above SSB, which can be done by regulating fishing mortality. How fishing mortality will affect SSB in the years to come is investigated in a forecast. Take for example select North Sea herring (her.27.3a47d) (Fig. 3). Here you will see that R increases with increasing SSB only at low values of SSB. At higher SSB, R does not increase with any further increase of SSB. This is referred to as density depend regulation (more about that later). Blim-type-1 (blue lines in Fig. 3 and 4) or Blim-type2 (red lines in Fig. 3 and 4) are two common methods for estimating Blim. If you choose Blim-type1 you also need to define what you think is a ”good recruitment”. In the example used in Fig. 3 and 4, recruitment values above the 75% lowest values is defined as “good” recruitment. You can explore other stock and options at https://sites.dtu.dk/ecoman.

This work was published: van Deurs, M., Brooks, M. E., Lindegren, M., Henriksen, O., & Rindorf, A. (2021). Biomass limit reference points are sensitive to estimation method, time-series length and stock development. Fish and Fisheries, 22(1), 18-30.

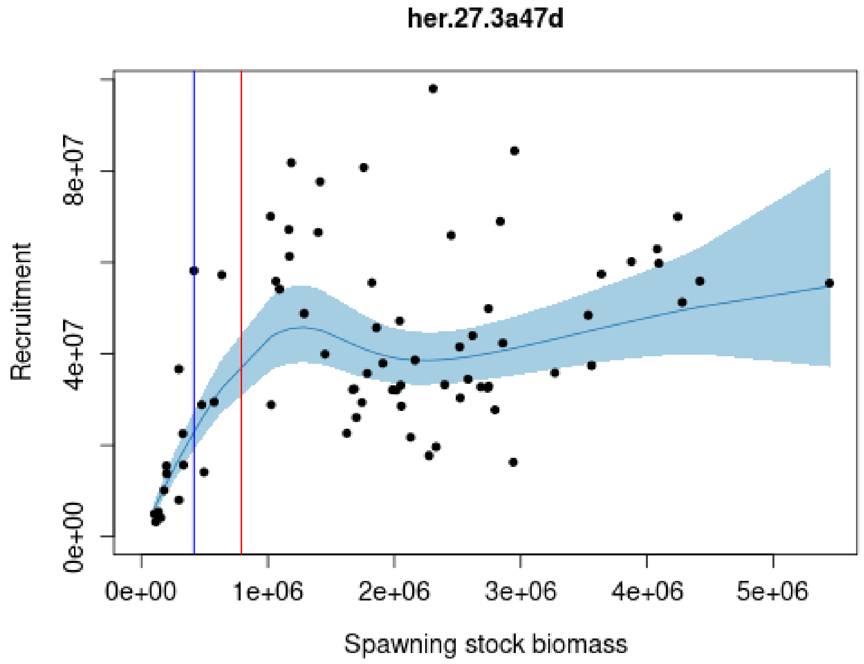

Figure 3. Stock-recruitment plot, for North Sea herring, showing the relationship between spawning stock biomass and recruitment. Vertical lines depict the estimated Blim reference points, based on the ICES type-1 (blue) and type-2 (red). Be aware that the reference points shown here may not align with what is used in the ICES advice. This is because other methods (type-3 etc.) is available and sometimes additional evidence is taken into considerations when the operational reference points for management are defined.

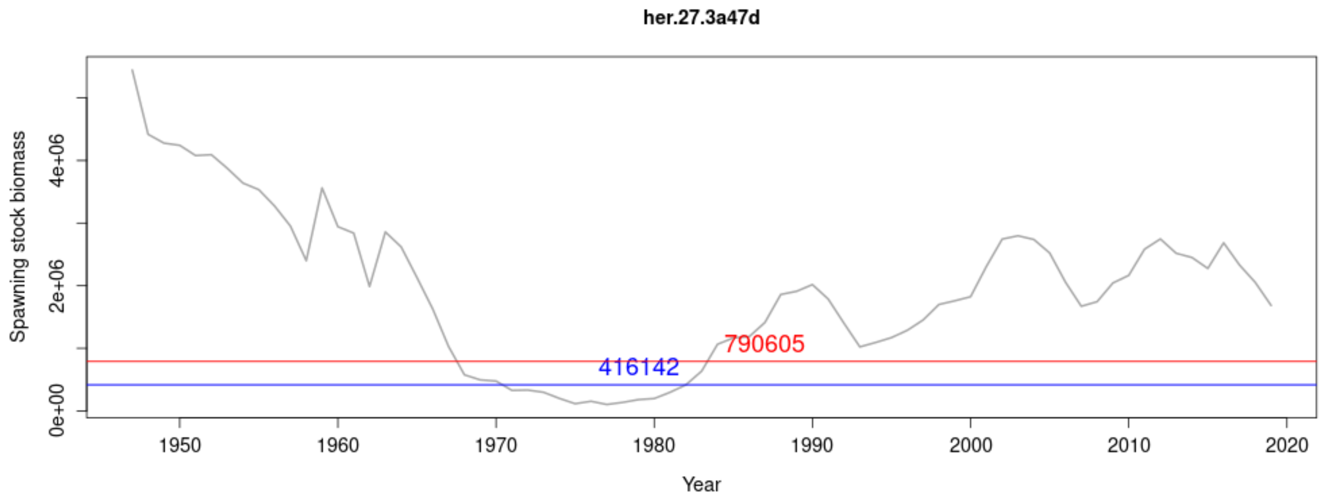

Figure 4. Development of the spawning stock over time for North Sea herring. Horizontal lines depict the estimated Blim reference points, based on the ICES type-1 (blue) and type-2 (red). Be aware that the reference points shown here may not align with what is used in the ICES advice. This is because other methods (type-3 etc.) is available and sometimes additional evidence is taken into considerations when the operational reference points for management are defined.

The assumption of a relationship between SSB and R has been an imperative element in fisheries science since the 1950s. Most conventional stock-recruitment models assume that R is proportional to SSB, independent of size, age and body condition. However, recent research has caused a debate of whether the empirical evidence for individual-level relationships between spawner quality and reproductive potential is relevant also at the stock-level. This has therefore also recently been incorporated into the GES indicators under the European Marine Strategy Framework formulated as a need to ensure that commercially fished stocks are ‘characterized by a high proportion of old, large individuals’. In the example below, the correlations between R (after accounting for SSB) and the proportion of older spawners (a measure of spawner quality) are calculated for the eleven North Sea stocks. As can be seen, no positive correlations between spawner quality and R was found. On the contrary, and surprisingly, negative correlations were seen for all eleven stocks. It cannot be concluded that old spawners have negative effect on recruitment, but it do indicate that for most stocks other factors are more important that proportion of old spawners. In Fig. 6 we see how the proportion of old spawners have developed over time for North Sea cod. Note how the proportions were low in the middle of the time-series, which coincide with period of high fishing mortality. Same patterns can be seen for other stocks as well. Visit https://sites.dtu.dk/ecoman and look at other stocks ore try out other measures of spawner quality. For example, you will then see that spawner weight seem to have a positive impact on recruitment for the majority of stocks.

The details of the methods and materials is found in a manuscript (tentative title: Are older fish key to getting abundant surviving off-spring?) that currently is being prepared for publication and the text is therefore not enclosed in this report (contact mvd@aqua.dtu.dk for latest version).

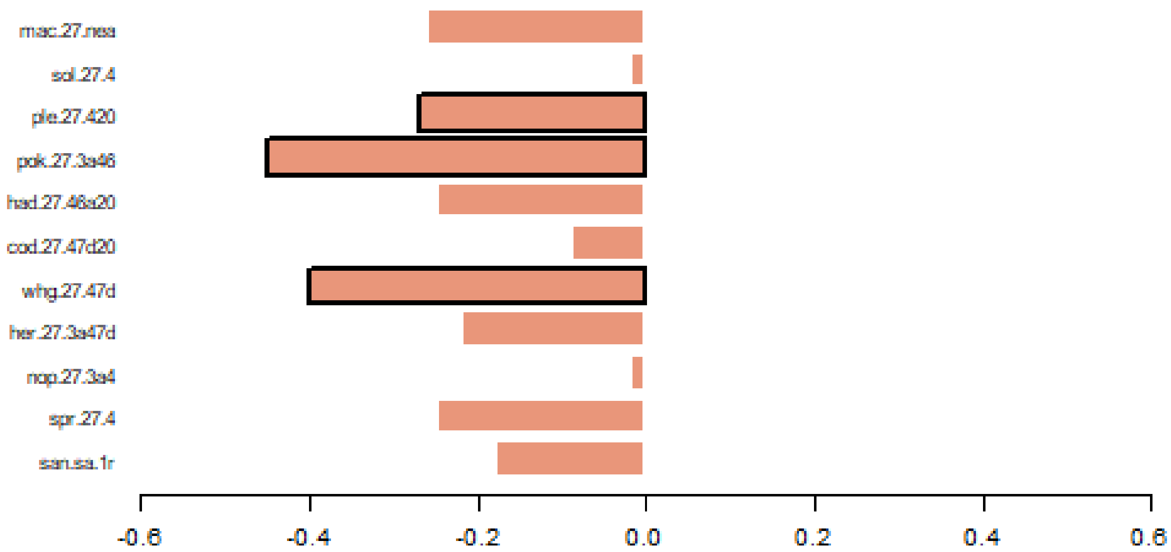

Figure 5. The correlations between R (after accounting for SSB) and spawner quality (proportion of old spawners) are calculated for the eleven North Sea stocks. The horizontal bars indicate the correlation coefficients and a black box around the horizontal bar indicates if the correlation is statistically significant.

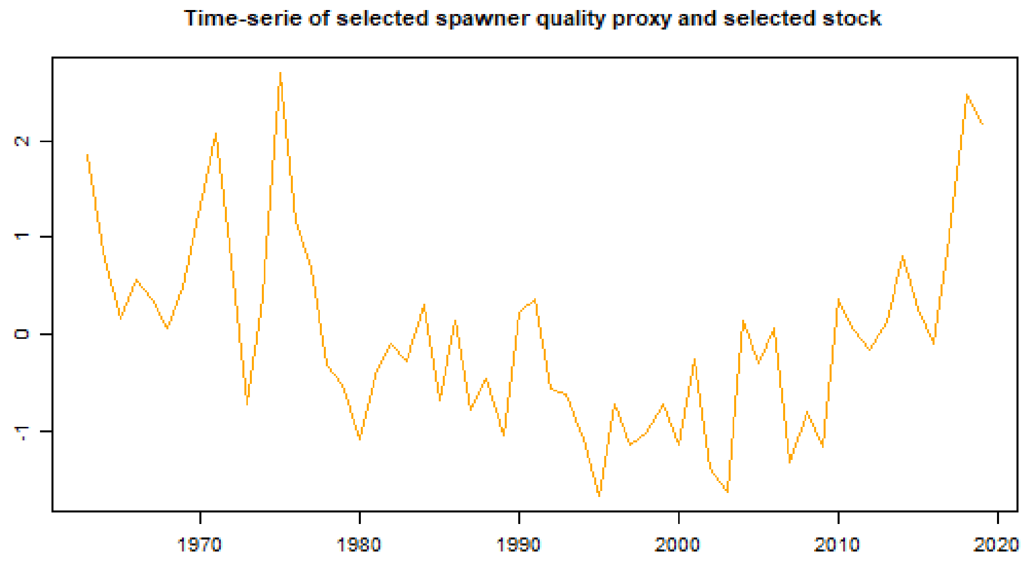

Figure 6. Proportion of old spawners developing over time for North Sea cod.

Although rarely accounted for in fisheries management, fish stocks can be experiencing density dependent regulations in several ways. In ECOMAN we explored three different types of density dependent regulation: (1) A large year class (i.e. large R) result in competition for resources (food) and therefore growth among the young fish decline. (2) A large stock biomass result in food competition and less food for the individual fish. (3) R decreases at very high levels of SSB because of density dependent processes such as cannibalism. We investigated to what extent the eleven North Sea stocks show signs of density dependent regulation. For example, we found, that 8 out of 11 stocks showed signs of significant density dependent regulation when correlating stock biomass and growth (Fig. 7). Visit https://sites.dtu.dk/ecoman and try out the two remaining types of density dependence.

The details of the methods and materials can be found in the following manuscript: Rindorf, A., van Deurs, M., Howell, D., Andonegi, E., Berger, A., Bogstad, B., ... & Collie, J. (2022). Strength and consistency of density dependence in marine fish productivity. Fish and Fisheries.

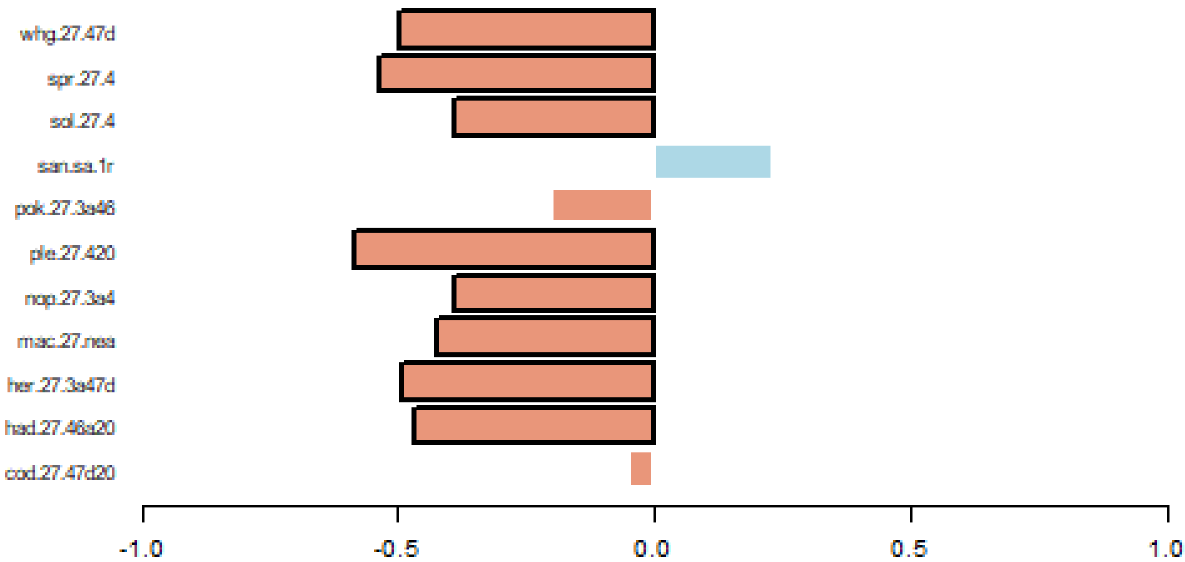

Figure 7. Density dependent regulation. The horizontal bar plot depicts the correlation coefficients for stock biomass vs growth. A red horizontal bar with a black box around indicate statistically significant density dependent regulation.

The productivity that is observed in our ocean ecosystems are closely coupled to the environmental variability. Thus, it is essential to develop methods that may capture the environmental fluctuations, which may account for some of the random stochasticity that influences both biodiversity and potential fisheries productivity. The overview given in Fig. 8 includes variables that are able to describe the full spectrum of physical biochemistry in the ocean interlinking oceanographic processes to fluctuations in environment and primary production. Data were obtained from the Copernicus project under the European Commission (Copernicus website: http://marine.copernicus.eu/). Annual averages were calculated (averaging across grid cells, months and depth) and converted into anomalies for the North Sea region. The methodology includes model smoothing and clustering that provide a general overview depicted as heatmaps.

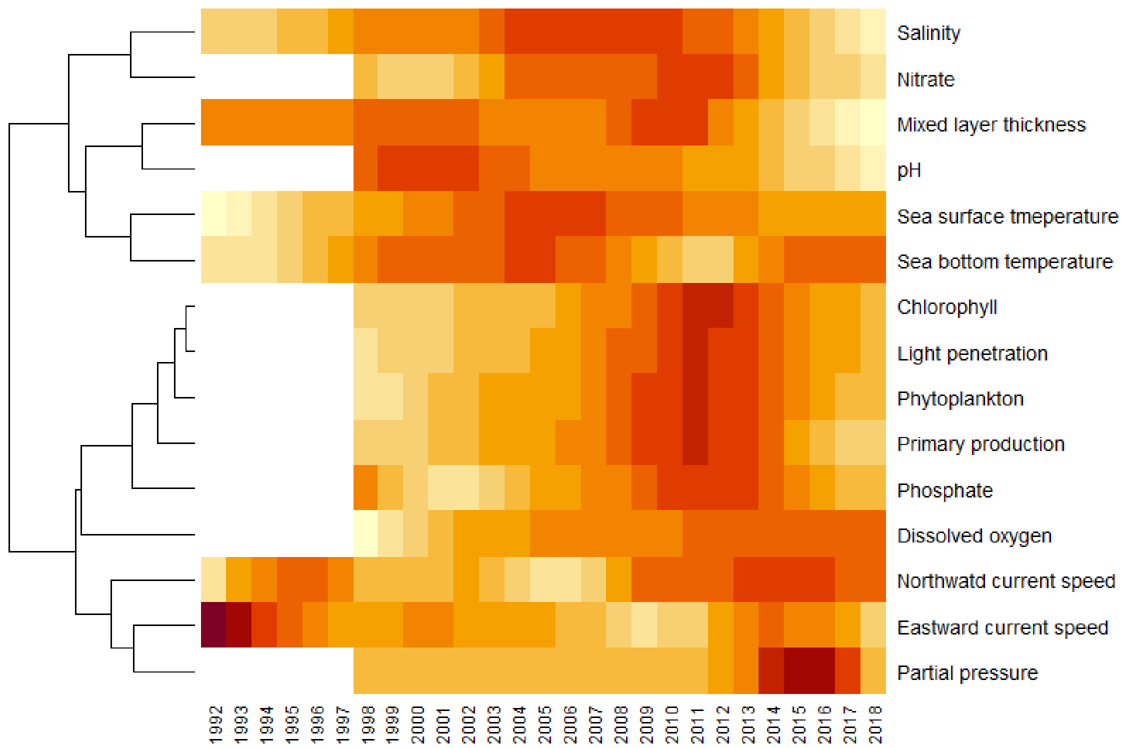

Figure 8. Overview of environmental variables (red means high values and light yellow means low values). The environmental variables are sorted using a clustering technique to pair up those variable that follow the same trends over time. The values are all North Sea means smoothed over time to high light the temporal trends rather than the year-to-year variation. However, the data base allows for data extraction at pre-defined spatial sub areas. Note that the data is modelled data.

A study exemplifying the role of environmental drivers was presented at the Decadal Variability of the North Atlantic and its Marine Ecosystems: 2010-2019, which is a decadal ICES symposium that were hosted in Bergen 2022. The presentation is on how temperature affects fish stocks exemplified through a sandeel case study (see appendix 6.2).

3. Work package 3 – Multispecies model

The SMSApp (http://ono.dtuaqua.dk:8282/SMSapp/ - the current version was developed in ECOMAN) makes forecast scenarios for the main fish stocks in the North Sea or Baltic Sea area, based on the results from the Stochastic Multispecies Model (SMS) used by ICES to provide multispecies mortalities. Future fishing pressure and exploitation pattern can be changed for the stocks, and the model will then calculate future fishing yield and stock sizes. SMS takes into account that fish eats fish, and that birds and marine mammals also eats fish. A change in fishing pressure for a given commercial species will therefore directly change its stock size and yield, but may also change stock size and yield for other species which are prey or predator for the given species.

Forecast scenarios can be made for two areas; the North Sea or the Baltic Sea. The North Sea is a species rich ecosystem and the SMSapp incorporates 27 species, which include 18 commercial fish species, but also 7 species of seabirds and 2 species of marine mammals which feed on fish. The Baltic Sea is more simple and the SMSApp includes cod as predator and herring and sprat as preys.

The SMSApp is available from http://ono.dtuaqua.dk:8282/SMSapp/ and can also be found on https://sites.dtu.dk/ecoman.

The SMS model is used by the ICES Working Group on Multispecies Assessment Method, WGSAM (ICES, 2021) to estimate the historical natural mortalities, which are used in the ICES stock assessment and TAC advice for number of species in the North Sea and Baltic areas. SMS is a so-called multispecies model, which uses observed stomach content from a quarter of a million of animals to estimate the natural mortality due to predation (fish eating fish), together with fishing mortality and stock sizes.

In this App, SMS is also used as a forecast model. This is done from the model parameters, e.g. food suitability and exploitation pattern, estimated in the historical SMS, and assumptions of future fishing pressure and recruitment. The forecasts or scenarios assumes that everything is kept constant in the future, if not changed by the user. The is a crude assumption when the forecast is made for a long time period. This and the fact that there in general is rather high uncertainties in a complex model like SMS, means that the results should be seen a scenario results rather than strict prediction of future changes.

4. Work package 4 – Mixed Fisheries

Due to its low quota in the past years, cod has been the most limiting stock (choke species) for all Danish fleets and most international fleets. Since the implementation of the Landing Obligation (LO), emergent choke species effects have become a challenge for the North Sea fisheries. This has led to developing methods to avoid cod catches in the demersal gears. However, little is known on the consequences of gear developments for the Danish fleets involved in the North Sea demersal fishery. The goal of this study was to analyze if Danish gear developments can reduce the choke species issues in Danish fisheries in the North Sea and Skagerrak via mixed fisheries modeling.

The European Maritime and Fisheries Fund (EMFF) and National Fisheries Agency grant number 39809 (UnCod), focuses on analyzing data from Danish gear technology developments. These results were used to estimate significant changes in TR1 and TR2 gear catchability compared to the current gears used in the Danish fishery (TR1= trawl gear >=100mm and TR2=trawl gear 70-100 mm TR1 is usually used for fish stocks and TR2 for Nephrops) (the details are currently being prepared for publication and the text is therefore not enclosed in this report; contact molbr@aqua.dtu.dk for the latest version).

These new catchability values were used to inform gear development scenarios to investigate the consequences of gear developments for the Danish fleets, in terms of catches, profits, choking issues and stock developments. The study develops the advice model currently used in the International Council for the Exploration of the Sea (ICES), the FL Bio-Economic Impact Assessment (FLBEIA) model (Garcia et al. 2017; ICES 2021a) to run stochastic projections under different effort and gear scenarios. Three gear scenarios were considered: the “Baseline” scenario were the catchability corresponds to the current catchability with the current gears, the “DK only” scenario where the catchability is the new gear developments catchability for the Danish fleets only, and the “All fleets” scenarios where the gear changes are applied to all modeled fleets using TR1 and TR2 gears.

The study shows that Danish gear developments can reduce the choking effect on cod in the medium-term (Fig. 9) but reducing fishing effort has a larger positive effect on the Danish fleet profits than changing gear selectivity (Fig. 10).

Full details of the simulation study can be found in Appendix 6.3 and all the results are available at https://ono.dtuaqua.dk/ECOMAN/.

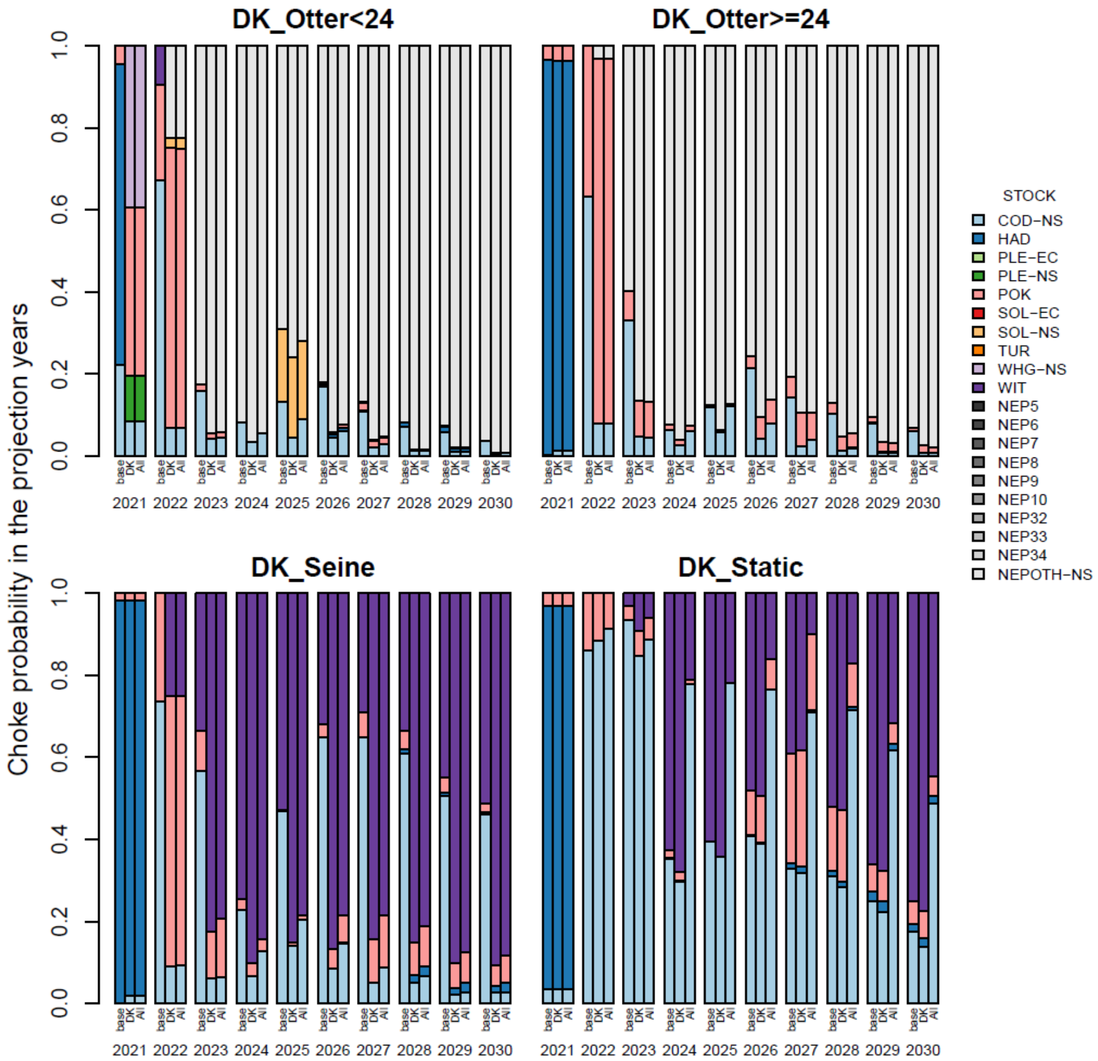

Figure 9. Proportion of choke across the 500 iterations over the projection years in the minimum scenario for each gear scenarios.

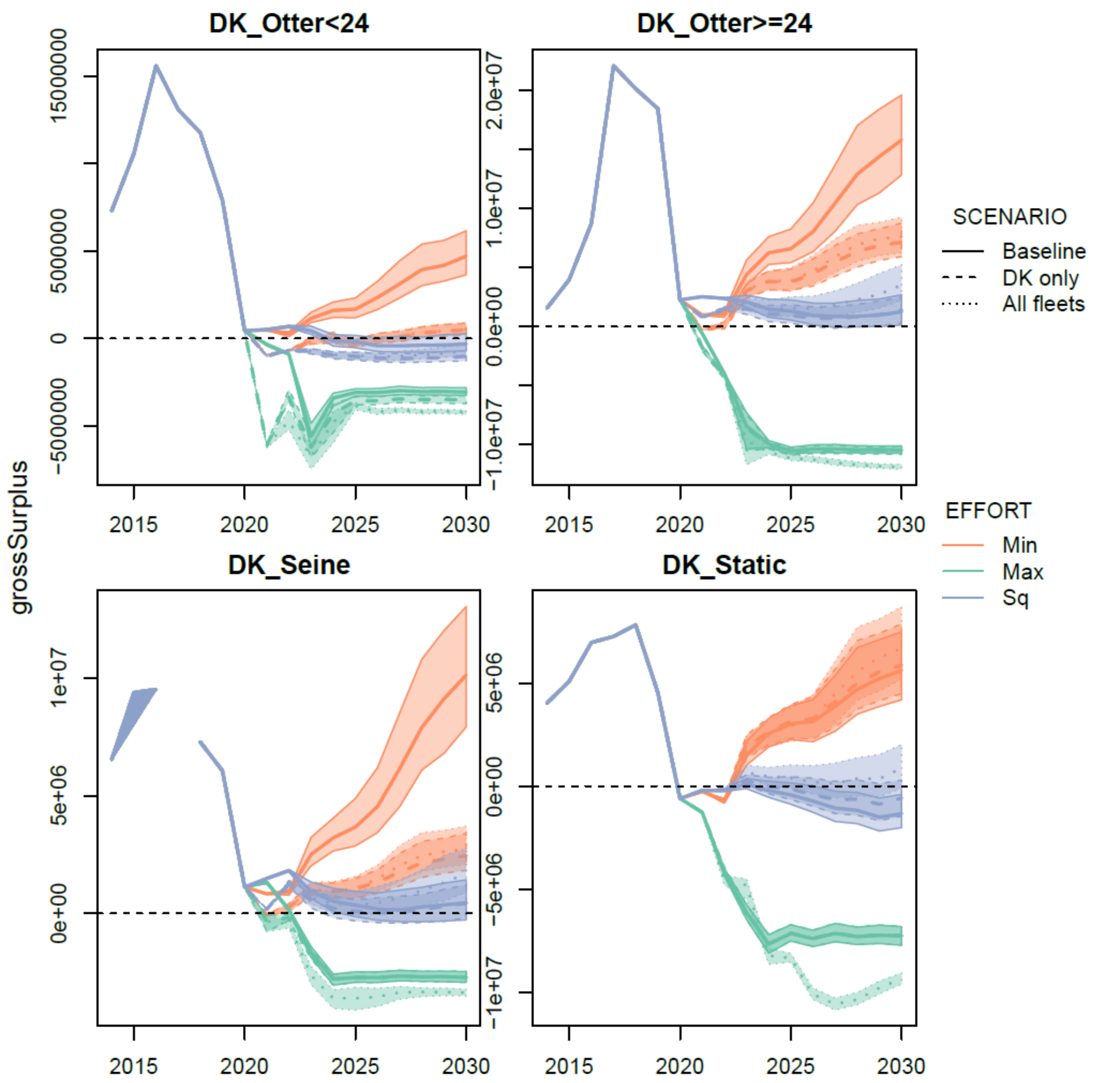

Figure 10. Profit per Danish fleet for all scenarios. The different lines are the median estimates around the 500 iterations. The shaded areas show the 95% quantiles.

Different contributions were made as part of the ECOMAN project, as follows:
Model developments: FCube (Ulrich et al. 2011), was the advice model for the North Sea mixed fisheries until 2020. The FLBEIA model was developed prior and during the ECOMAN project and was chosen as replacement of FCube following an ICES inter-benchmark process in 2021 (ICES 2021b). A large contribution of the project was spent in developing the FLBEIA model to make it acceptable for mixed fisheries advice in ICES. This model has the advantage to allow for bio-economic modelling of the technical interactions between fleets and métiers in the North Sea. The model is also built to allow for management strategies evaluation.

Meeting participation with relevance to this work:

- ICES WGMIXFISH*-Methods: 2019-present (1 meeting per year)
- ICES WGMIXFISH*-Advice: 2019-present (1 meeting per year)
- ICES WKMIXFISH* stakeholder meeting, 2020
- ECOMAN stakeholder meeting, 2021
- ICES IBPMIXFISH: change from FCube to FLBEIA, 2021

*Vanessa Trijoulet is now the ICES WGMIXFISH North Sea case study leader, from 2022

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5. Work package 5 – Dissemination of results

Most of the results produced in ECOMAN is made available at https://sites.dtu.dk/ecoman. The purpose of the web site is to provide an easy way to access complex data, analysis and information relevant to scientists as well as stakeholders interested in ecosystem based fisheries management. Because of the complexity, it will take a couple of hours to venture through the full web site and its dynamic applications. However, after doing that the user should be better equipped for engaging in discussions and workshops on the topic. Hence, this is both a dissemination of scientific results and a tutorial. This is also the first version and we hope to get a chance to improve and perhaps expand the web site in the future. As it is now, resources for annual updates of data and analysis is not available although that would significantly improve the value of this tool.

During the early phase of the web-site development, we invited a range of relevant stakeholders to receive feedback. Below is a summary of the feedback we received. In total 10 stakeholders participated in the workshop, which took place 10th May 2021.

Feedback from stakeholder meeting regarding the part about stock productivity

- Data used in our app should be available for download in a excel-/txt-file
- Standard graphs, as provided in rapports from ICES, would be a nice asset to have in the app
- If possible, reference points should be included
- Latest reference point, as well as back in time
- Heatmap showing whether a stock is above versus below a reference point
- Productivity estimates (older spawners, recruit per spawner etc.) did not provide any extra value. Although, R/SSB probably should be included
- Extra widgets in a shiny application
- Checkbox should be included for species and stocks
- Ability to sign in and use a favorite bottom
- Alphabetical sorting should be possible
- A total option (all species/stocks) summing all should be available
- Possible division of small pelagics, gadoids flatfish
- Category of stock should include all separate stocks for a species
- Everything should be in anomalies for heatplots
- Option to combine measures of environment, stock assessment results, fisheries and productivity in same heatplot (e.g. temperature, R for Cod, R/SSB for cod and F for cod)
- Possibility for linking to relevant information associated with for any stock/species (e.g. scientific rapport, distribution map, advice, publication and working group)

How stakeholder meeting helped improving the SMS app

The App was seen as a useful tool for multispecies scenarios, however it was also mentioned that scenarios produces by SMSApp, should directly be translated into ecosystem based advice. There was also a discussion on the effect of the rather old data for fish diet (mainly sampled in the period 1981-1991) and future development of multispecies models and its use in management. One main comment from the stakeholder meeting was about the target user of the SMSApp. Even though the exercise (evaluate the effect of a 50% reduction in F for cod) done during the meeting was well presented, some of the users found the App and probably also the multispecies concept were too complex for such short presentation. With its 27 species included the North Sea configuration is complex as a beginner case. Since then, a much simpler three species Baltic Sea SMSapp has been developed (based on the result from the ICES WGSAM meeting in October 2022). The Baltic Sea SMSapp is conceptually the same as the North Sea implementation, but the fewer species makes it more suitable as first-time training example. This will give the dedicated stakeholder the possibility to first to use the simple Baltic Sea case as a training case and afterwards change to the more complex North Sea case.

6. Appendices

6.1 Appendix for WP1

Preliminary simulation study for WKBIOPTIM - Resampling with or without replacement

Introduction

Assume we have a data set S0 which was collected from a larger population P. If S0 were infinitely large, then we would know every estimator (e.g. mean or length frequency distribution) from P with perfect precision and no uncertainty. In reality with finite samples, if we want to know statistics about S0, then we can calculate them with perfect precision, e.g. we know the exact mean of S0. However, we do not know the exact mean (and other estimators) of P. To calculate uncertainty of statistics for P, we resample from S0 with replacement (i.e. bootstrap) to represent the distribution of P that we don't see but we expect will be similar to S0. Therefore, if we need to make inference about P, then we need to resample with replacement. Alternatively, if our scope of inference is S0 (i.e. S0 is the extent over which the inferences are to apply), then we have all the information in that sample, S0. We can ask what would happen if we hadn't taken as large of an S0 in that particular instance by looking at random subsets of S0. If we want to ask what would happen if we repeated the process of taking a sample from P that was smaller, then we would need to resample with replacement.

Simulation Methods

First, we simulated 10,000 fish per age for ages 0 to 10. Each fish was given a different value of L_inf from a lognormal distribution with CV 0.05. This represents the population available to be caught. The same number per age group were simulated here, but in future investigations, potential consequences and alternatives should be checked. Then length-at-age was calculated deterministically for each fish based on a Von Bertalanffy growth model (Fig 1).

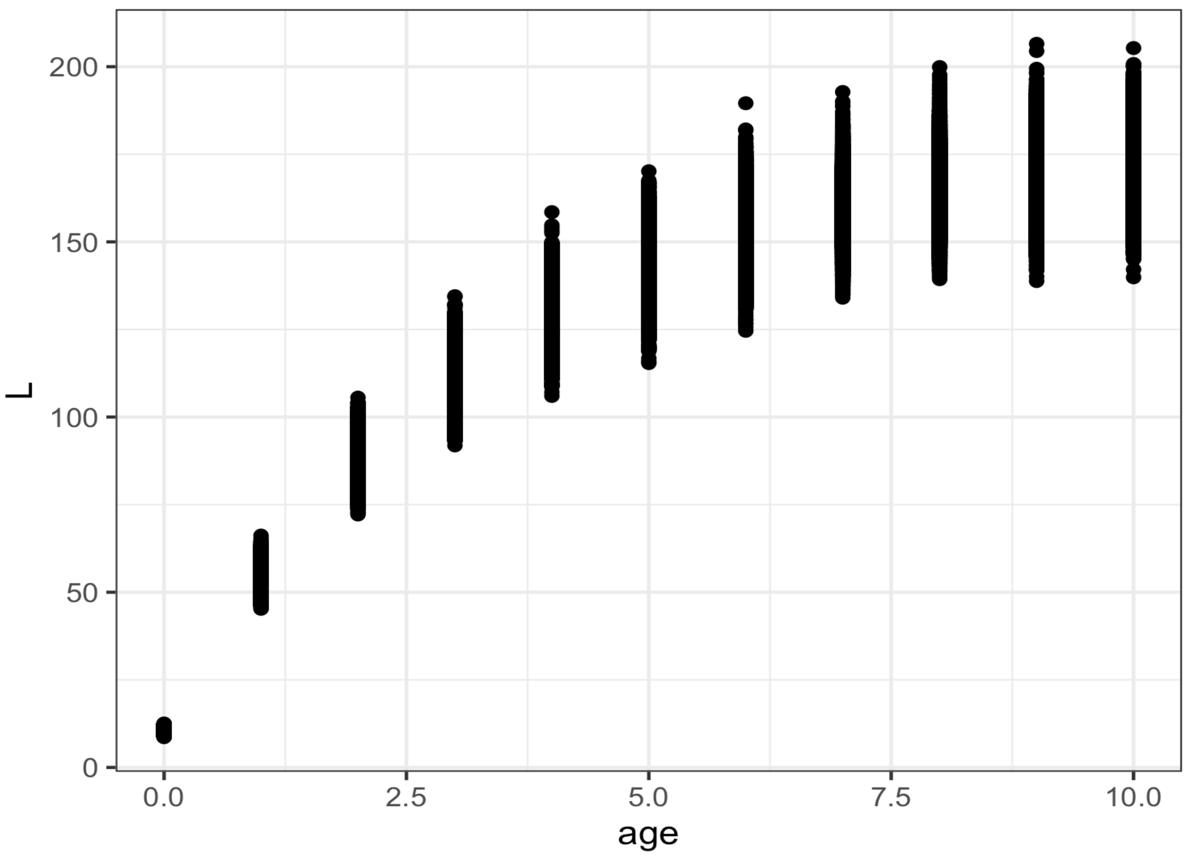

Fig 1. Simulated lengths at age. The population contains 10,000 individuals per age and individuals vary in their L_inf parameter with a CV = 0.05. The other parameters of the Von Bertalanffy growth model were t0=-0.2, k = 0.3, and mean L_inf = 180

A catch (S0, i.e. haul or landing) of size 50, 1000, or 10,000 fish were randomly sampled from the population described above. Then the catch was divided into 10 cm length classes. From each length class, nsamp (2, 5, 10, or 50) fish were randomly sampled with or without replacement, unless there were fewer than nsamp fish available and then only the number available were sampled. Based on these samples, we calculated mean and standard deviation length-at-age. The procedure was repeated 1000 times for each sampling design, i.e. 1000 replicate simulations per combination of S0 size and nsamp. Replicate simulations with the same S0 size used the same fish, i.e. the catch did not change, only the samples taken from the catch changed.

Results

All sampling designs produced fairly accurate estimates of mean length-at-age (Fig 2).

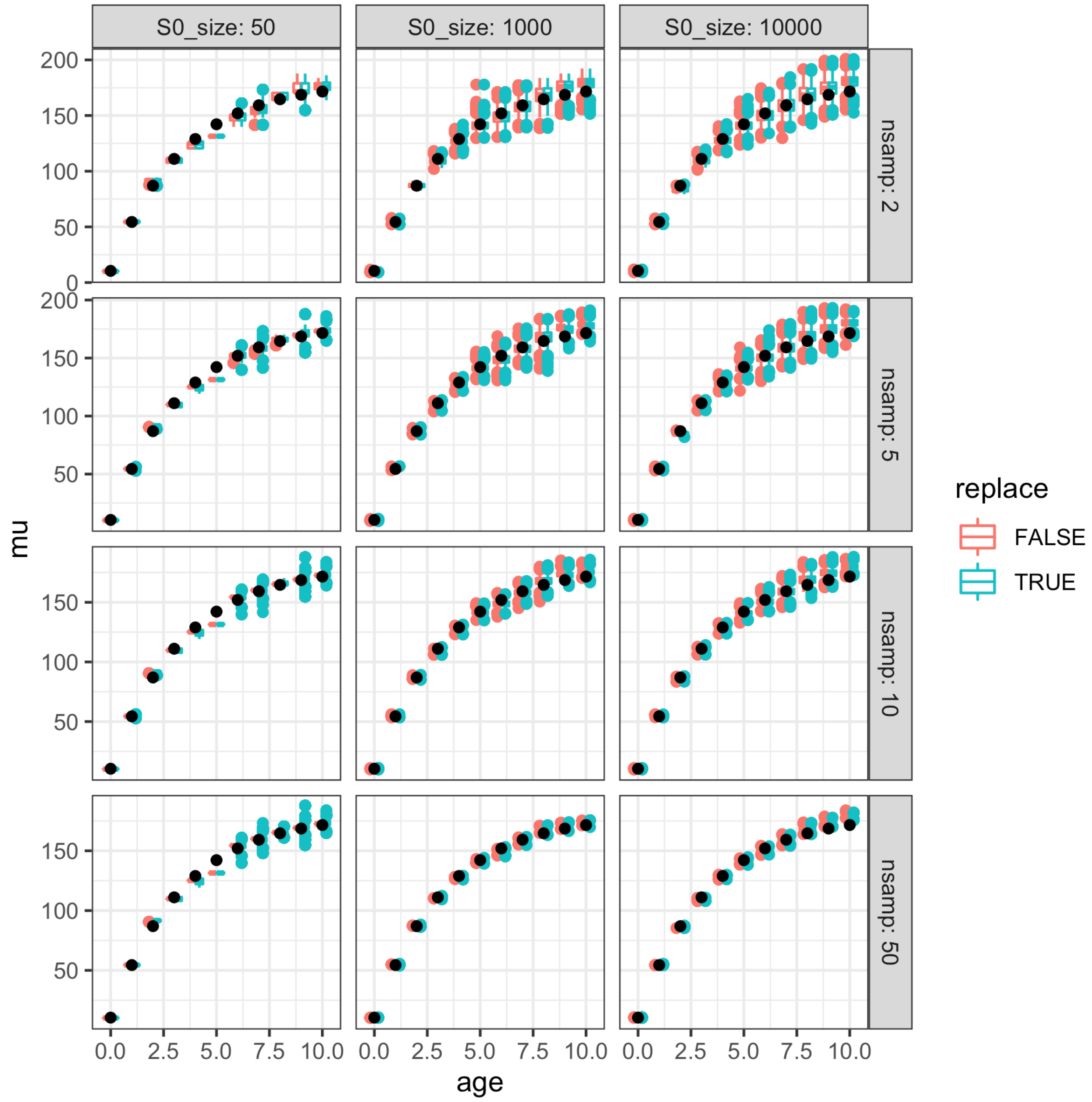

Fig 2. Mean length-at-age. Black dots represent the true value based on the true growth model underlying the simulated data. S0_size varies by column and is the size of the catch or haul that was being sampled. Rows vary nsamp which is the number of samples per length class. Red and green boxplots show the values of 1000 replicates for each sampling design.

Estimates of the standard deviation (sd) of length-at-age were mixed and sometimes biased (Fig 3). With a catch of size 50, there were too few samples to accurately estimate sd. With a catch size of 10,000, and nsamp equal to 10 or 50, estimates were inexplicably biased upward for higher age classes; more investigation is needed to confirm and explain.

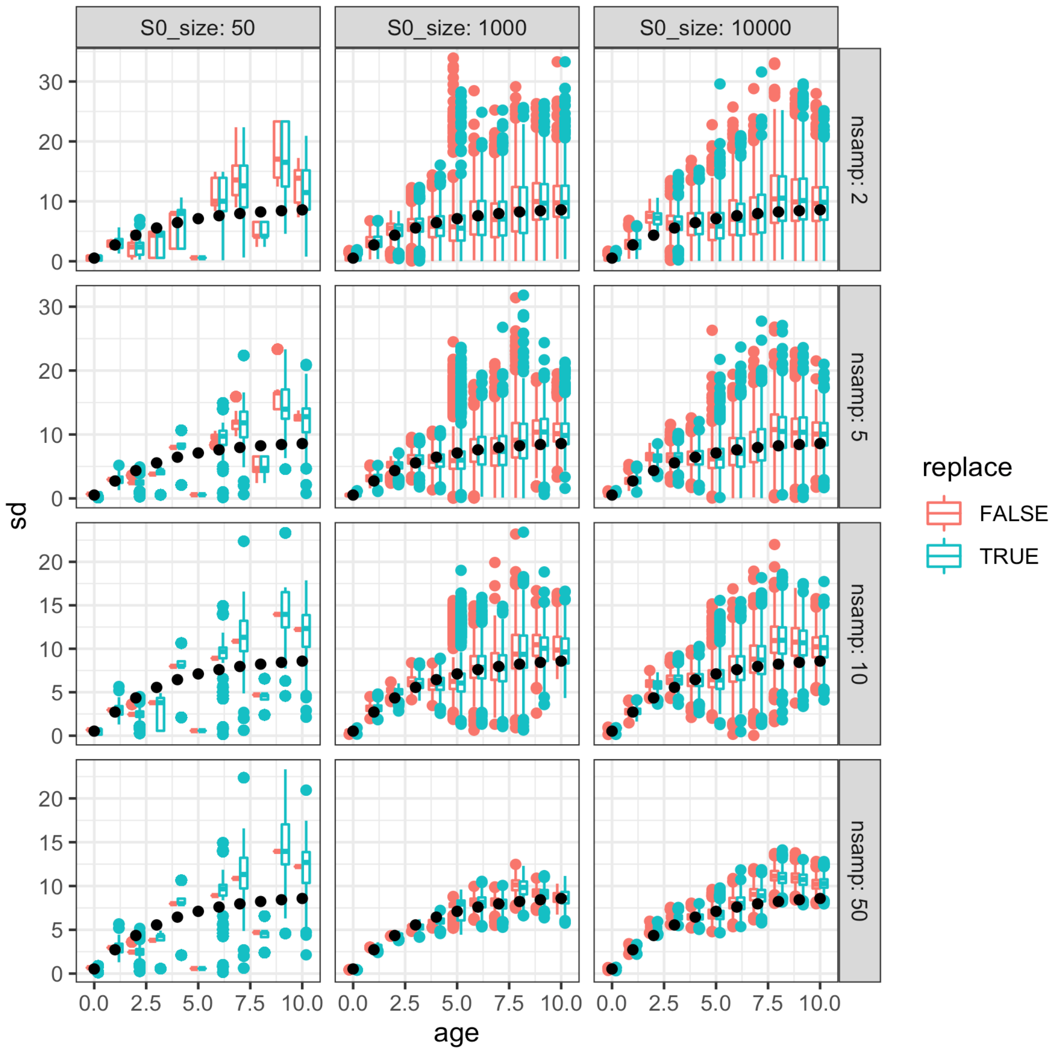

Fig 3. Standard deviation of length-at-age. Black dots represent the true value based on the true growth model underlying the simulated data. S0_size varies by column and is the size of the catch or haul that was being sampled. Rows vary nsamp which is the number of samples per length class. Red and green boxplots show the values of 1000 replicates for each sampling design.

With nsamp = 2 or 5, some of the replicates had too few samples in some age classes to estimate a standard deviation for that age class.

Discussion

More investigation is needed to make sure that these results are valid and to understand the bias of standard deviation estimates. Future work could also investigate age-length keys derived from this type of simulated data. The same results we show for mean length-at-age should hold for mean weight-at-age, but this could be discussed at a future WKBIOPTIM meeting.

6.2 Appendix for WP2

Environmental variables of productivity in the North Sea

Methods

Measures of environmental variables were obtained from from the UK MetOffice issued under the European Commission (Copernicus website: **http://marine.copernicus.eu/**). The data are the results of the Atlantic-European North-West Shelf-Ocean Physics Reanalysis (1992-2018, NORTHWESTSHELF_REANALYSIS_PHY_004_009) and the Biogeochemistry Reanalysis (1998-2018, NORTHWESTSHELF_REANALYSIS_BIO_004_011), respectively. Data were downloaded as monthly values in a grid of longitudinal–latitudinal 7 km^2 cells Annual averages were calculated (averaging across grid cells, months and depth) for regional divisions. Anomalies were calculated for three regional divisions; one for the whole "North Sea", one for "Southern North Sea" and one for "Northern North Sea". The data were split into a northern and southern division at 55°N (Fig. 1a). For 13 out of 15 environmental variables depth range were 0-2000m (Table 1).

For all variables the standardised anomaly were calculated: $Anom = \frac{X_{iy} - \bar{X}_i}{sd(X_i)}$, where X is the estimate of environmental varible i in year y and $\bar{X}$ is the average value of the time series *sd* is the standard deviation of the estimate. The LOESS (locally estimated scatterplot smoothing) regressions were applied to describe each environmental variable through time, which is a common method to smoothen volatile time series. It is a non-parametric regression meta-model that join multiple regression models in a *k*-nearest-neighbour-based method. The the degree of smoothing were controlled by having the span at 0.5 (i.e. 50% smoothing) within the model. A heatmap were provided using a simple clustering method that cluster by mean values of each the time series into a dendrogram. The analysis was done using the free statistical software *R* (version 4.2.0) using the package *stats* and implemented with the function *loess()* for the model smoothing and *heatmap()* for the clustering and graphical output.

Results and discussion

The heatmaps showed various trends for different environmental variables. In general, the model smoothing and clustering method seem to provide a good overview and serves as a transparent graphical representation of data for both scientists and stakeholders. As for now, the current analysis are preliminary and there is a need to be scrutinised the work further before making any firm conclusions on the results. The stakeholders showed minimal interest for this part of the project, and as such the current overview are merely provided as a preliminary template for further development. We highlight four limitations to the current analysis that need to be investigated thoroughly for the heatmaps to be validated and presented as a final format. Firstly, the aggregation in space over grid cells and depth should be explored further. The exact spatial split in data (i.e. northern versus southern, Fig. 1a)) are based on previous studies that highlight a north-south gradient in biophysical processes that influence the North Sea ecosystem (Engelhard et al. 2014, Reiss et al. 2010). Yet, important boundary effects around coastal areas are ignored in the current data aggregation. Thus, other spatial data aggregations should be considered and likewise stakeholder requests (e.g. split into ICES areas) may be implemented. Furthermore, the environmental variables vary with depth and averaging across a range between 0 and 2000m is not optimal for accurate measures of the environment. Secondly, variation through time accounting for seasonality are important in order to discriminate and correlate environmental estimates to other production estimates (e.g. fish biomass). Thirdly, sensitivity tests on the degree of model smoothing (i.e. setting *k* knots) should be investigated through model optimisation in order to find best-fits, e.g. using the *optim()* functionality in the implemented method to minimise the sum of squared errors. Furthermore, other more flexible alternatives such as general additive models (e.g. implemented through *mgcv* or *TMB*) to non-parametric LOESS-regressions should be considered. Lastly, the clustering method should be revisited to decide if a more accurate methodology should be implemented. Multivariate statistics such as principal component analysis and tensor decomposition are strong tools that may be used to discriminate and cluster the data (e.g. see Frelat et al. 2017, Henriksen et al. 2018).

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Tables and figures

Table 1. Summary of environmental variables

Env. variable	Time series	Units	Depth range	Description
Sea bottom temperature	1992-2018	°C	-	Sea floor potential temperature
Sea temperature	1992-2018	°C	0-2000m	Sea Water Potential Temperature
Salinity	1992-2018	‰	0-2000m	Sea Water Salinity
Eastward current speed	1992-2018	$m\ s^{-1}$	0-2000m	Eastward Current Velocity in the Water Column
Northward current speed	1992-2018	$m\ s^{-1}$	0-2000m	Northward Current Velocity in the Water Column
Mixed layer thckness	1992-2018	m	-	Ocean mixed layer thickness defined by density (as in Kara, 2000, with the reference depth at 3m instead of 10m)
Light penetration	1998-2018	m^{-1}	0-2000m	Volume Beam Attenuation Coefficient of Radiative Flux in Sea Water
Chlorophyll	1998-2018	$mg\ m^{-3}$	0-2000m	Mass Concentration of chlorophyll in Sea Water
Phytoplankton	1998-2018	$mmol\ m^{-3}$	0-2000m	Mole Concentration of Phytoplankton Expressed as Carbon in Sea Water
Primary production	1998-2018	$mg\ m^{-3}\ day^{-1}$	0-2000m	Net Primary Productivity of Carbon
Dissolved oxygen	1998-2018	$mmol\ m^{-3}$	0-2000m	Mole Concentration of Dissolved Oxygen in Sea Water
Nitrate	1998-2018	$mmol\ m^{-3}$	0-2000m	Mole Concentration of Nitrate in Sea Water
Partial pressure	1998-2018	Pa	0-2000m	Partial pressure of carbon dioxide in sea water
Phosphate	1998-2018	$mmol\ m^{-3}$	0-2000m	Mole Concentration of Phosphate in Sea Water
pH	1998-2018	pH	0-2000m	Sea water pH reported on total scale

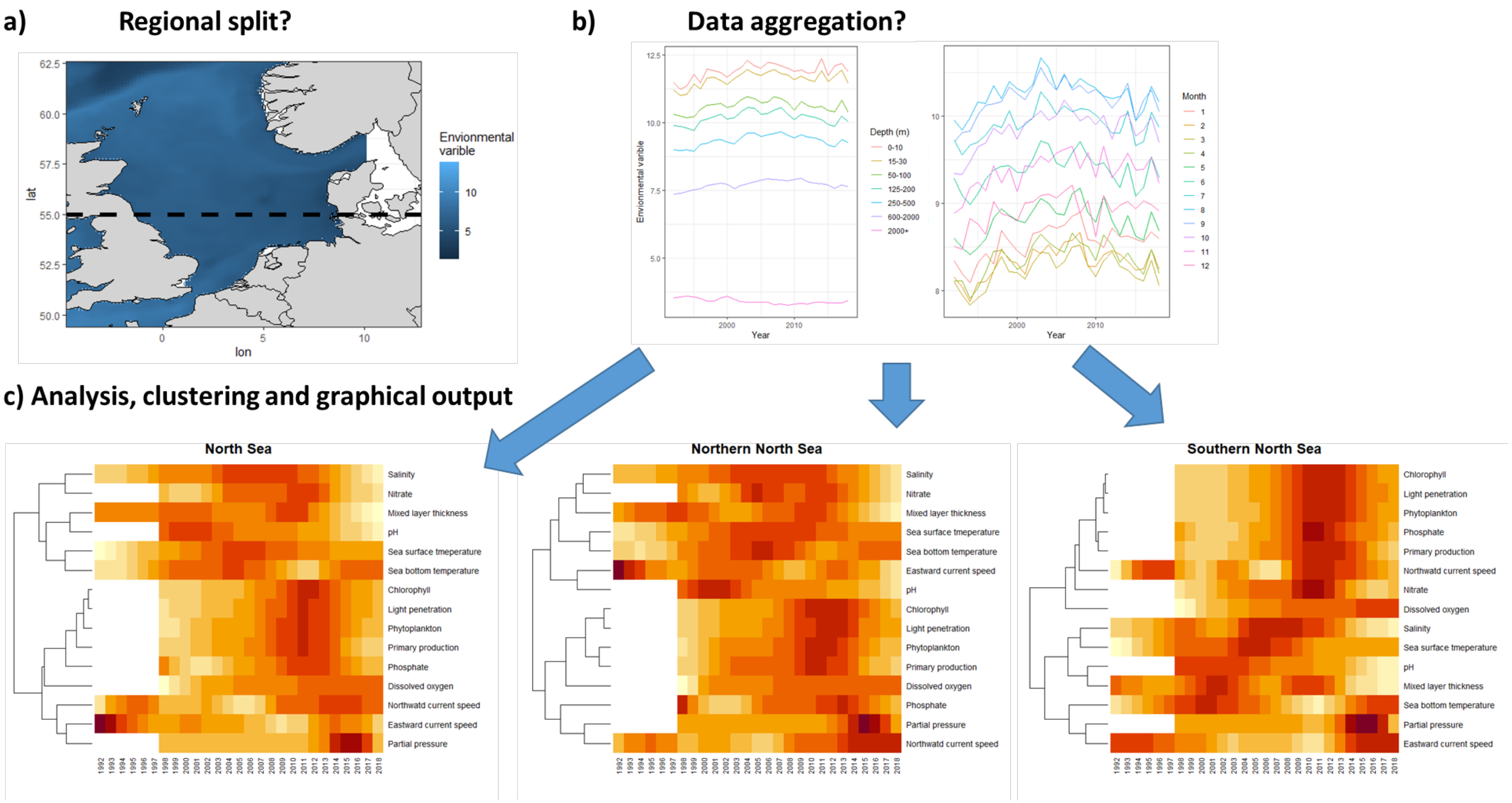

Figure 1. Roadmap from data to graphical output showing the process of consideration on a) spatial data split, b) aggregation and averaging across c) space/time and analysis and final output. A map of data from the Copernicus project are shown a) with the regional north-south split at 55°N (dashed line). Overview of data resolution and aggregation options b) showing annual environmental data at different depth and months. Examples of the final graphical output c) that can be provided.

6.3 Appendix for WP4

Mixed fisheries simulations, WP4, working document

Vanessa Trijoulet

Contents

1 Introduction

Most of the demersal fisheries in the North Sea are mixed, i.e., they catch several stocks at once. Fisheries in the North Sea are managed using single stock advice that do not account for stock mixing. Following the implementation of the Landing Obligation (EU 2019), catching a mixed of stocks can have important consequences on fishing opportunities, due to unavoidable low quota stocks that become choke species (i.e., stock that reduces fishing opportunity on other stocks with larger quotas due to its low quota).

According to the 2021 mixed fisheries advice, cod is the choke species for most fleets in the North Sea and for all Danish fleets (ICES 2021a). This has led to the development of methods to avoid unwanted catches in many places in Europe (e.g., gear development, change in fishing strategies). In Denmark, some effort has been put into gear developments with the main goal being to reduce cod catches. The work presented here builds upon the progress recently made as part of the European Maritime and Fisheries Fund (EMFF) and National Fisheries Agency grant number 39809 (UnCod), focusing on analyzing data from Danish gear technology developments.

In this study, we used the results of the analysis of Danish gear developments and the subsequent changes in gear selectivity to investigate the consequences for medium-term future fishing opportunities in the North Sea mixed fisheries via stochastic simulations using the 2021 mixed fisheries model currently used for advice in the North Sea.

We show that Danish gear developments can reduce the choking effect on cod in the medium-term but reducing fishing effort has a larger positive effect on the Danish fleet profits than changing gear selectivity.

2 Methods

2.1 North Sea mixed fisheries model

The study builds upon the 2021 North Sea mixed fisheries advice model (ICES 2021a) based on the FLBEIA FLR package (Garcia et al. 2017). The model was developed prior and during the ECOMAN project and was chosen as replacement of FCube (Ulrich et al. 2011) following an ICES inter-benchmark process in 2021 (ICES 2021b). It was developed to represent the dynamics of the demersal North Sea fisheries and includes stocks distributed in ICES Division 4 (North Sea), 3.a (Skagerrak and Kattegat) and 7.e-d (English Channel).

The model is a multifleet multimétier mixed fisheries simulation model where fleets are defined by a combination of country, gear (e.g., otter trawl, beam trawl, seine), and vessel length. The fleets are disaggregated further into métiers that are defined by precise gear types (e.g, TR1, TR2) and fishing area. Historical observed catches at the métier level submitted to ICES by each country are used to condition the fleets in the projections years.

The 2021 North Sea mixed fisheries model consists of 40 fleets, whose 4 are Danish fleets as follows:

- The Danish otter trawlers with a length of less than 24 meters (DK_Otter_lthan_24). This fleet consists of 5 métiers: TR1 in ICES Division 3.a North (TR1.3AN), TR1 in ICES Subarea 4 (TR1.4), TR2 in ICES Division 3.a North (TR2.3AN), TR2 in ICES Subarea 4 (TR2.4), and other métiers (OTH).
- The Danish otter trawlers with a length greater than 24 meters (DK_Otter_gthan___equal_24). This fleet consists of 7 métiers: TR1 in ICES Division 3.a North (TR1.3AN), TR1 in ICES Subarea 4 (TR1.4), TR2 in ICES Division 3.a North (TR2.3AN), TR2 in ICES Subarea 4 (TR2.4), OTB in ICES Subarea 4 (OTB32-69.4), OTB in ICES Division 6.a (OTB32-69.6A), and other métiers (OTH).
- The Danish seiners (DK_Seine). This fleet consists of 2 métiers: TR1 in ICES Division 3.a North (TR1.3AN), and TR1 in ICES Subarea 4 (TR1.4).
- The Danish vessels using static gears (DK_Static): This fleet consists of 3 métiers: gill nets in ICES Division 3.a North (GN1.3AN), gill nets in ICES Subarea 4 (GN1.4), and other métiers (OTH).

A full description of the other fleets and métiers can be found in ICES (2022a).

The model includes 20 stocks whose 10 are fish stocks (cod, haddock, plaice and sole in the English Channel and the North Sea, saithe, turbot, whiting and witch flounder) and 10 are Norway lobster (*Nephrops norvegicus*) stocks in ICES Functional Unit (FU) 5, 6, 7, 8, 9, 10, 32, 33, 34, and other FUs (Table 1). The stock estimates comes from the respective 2021 assessment models.

The model includes economic data taken from the Scientific, Technical and Economic Committee for Fisheries (STECF 2020). Some assumptions were taken to match STECF fleet definition with ICES fleet definition. The Scottish beam fleet (SC_Beam) did not include cost data so it was assumed that the costs were the same as the English beam fleet (EN_Beam).

2.2 Forecast projections

The 2021 North Sea mixed fisheries model was used as basis for 10-year mixed fisheries stochastic projections starting from the last assessment year (2020) so that the projections are run up to 2030. A total of 500 iterations were run, which were enough to get results consistent with those for a larger number of iterations (1000). Similarly to the mixed fisheries advice, the fish stocks are modeled dynamically in the projection years following common age-structured population dynamics equations, while the Norway lobster stocks are assumed to have a constant biomass.

2.2.1 Stock-recruitment assumptions

For each stock species, a segmented regression was fitted to the entire time series of estimated SSB and recruitment pairs coming from the assessment model. The fitted parameters of the stock-recruitment (SR)

Table 1: Naming convention for the stocks present in the model.

Common name	Model name	ICES name
North Sea cod	COD-NS	cod.27.47d20
Haddock	HAD	had.27.46a20
English Channel plaice	PLE-EC	ple.27.7d
North Sea plaice	PLE-NS	ple.27.420
North Sea saithe	POK	pok.27.3a46
North Sea sole	SOL-NS	sol.27.4
English Channel sole	SOL-EC	sol.27.7d
North Sea turbot	TUR	tur.27.4
North Sea whiting	WHG-NS	whg.27.47d
Witch	WIT	wit.27.3a47d
Norway lobster in FU 5	NEP5	nep.fu.5
Norway lobster in FU 6	NEP6	nep.fu.6
Norway lobster in FU 7	NEP7	nep.fu.7
Norway lobster in FU 8	NEP8	nep.fu.8
Norway lobster in FU 9	NEP9	nep.fu.9
Norway lobster in FU 10	NEP10	nep.fu.10
Norway lobster in FU 32	NEP32	nep.fu.32
Norway lobster in FU 33	NEP33	nep.fu.33
Norway lobster in FU 34	NEP34	nep.fu.34
Norway lobster in other North Sea FUs	NEPOTH-NS	nep.27.4outFU

curve (α and β) are used to inform recruitment in the projections years. For each fit, the standard deviation of the residuals (σ) was used to create uncertainty around the projected SR curve as follows (example for recruitment at age 0): $R_y = \alpha.SSB_y * exp(\varepsilon_y)$, if $SSB \leq \beta$ and $R_y = \alpha.\beta * exp(\varepsilon_y)$, if $SSB > \beta$, with $\varepsilon_y \sim N(-0.5.\sigma^2, \sigma)$ (the mean of the Normal distribution is corrected for bias).

2.2.2 Effort scenarios

Following the common effort assumptions taken in the mixed fisheries advice, three effort scenarios were considered for the projections: minimum, maximum and status quo effort scenarios.

The minimum scenario (min) is the most restrictive scenario where a fleet stops fishing when the first stock quota is reached independently of other quotas not being taken. This scenario allows to determine choke species issues where a fleet looses fishing opportunities on other stocks when the quota on the first stock is reached.

The maximum scenario (max) is the least restrictive scenario where a fleet continues to fish until all its quotas are reached. This scenario therefore induces overshoot of quotas for all stocks but the least restrictive.

Finally, the status quo scenario (sq) corresponds to the scenario where the fleets have a constant effort in the projections, set as the last year (2020) effort.

2.2.3 Gear development scenarios

For each métier, catchability is estimated historically as a proxy of selectivity on each stock (see Garcia et al. (2021) for more information). Three gear scenarios were simulated in this study by modifying the catchability of the métiers. The results from the analysis of Danish experiments on gear technology development (UnCod, European Maritime and Fisheries Fund (EMFF) and National Fisheries Agency grant 39809) were used to inform realistic changes in fleet catchability per stock. It resulted in catchability change for cod caught by TR1 gears and for cod, haddock, plaice, turbot, whiting, witch, and Norway lobster caught by TR2 gears

(Figures 1 and 2). While the experiments only recorded changes in catchability for plaice, we chose to use the same assumption of change in catchability for witch and turbot due to similarities in behavior.

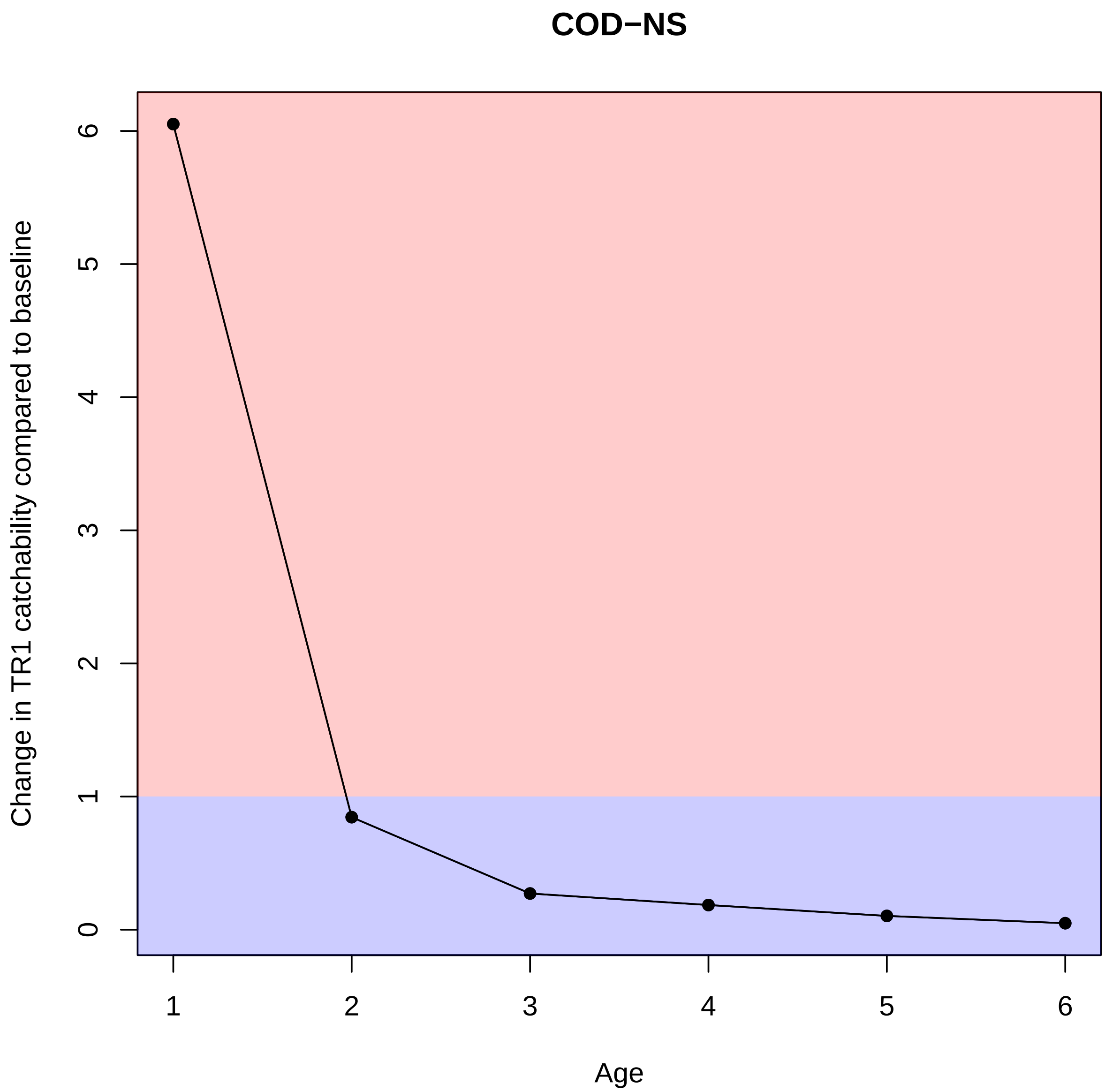

Figure 1: Change in catchability for TR1 gears compared to the baseline catchability. The blue area shows where the catchability is decreased compared to the baseline, and the red area where it is increased.

For most stocks, the gear developments induce a decrease in catchability except for young ages that might be poorly selected by the fisheries. While the developments were intended to reduce catchability on cod without affecting catchability on the other stocks, the experiments show that catchability for the other stocks is also reduced.

The projections assume three different gear developments scenarios:

- The "Baseline" scenario corresponds to the commonly used advice assumption where the catchability of each fleet is assumed constant in the projections years (equal to the last year catchability). In this

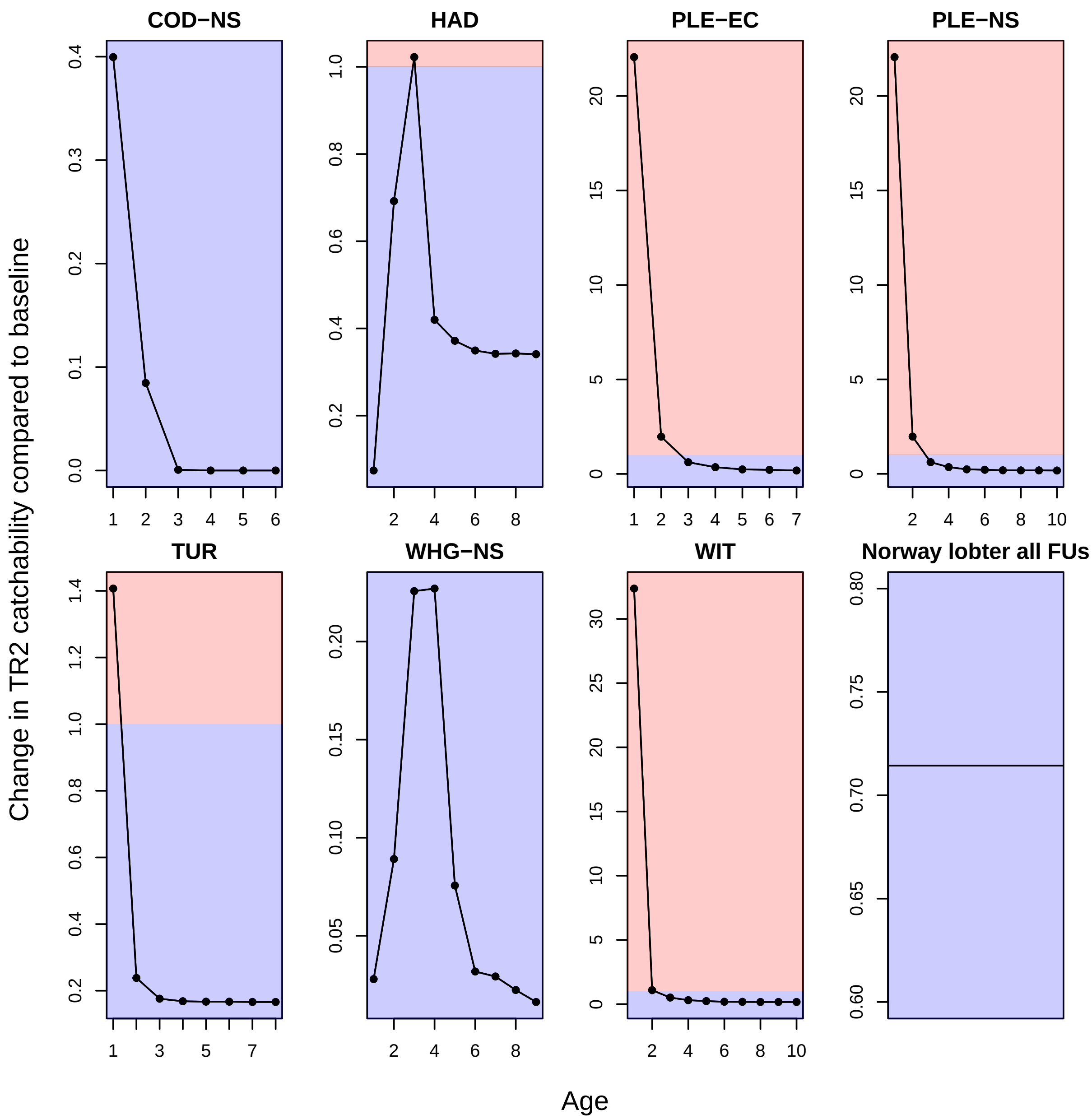

Figure 2: Change in catchability for TR2 gears compared to the baseline catchability. The blue area shows where the catchability is decreased compared to the baseline, and the red area where it is increased. The Norway lobster stocks are biomass aggregated stocks so there is no age available and the change is just a single scaler on the baseline catchability.

scenario, the catchability of the fleets is therefore not affected by gear developments.

- In the "DK only" scenario, the catchability of the Danish fleets using TR1 and TR2 gears were modified in the projection years by multiplying the baseline catchability by the catch rate ratio given in Figures 1 and 2.
- In the "All fleets" scenario, the Danish gear developments were applied to all fleets using TR1 and TR2 gears. While it may seem simplistic that all fleets would have the same catchability change than the Danish fleets following Danish gear improvements, it gives an indication of how the North Sea fisheries dynamics could change if all countries would make gear developments in a realistic way.

2.3 Diagnostics

All iterations were aggregated in terms of median and 95% quantiles estimates. All stocks, fleets and metiers outputs were collected. In this study, we focus on investigating the consequences of plausible gear developments on spawning stock biomass (SSB) and catch for the dynamic stocks (fish stocks), on fleet catches and profit (revenues-costs), and on changes in choke species per fleet over the projection period. For the Norway lobster stocks, biomass is kept constant in the projections so the SSB and catch results are not presented for these stocks. The main interest is on the consequences for Danish fleets, so these are the only fleets presented here.

3 Results

3.1 Fish stocks projections

For most fish stocks, the gear developments do not make a clear change in total catch in the projections, except for the scenarios where all the modeled fleets apply the change in gear (Figure 3). However, for cod, for which both TR1 and TR2 gears are affected by the change in catchability, there is more variation between the gear scenarios. Applying the change to the Danish fleets in the status quo scenario induces an increase in the cod catch that is even larger when the change in catchability is for all fleets.

The SSB per stock varies more with the effort scenarios than the gear scenarios (Figure 4). The direction of the impact of the gear developments on the stocks' SSB depends on the effort scenarios. For all stocks except cod, whiting, and witch, gear developments at the scale of the entire fishery induce a decrease in SSB in the max scenario compared to the baseline. Cod and witch are the two stocks that show an increase in SSB when the Danish fleets reduce their catchability (for >2 years old fish) in the min and sq scenarios. Due to the technical interactions, the stocks for which the gear developments did not result in a change in catchability (saithe and sole) are also affected by the gear development scenarios.

3.2 Danish fleets projections

The different effort strategies (min, max, sq) have different consequences in the short- (0-5 years) and medium-term (5-10 years, Figure 5). As expected, the max scenario secures large catches in the short-term but catches are the lowest in the medium-term as the fleets fish the stocks down. Inversely, while the min scenario results in smaller catches in the short-term, catches are the highest in the medium-term for most Danish fleets. For all fleets except DK_Static, the gear developments result in a decrease in the total fleet catch compared to the baseline catch. However, if the Danish fleets do not change their fishing effort in the future (sq scenario), and if gear developments are applied to all modeled fleets, the catches might be larger than the baseline catch in the medium-term, except for DK_Otter<24.

When looking at the fleet profits, it is clear that overfishing in the max scenario is detrimental and results in negative profits in the short- and medium-term for all Danish fleets (Figure 6). Interestingly, if the fleets stop fishing after the first quota is reached (min scenario), creating an undershoot of quotas for many stocks, the profit of the Danish fleets is largest, certainly due to a decrease in variable costs as the effort is reduced compared to the other scenarios. Gear developments are only beneficial for the DK_Static fleet where profits

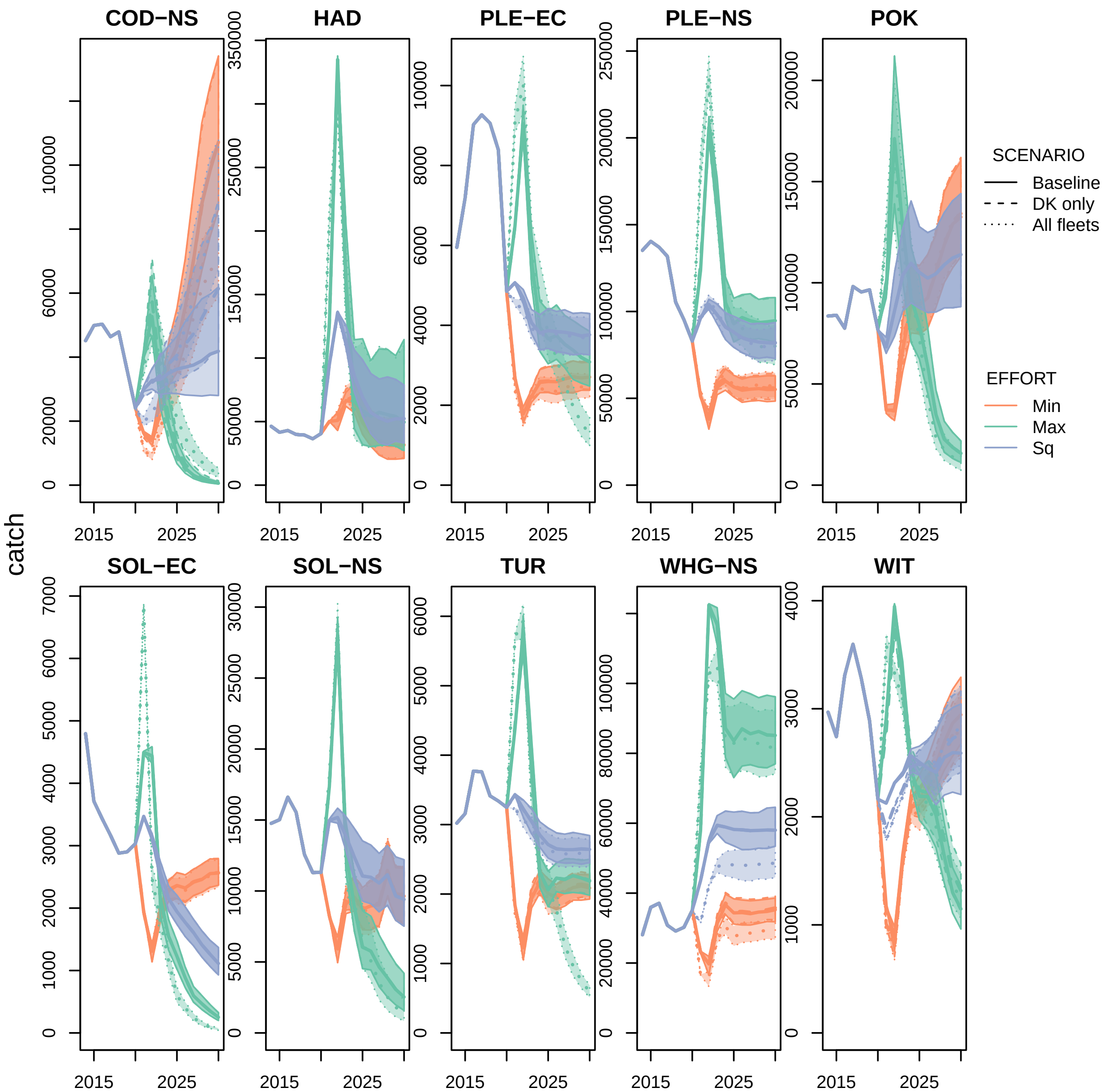

Figure 3: Catch in the projections years for all dynamic fish stocks. The different lines are the median estimates around the 500 iterations. The shaded areas show the 95% quantiles.

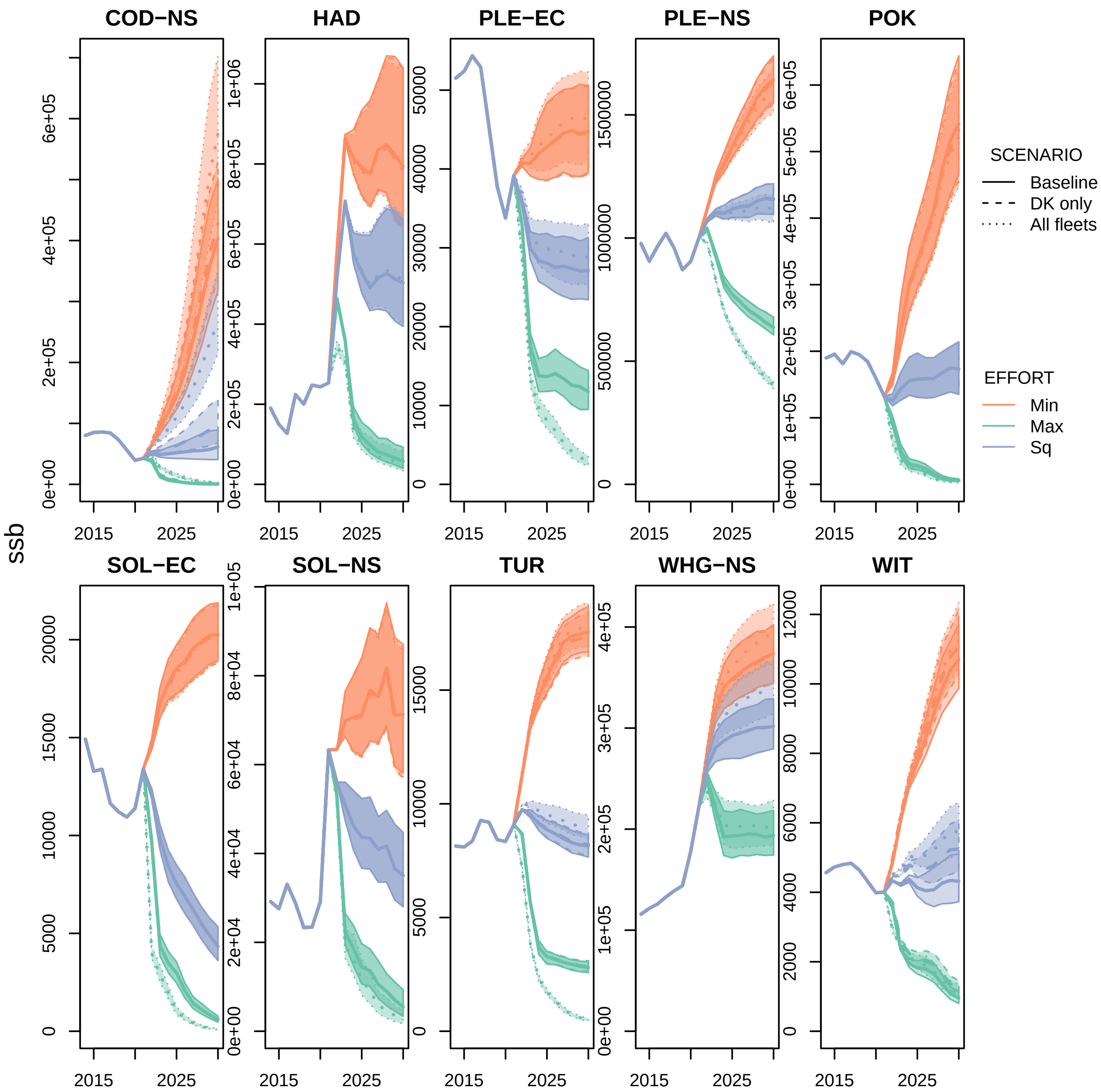

Figure 4: Spawning stock biomass (SSB) in the projections years for all dynamic fish stocks. The different lines are the median estimates around the 500 iterations. The shaded areas show the 95% quantiles.

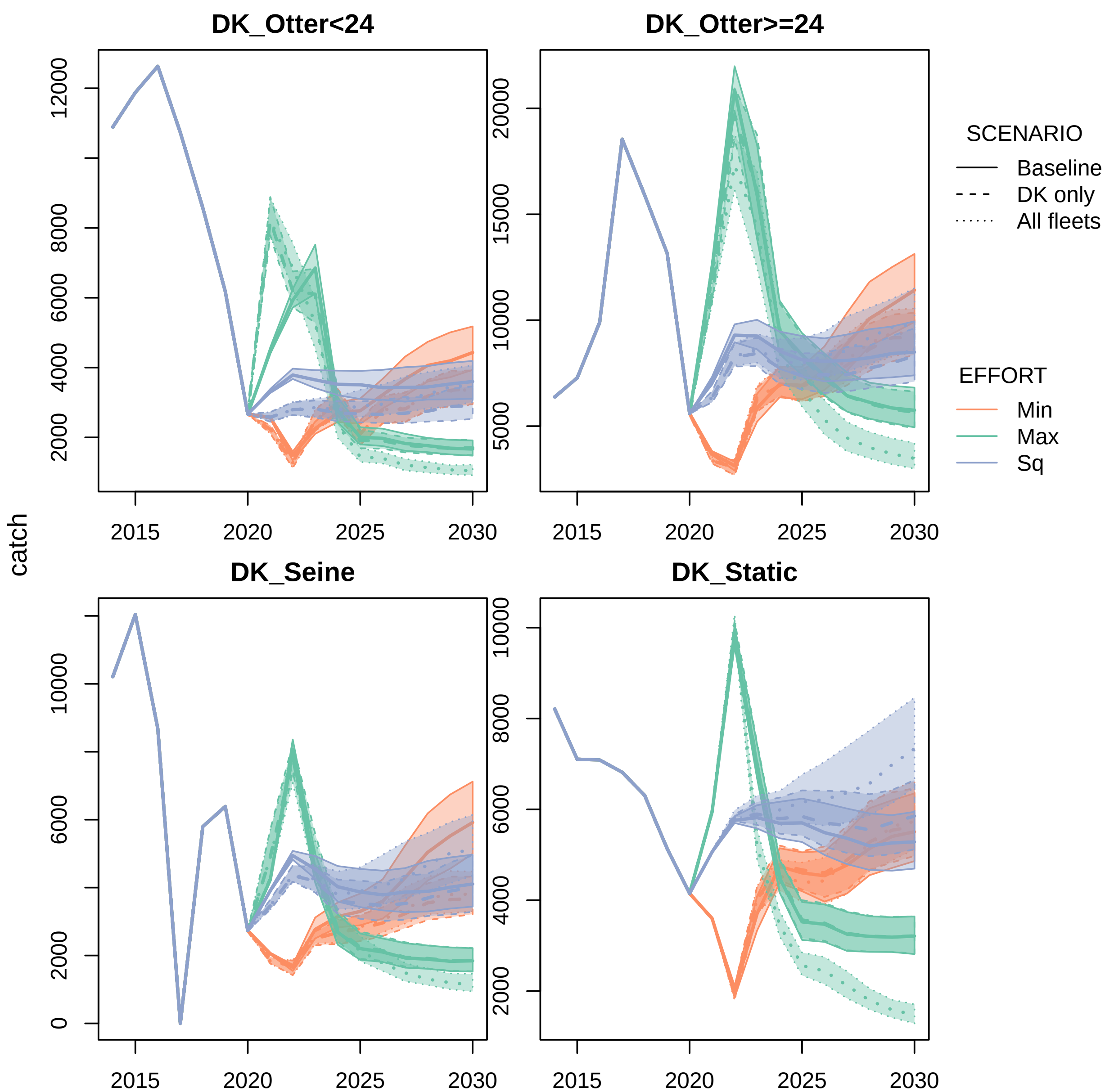

Figure 5: Total catch per Danish fleet for all scenarios. The different lines are the median estimates around the 500 iterations. The shaded areas show the 95% quantiles.

are larger than the baseline. This is however an artefact of the change in catchability for the other fleet as this fleets does not use TR1 or TR2 gears for which the change in catchability applies.

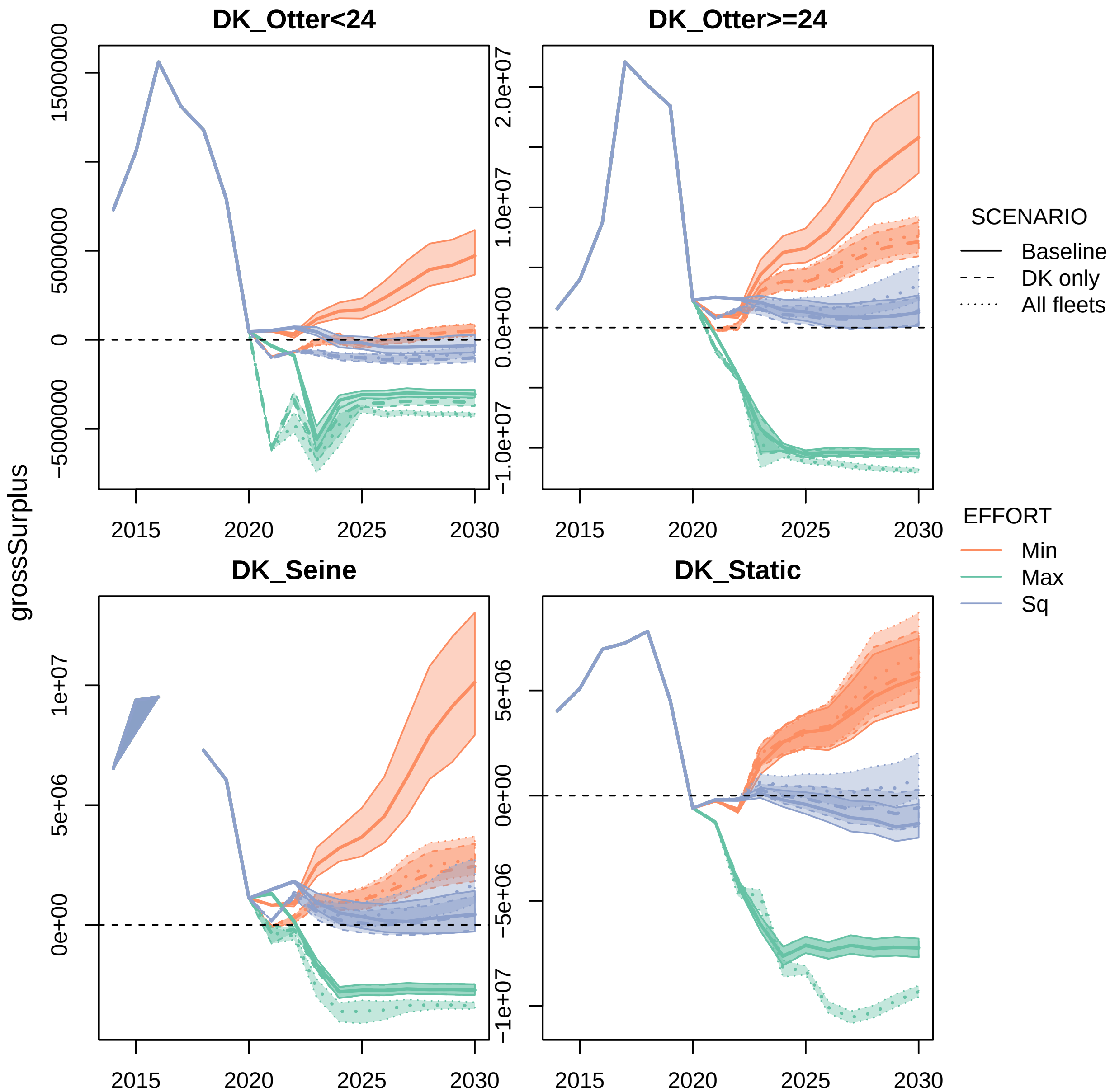

Figure 6: Profit per Danish fleet for all scenarios. The different lines are the median estimates around the 500 iterations. The shaded areas show the 95% quantiles.

The min scenario allows to identify the most limiting stock (choke species). For all min scenarios iterations, the choke species was extracted so that we obtain a proportion across iterations of the different stocks that are choke species (Figure 7). As observed in the 2021 mixed fisheries advice (ICES 2021a), in the baseline scenario, cod is the main choke species for all Danish fleets in the advice year (2022). Saithe and witch are also most limiting for some of the iterations in 2022. When gear developments are introduced, the proportion of cod being a choke species is largely reduced in 2022 for all Danish fleets except DK_Static, to the detriment of saithe, witch and Norway lobster in other North Sea FUs.

For the two Danish otter trawl fleets, choking on cod is reduced when gear developments are introduced for the Danish fleets or for all fleets and Norway lobster in other North Sea FUs becomes the most limiting stocks after 2022, despite its catchability being reduced when gear developments are in place. For Danish seiners, gear developments clearly reduce choking by cod in the projection years and witch becomes the main choke species when these developments are introduced. Similar results are observed for the Danish fleet using static gears, except that when all fleets change gear, the choking on cod is actually increased. Given that this fleet does not use TR1 and TR2 gears, its catchability on all the stocks is the same as for the baseline scenario. The change in choking for this fleet when the new gears are in place is a consequence of the changes in catchability for the other fleets, which affect fishing opportunities for the static gear fleet. This is an illustration on how changes in fishing behavior or gears for certain fleets can affect stock dynamics and therefore the entire fishery.

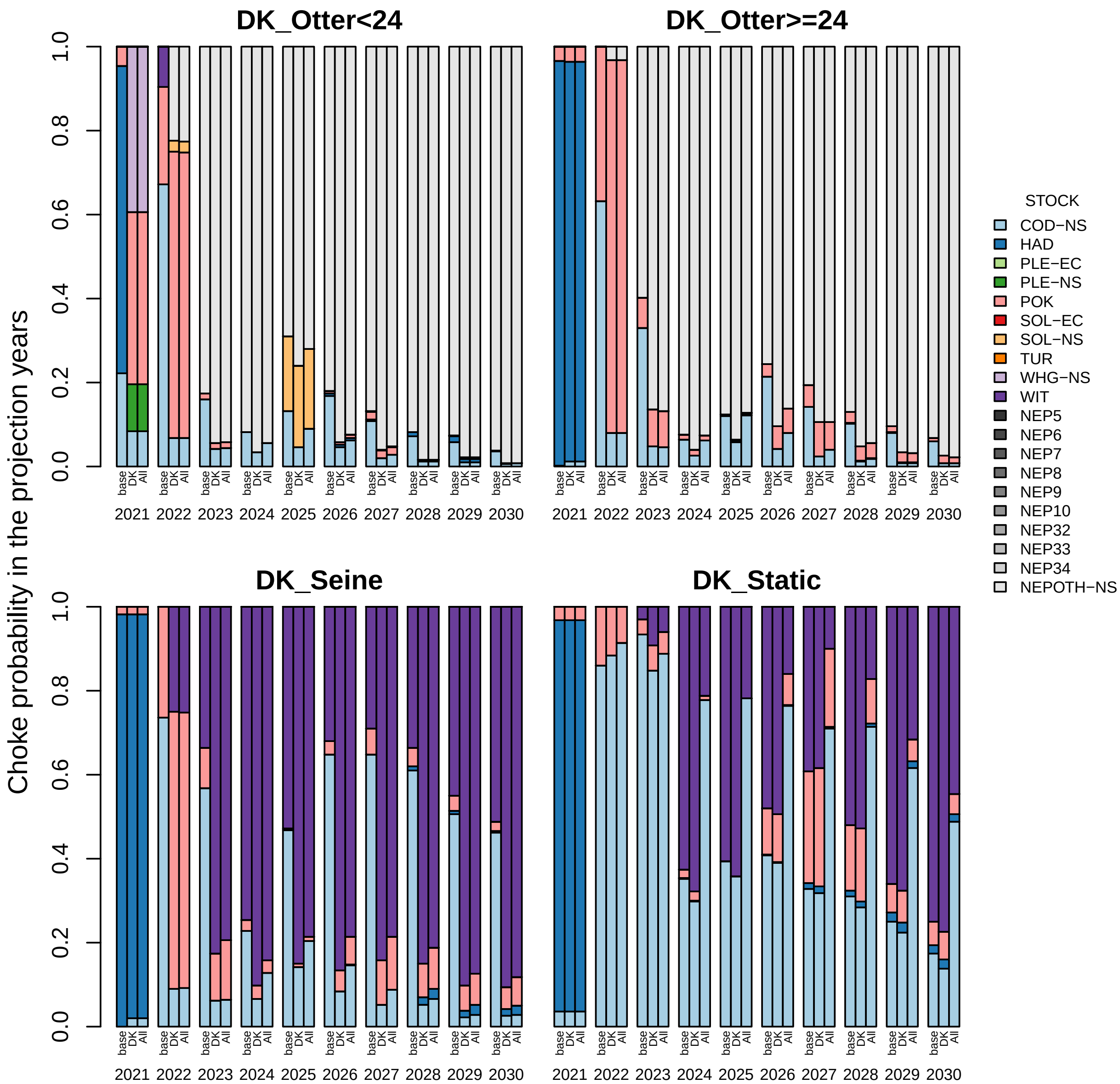

Figure 7: Proportion of choke across the 500 iterations over the projection years in the minimum scenario for each gear scenarios.

The results for all the other fleets and indicators are available at https://ono.dtuaqua.dk/ECOMAN/.

4 Discussion

Cod and witch are the stocks that are mainly affected by the change in gear catchability following Danish gear developments. Their SSB increase in all the effort scenarios when the gear developments are introduced at the scale of the Danish fleets only but also of the entire North Sea fishery. Cod was the choke species for most North Sea fleets, including the Danish fleets in 2022 (ICES 2021a) and witch is predicted to be the choke species in 2023 (ICES 2022b). The introduction of the gear developments clearly reduced the choking effect on cod for the Danish otter trawlers and seiners but can increase the choking effect on witch for the Danish seiners.

The simulations are based on different assumptions that may not be fully representative of fishing behavior in the North Sea fisheries. For instance, catchability per métier is kept constant in the projections, but in reality it might vary over time due to changes in fishing behavior or stock distribution. These can be difficult to model without having a vessel-based spatial model. The variable and fixed costs per fleet were estimated given STECF (2020) and assumptions were taken to match fleet definition between STECF and ICES. While the costs may not be exact for each fleet, the changes should be realistic relatively to the baseline runs. While the results presented here follow assumptions on effort and costs per fleet that may not be fully realistic, relative comparison to the baseline runs are still very relevant.

The economical consequences of gear developments is fleet dependent. For the Danish fleets, gear developments are only economically beneficial for the fleet that fish with baseline catchability (DK_Static). A limitation of the gear developments obtained in this study is that, overall, the catchability is significantly reduced on many stocks rather than only for cod. As a result, applying the change in gear can result in a decrease in the catch of other stocks such as plaice or Norway lobster for which the selection should ideally be unaffected or improved.

Reducing fishing effort (min scenario) is the most economically beneficial scenario for the Danish fleets in the medium-term as it enables the increase in fish stock abundance so that less effort does not mean lower catch but lower costs. However, the effort scenarios tested in this study assume all fleets are limited at the same time. This assumption will be challenged if the fleets are acting differently from each others or if quotas are exchanged between the countries and fleets.

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