



STUDY TO ASSESS THE ROBUSTNESS OF MIXED FISHERIES SCENARIO ASSUMPTIONS

CINEA/EMFAF/2021/3.1.4 Lot 1 Specific Contract No.13

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LIST OF ABBREVIATIONS

Term	Description
AER	STECF annual economic report
AFBI	Agri-Food and Biosciences Institute
ALB	Albacore tuna
ANE	European anchovy
ANF	Anglerfish
ANK	Blackbellied anglerfish
ANX	Anchovies
ARG	Argentines
BEF	Bigeye tuna
BFT	Bluefin tuna
BIB	Bib
BLL	Brill
BOR	Boarfish
BRF	Blackbelly rosefish
BSS	Seabass
CAA	Wolffish
Cefas	The Centre for Environment, Fisheries and Aquaculture Science
CINEA	European Climate, Infrastructure and Environment Executive Agency
COD	Cod
COE	Conger eel
CPUE	Catch per unit effort
CRE	Edible crab
CTC	Common cuttlefish
DAB	Dab
DCF	Data Collection Framework
DISPLACE	A spatial model of fisheries to help sustainable fishing and maritime spatial planning
EASME	Executive Agency for Small and Medium-sized Enterprises
EC	European Commission
EC	English Channel when in association with a three alpha species code, (e.g. SOL-EC)
EMFF	European Maritime and Fisheries Fund
ETP	Endangered, Threatened and Protected species
EU	European Union
F	Fishing mortality pressure
FDF	Fully documented fisheries
FDI	Fisheries Dependent Information
FIDES	Fisheries Data Exchange System

Term	Description
FLBEIA	Bio-Economic Impact Assessment using FLR (Fisheries Library in R)
FLE	Flounder
FLFleet	A data object in R which is a representation of amalgamated biological, assessment and fleet data
FLR	Fisheries Library in R
FLStock	A data object in R that is a representation of a stock assessment and contains the inputs and outputs of the single-species stock assessments and forecasts
FMSY	Fishing mortality supporting maximum sustainable yield
FMSY lower	MSY estimates are often given as a point estimate and a range of fishing mortalities may be associated with generating the MSY estimate, FMSY lower is the lower, more conservative, estimate of the range
FU	Functional Unit, a <i>Nephrops</i> stock assessment unit
GAM	Generalised additive model
GSA	Global sensitivity analysis
GUG	Grey gurnard
GUR	Red gurnard
GUU	Tub gurnard
GUX	Gurnards
HAD	Haddock
HAL	Halibut
HCR	Harvest Control Rule
HER	Herring
HKE	European hake
HKX	Hakes
HOM	Horse mackerel
ICES	International Council for the Exploration of the Sea
ICES WKFO2	ICES second workshop on fisheries overviews
JAX	Jack and horse mackerels
JOD	John dory
LBE	European lobster
LEM	Lemon sole
LEZ	Megrim
LIN	Ling
MAC	Mackerel
MAPE	Mean of absolute percentage error
MEG	Megrim
MON	Monkfish
MPE	Mean percentage error
MSE	Management strategy evaluation
MSS	Marine Scotland Science
MSY	Maximum sustainable yield

Term	Description
B _{trigger}	A biomass reference point that triggers a cautious response within the ICES MSY framework
MUR	Surmullet
NEP	<i>Nephrops</i>
NOP	Norway pout
NS	North Sea
NS–WoS	North Sea – West of Scotland
OAT	One (factor) at a time
OCZ	Octopus
OM	Operating model
OTB	Bottom otter trawl
OTH	‘Other’
PCA	Principal component analysis
PIL	European pilchard
PLE	Plaice
POK	Saithe
POL	Pollack
ProByFish	Protecting bycaught species in mixed fisheries
PTM	Midwater pair trawl
RDB	Regional Database (precursor to the RDBES)
RDBES	Regional Database and Estimation System
RED	Redfishes
RJC	Thornback ray
RJH	Blond ray
RJM	Spotted ray
RJU	Undulate ray
SCE	King scallop
SDN	Danish seine gear
SDV	Smooth-hounds
SKA	Skates and rays
SMD	Smooth-hound
SOC	Sockeye salmon
SOL	Common sole
SOX	Soles
SPiCT	Surplus production models in continuous time
SPR	Sprat
SQC	Common squid
SqE	Status quo effort
SQI	Northern shortfin squid

Term	Description
SQR	European squid
SQS	Sevenstar flying squid
SQU	Squids
SSB	Spawning stock biomass
SSC	Scottish seine gear
STECF	Scientific, Technical and Economic Committee for Fisheries
SWO	Swordfish
SYC	Small-spotted catshark
TAC	Total allowable catch
TAF	Transparent Assessment Framework
TMB	Template Model Builder (see Kristensen et al., 2016)
TUR	Turbot
VMS	Vessel monitoring system(s)
WG	Working group
WGBIE	Working Group for the Bay of Biscay and the Iberian Waters Ecoregion
WGCSE	Working Group for the Celtic Seas Ecoregion
WGECON	Working Group on Economics
WGMIXFISH	Working Group on Mixed Fisheries
WGMIXFISH-ADVICE	Working Group on Mixed Fisheries Advice
WGMIXFISH-METHODS	Working Group on Mixed Fisheries Advice Methodology
WGNSSK	Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak
WGRDBESGOV	Working Group on Governance of the Regional Database & Estimation System
WHB	Blue whiting
WHG	Whiting
WKMIXFISH	Workshop on Mixed Fisheries
WIT	Witch flounder

ABSTRACT

This study tackles the challenges of providing advice for fishing EU demersal stocks when based solely on single-species data and Total Allowable Catches. Such advice neglects intricate multi-species interactions and could result in the over-exploitation of more vulnerable stocks. In this study, we explore 'mixed fisheries', a concept developed within ICES over the past decade. This looks at multi-species fisheries, where different species are caught together, to provide a more holistic approach to assessment, a step beyond single species considerations. To assess mixed-fisheries, scenario-based modelling is carried out considering different fishing regimes. However, the underlying assumptions of each scenario can lead to unrealistic recommendations, risking stock under-utilisation. The primary objective of this study was to analyse these assumptions and their impacts.

Case studies in the North Sea, Celtic Sea and Bay of Biscay assess uncertainties and sensitivities of mixed-fisheries assessments used to guide European policy decisions on fishing and stock protection. This study addresses data source and resolution challenges, and shows that accurate fleet activity data are essential for identifying technical interactions. Examining fleet and métier definitions highlights the need to address overall model structural uncertainty, particularly in terms of fleet dynamics models. Characterising uncertainty in mixed-fisheries models sheds light on input parameter significance.

Furthermore, this project introduces conceptual frameworks for scenario evaluation, stock rebuilding, adding new stocks and developing models for new areas within mixed-fisheries models.

RÉSUMÉ

Cette étude aborde les défis liés à la fourniture d'avis sur la pêche des stocks démersaux de l'Union européenne lorsqu'ils se fondent uniquement sur des données relatives à une seule espèce et sur les Totaux Admissibles de Captures (TAC). Ces avis négligent les interactions complexes entre plusieurs espèces et pourraient entraîner la surexploitation des stocks les plus vulnérables. Dans cette étude, nous explorons les "pêcheries mixtes", un concept développé au sein du CIEM au cours de la dernière décennie. Cela examine les pêcheries mixtes, où différentes espèces sont capturées ensemble, afin de fournir une approche d'évaluation plus holistique, allant au-delà des considérations liées à une pêcherie monospécifique. Pour évaluer les pêcheries mixtes, des modèles basés sur des scénarios variables sont réalisés en tenant compte de différents régimes de pêche. Toutefois, les hypothèses sous-jacentes à chaque scénario peuvent conduire à des recommandations irréalistes, risquant de conduire à une sous-utilisation des stocks. L'objectif principal de cette étude était d'analyser ces hypothèses et leurs impacts.

Des études de cas en mer du Nord, en mer Celtique et dans le golfe de Gascogne évaluent les incertitudes et les sensibilités des évaluations des pêcheries mixtes utilisées pour guider les décisions politiques européennes en matière de pêche et de protection des stocks. Cette étude aborde les défis liés à la source et à la résolution des données et montre que des données précises sur l'activité des flottes sont essentielles pour identifier les interactions techniques. L'examen des définitions des flottes et des métiers met en évidence la nécessité d'aborder l'incertitude structurelle globale du modèle, en particulier en ce qui concerne les modèles de dynamique des flottes. La caractérisation de l'incertitude dans les modèles de pêche mixte met en lumière l'importance des paramètres d'entrée.

De plus, ce projet introduit des cadres conceptuels pour l'évaluation de scénarios, la reconstruction des stocks, l'ajout de nouveaux stocks et le développement de modèles pour de nouvelles zones au sein des modèles de pêcheries mixtes.

EXECUTIVE SUMMARY

Typically European Union (EU) fisheries management is guided by single-species advice and total allowable catches (TACs). Such an approach often does not consider interactions and vulnerabilities among stocks caught together, risking overexploitation of the more vulnerable ones. This study examines the underlying assumptions in applying mixed fishery assessment models within the EU.

To consider these issues, this study examines mixed-fisheries models that integrate the implications of capturing multiple species within multiple fisheries with different catchabilities and targeting behaviour or objectives. The concept of 'mixed fisheries' has been actively developed within the International Council for the Exploration of the Sea (ICES) for more than a decade. ICES provides scenario-based considerations using models like fleets and fisheries forecast model Fcube and Bio-Economic Impact Assessment using Fisheries Library in R (FLR) (FLBEIA). ICES produces considerations for the North Sea, the first eco-region for which ICES developed mixed-fisheries scenarios, the Celtic Sea, Iberian waters, and the Bay of Biscay. In 2022, ICES expanded its mixed-fisheries scenarios to include the Irish Sea.

However, the assumptions underlying these models can lead to catch scenarios that do not align with reality, potentially causing stock under-utilisation. The current study aimed to analyse these assumptions and their impacts, while involving close collaboration with ICES.

The goal was to provide the European Commission (EC) with insights into the reliability of ICES mixed-fisheries scenarios. Through case studies in the North Sea, Celtic Sea, and Bay of Biscay, this study examines uncertainties and sensitivities, aiding European policy decisions on fishing opportunities and stock protection.

Data availability

The data sources used for the analyses were gathered from Member States, ICES and the EU Data Collection Framework (DCF), each offering a varying level of detail. The main challenge was obtaining data that accurately reflect fleet activities at a meaningful resolution. Technical interactions can only be identified at the haul level, which currently lacks comprehensive data. The Regional Database and Estimation System (RDBES) aims to address this, linking multiple data sources for consistency. However, its spatial resolution is limited. To overcome this limitation, bespoke datasets from Member States are explored while respecting data sensitivity and national confidentiality rules.

Sensitivity and uncertainty to fleet

In the context of two case studies, the North Sea and the Celtic Sea, the base components of mixed-fisheries models, namely fleets and métiers, were examined. These components have evolved over time in accordance with DCF guidelines, but there remains room for refinement. These case studies aimed to evaluate the current fleet and métier definitions used, suggest potential improvements, and assess the impact of different aggregations of fleets and métiers on catch forecasts.

In the North Sea case study, the analysis explored the influence of different fleet and métier aggregations, such as gear used and species targeted, on projected catch forecasts. While Principal Component Analysis (PCA) was used to assess the impact of data aggregation on catch profiles (similar species compositions), it became apparent that PCA alone could not entirely define fleets and métiers. Additional information concerning quota distribution, technical vessel characteristics and catchability is also needed. The study revealed aggregation of the data used by ICES WGMIXFISH at the country and gear levels had minimal impact on data variability. However, linking the results of the PCA and cluster analysis to the métier definitions used in the WGMIXFISH

North Sea model underscored the need for more detailed definitions in specific fleet-métier combinations given the variability in landings-composition present in the input strata of those métiers. Nevertheless, as long as nothing changes at the fleet level, disaggregating métiers would not impact mixed fisheries projections given the assumption of static métier effort shares. In a static fishing effort distribution it is only the creation of additional fleets, that would result in a variation to the projected forecast.

Furthermore, the study emphasised the significance of addressing the structural uncertainty of the models, particularly fleet dynamics models (which dictate effort utilisation across métiers assuming specific behavioural patterns). It was found that the choice of fleet dynamics model had a more pronounced effect on outcomes than fleet and métier definitions alone. An alternative fleet dynamics model was explored, offering greater flexibility in effort proportions across métiers, which led to improved quota utilisation but also lowered catch per unit effort (CPUE) because of an emphasis on métiers with low catchabilities. The adoption of historical effort constraints resulted in more realistic behavioural patterns.

The Celtic Sea case study concentrated on defining fleets and métiers using highly spatially disaggregated data. This approach aimed to provide a more accurate representation of fishing dynamics. An illustrative example involved examining cod interactions within the Irish *Nephrops* fleet. By harnessing data from fishers' reports and specialised tools, the study identified species interactions and assessed their significance. Even at the trip and ICES rectangle level, interactions between *Nephrops* and cod could not be decoupled in an area known to have lower cod presence (the Porcupine Bank). The key insight here was that acquiring more spatially disaggregated, high-resolution data is crucial for the accurate identification and delineation of fleets. This could potentially change our perception of technical interactions between fleets and stocks, and may result in fewer lost opportunities due to the elimination of artificial choking patterns (choking being, the result of a lower quota stock reaching its limit preventing continued fishing for higher quota stocks).

Additionally, the study introduced Monte Carlo simulations, which stochastically sampled input parameter values from historical data. These simulations showed that parameter uncertainty significantly affected model outputs. Variations in forecasted catches were observed under different effort scenarios, underscoring the necessity for more results of mixed-fisheries forecasting to be accompanied with robust estimates of confidence to ensure that the limitations of the forecasts are clearly communicated, and areas for improvement can be easily identified, i.e. level of data aggregation.

Uncertainties in input data, such as catchability conditioning (the process by which catchability values for future years are chosen based on certain assumptions of past values), may be linked to data quality issues or shifts in fleet behaviour, which could also be influenced by spatial differences in catch composition. The current ICES dataset does not allow for a comprehensive identification of such mechanisms. Therefore, it is imperative that these outstanding questions be evaluated on a nuanced case-by-case basis. These limitations posed by the lack of high-resolution data are recognised and emphasise the importance of addressing these questions in future research and analysis.

Sensitivity and uncertainty to forecast

In the context of two case studies, the North Sea and the Bay of Biscay, the uncertainty in mixed-fisheries models was characterised by focusing on the impact of forecast conditioning. The aim was to understand how uncertainties in historical data and input parameters affect model projections. Parameter uncertainties in forecasting were examined, and output uncertainty quantified to enable identification of the most influential parameters.

The mixed-fisheries models involve numerous input parameters, including catchability, effort distribution and quota allocations. These models rely on historical data, which may be error-prone, for parameter conditioning. Sensitivity analysis is crucial for understanding the relationship between input uncertainties and output variations. Global sensitivity analysis (GSA) efficiently characterises this relationship but can be computationally demanding. Within the Bay of Biscay case study, GSA was implemented to assess the sensitivity of catchability, quota-share and effort proportion. For the North Sea case study, a less computationally intensive approach was adopted, conducting separate uncertainty analyses for catchability, landings proportions and effort proportion.

The Bay of Biscay case study focused on conducting an uncertainty analysis and GSA for demersal mixed fisheries in the region, with a particular focus on French and Spanish fleets. Catchability was conditioned based on interspecies interactions within each métier, considering unidimensional year effects per stock. Uncertainty in effort proportion and landings proportions were introduced using a Dirichlet distribution (a multivariate probability distribution). The GSA analysis then characterised the output variance as a function of input factor variances (catchability was separated in selectivity and intensity), including consideration of interactions between input factors. Three fleet (average effort, maximised catches, minimised catches) dynamic scenarios were examined, each with distinct factors affecting the outcomes. In the scenario maximising catches, the overall effort primarily depended on fleet intensity across various métiers, and interaction between input factors played a significant role in explaining variance. In the most restrictive scenario (minimised catches), the intensity in the most important métier had the greatest impact, with quota-share affecting the output variance for most stocks (excluding horse mackerel). The probability of a stock becoming a choke point for fishing effort was particularly influenced by quota-share, although it was not the only factor.

For the North Sea case study, in terms of deviation from the observed values, the current assumptions, setting values equal to the last available data, generally provide unbiased predictions. Three alternative assumptions were tested, but the current assumption often outperformed the alternatives by having a lower level of uncertainty. Sensitivity tests then compared runs using the current assumption with runs using the actual observed values. Catchability and effort proportion assumptions had limited impacts on choke and least-limiting (more abundant) stocks, highlighting that current assumptions generally perform well for these parameters. Landing-proportion assumptions had significant impacts on choke effects, with real data showing lower choke effects. However, it should be noted that challenges with re-conditioning, including varying stock inclusions, differences in assessments, and the manner in which the historical advice was used, affected the accuracy of the results. To accurately assess the effects of the parameters on model performance a more complex approach is advisable.

Stock interactions

Technical interactions, the interactions between fishing activities and fish stocks (spatial and temporal), are another crucial component in mixed-fisheries modelling. Current explanations of stock interactions in ICES ecoregions are provided in advice sheets, advice report sections, and Fisheries Overviews within ICES ecoregions where advice is produced annually. However, there is room for improvement in these descriptions, particularly in terms of finer spatial and temporal detail. An analysis of stock interactions at the ICES rectangle level and fishing trip level was executed and methodologies for exploring and analysing stock interactions in mixed fisheries are introduced, with code available for its application for future projects.

The analysis of mixed-fisheries interactions has shown their intricate and diverse nature from both technical and stock interactions, with diverse interactions between species

and stocks within local areas, trips, and across spatial and temporal scales. Technical interactions, and the measures used to alleviate pressures on stocks (such as gear changes or spatial and temporal closures) tend to occur at a finer scale than the fleet, métier and stock levels used within the models to provide mixed-fishery scenarios. Access to higher resolution data would likely provide better insight into the realised fishing patterns, and would reduce the impact of potential artificial technical interaction. Visualisations have been created to identify important stocks, their connections to fishing practices, and potential risks to these stocks. However, data limitations, particularly the exclusion of less commercially valuable species, present challenges in fully comprehending these interactions. Striking a balance between detailed modelling, computational capacity and interpretative issues was identified as a crucial element in mixed-fishery modelling. Ongoing research therefore aims to find alternative methods for quantifying these technical interactions, and efforts are made to address zero TAC stocks and vulnerable species within the models. These endeavours underscore the need for continual improvement in this field. Outstanding still is the question about the extent that higher resolution data will improve the output of the mixed fisheries scenarios. The robustness of model catch predictions and the sensitivity of these predictions can vary significantly depending on the specific cases. For instance, while some fleets and métiers may be well-represented in current models, others could benefit from more analysis at higher levels of disaggregation.

Framework development

The development of conceptual frameworks was explored to consider how they could be used to extend existing mixed-fishery models. Four frameworks have been put forward: 'scenario evaluation', 'rebuilding stock', 'incorporating additional stocks' and 'developing new areas'.

'Scenario evaluation' incorporates gear and technical measures (such as gear changes) and spatial closures into mixed-fisheries assessments, and aims to account for the downstream impacts of these measures on catch composition, fishing pressure, stock dynamics, fishery viability and markets.

The framework identifies the data, methodologies and steps necessary to account for the impact of gear-based and spatial technical measures within ICES mixed-fishery forecast projections. It outlines how management scenarios involving technical measures or spatial closures can be evaluated using existing modelling frameworks, such as FLBEIA (currently used by ICES) and DISPLACE, a spatial model of fisheries to help sustainable fishing and maritime spatial planning not currently used by ICES.

The implementation of management scenarios for gear selectivity and spatial closures requires distinct approaches. Assessing the impact of gear changes involves considering changes in catchability, which may require data from gear trial studies or expert knowledge. Challenges arise when matching gear trial results to mixed-fisheries models, especially regarding size/age structure and species representation. Gear changes can also influence fishing effort allocation, requiring dynamic modelling of fleet behaviour.

With respect to management scenarios that are based on spatial closures, it is important to be aware that mixed-fisheries models that used to provide mixed fishery considerations are not spatially explicit. Spatial effects can, however, be indirectly examined by defining métiers representing distinct spatial areas. The challenge here is that disaggregating métiers into discrete spatial units may be computationally expensive and limited by data availability. Another aspect is that fleet dynamics models are needed to predict how fishing effort would be reallocated in response to spatial closures or changes in stock distribution. The uncertainty in spatial management scenarios needs to be addressed; this can be done through management strategy evaluation (MSE).

It was also concluded that improved alignment of biological and economic information is essential for assessing downstream impacts; that long-term investment in research and development is necessary to maintain progress; and that stakeholder engagement, including feedback processes, is crucial for meaningful scenario development.

'Rebuilding stock', associated with lengthening the forecast projection period, is a framework for incorporating stock rebuilding dynamics into mixed-fisheries models, to allow for the rebuilding of stocks in the long term. Traditional mixed-fisheries considerations forecasts rely on short-term projections and static assumptions (such as effort distribution between fleets), which are suitable for immediate planning but not adequate for evaluating the long-term sustainability of fisheries management. Therefore, introducing dynamism and uncertainty is essential, which can be incorporated within both the FLBEIA model and the Fcube model.

Three main components play a crucial role in this framework: stocks, fleets and catch advice. The framework states that stocks need to be conditioned dynamically rather than statically, and that biological operating models need to account for changes in recruitment dynamics, biological parameters and stock assessment models. Regarding fleet dynamics, catchability, effort proportions and landing shares should also be subjected to dynamic approaches. These include profit maximisation and random utility models, which can be used to simulate future fleet characteristics. It is noted that capital dynamics, representing entry and exit of fishing units in fleets, is important but challenging to model. Should a management procedure component be incorporated, this would need to include an estimator reflecting stock status and an advice rule to generate catch advice. Uncertainty in biological and fleet parameters, as well as data, also needs to be considered; this should include process, observation, model, estimation, implementation and institutional uncertainty.

Lastly, it is important to consider that in order to assess the performance of stock-rebuilding approaches, performance statistics should ideally focus on fleet-level indicators. However, since there are no specific objectives at fleet level it is not possible to define performance statistics in terms of a target level. However, alternative statistics could include the probability of a stock being a choke stock, implementation error in catches, total yield, and variation in total effort.

'Incorporating additional stocks' is a framework for selecting and adding new stocks to mixed-fisheries case studies. It reviews existing methods for incorporating new stocks into modelling tools such as Fcube and FLBEIA, and highlights data requirements and potential limitations associated with including new stocks.

To address the growing and diverse need of mixed-fisheries considerations, ICES WGMIXIFSH has already developed several additional methodologies/tools to ensure the group is able to include different stocks. The inclusion of new stocks in mixed-fisheries considerations is not static, and should evolve alongside improvements in single-species stock assessments to better capture the dynamics of fish stocks. The process of incorporating new stocks requires continuous development through forums like ICES WGMIXFISH and ongoing communication with stock assessors, model developers and single-species working groups.

Best practice guidelines for including new stocks emphasise several criteria, including commercial importance, degree of mixed-fisheries interaction, and computational manageability. Stocks with surplus production models (ICES category 2) can be included in mixed-fisheries models already, with the possibility of running them within modelling frameworks like Fcube and FLBEIA. Stocks without assessments can be included using a constant CPUE assumption for short-term forecasts, although this is mainly for illustrative purposes. However, when it is desirable to introduce stocks that are beyond defined mixed-fisheries ecoregions, challenges arise. An example is hake in Bay of Biscay, where a significant portion of the catch occurs outside the ecoregion. Efforts are

then necessary to estimate and allocate missing catches from such stocks. These efforts can be made more consistent across cases. Similarly, challenges arise when trying to incorporate stocks that cover multiple case studies. In such instances specific assumptions need to be made about the stock distribution, and the fleet behaviour with respect to it. Models that include stocks that cover multiple eco-region areas (and therefore mixed-fisheries models) are combined to run consistent scenarios across both areas, splitting results out for the mixed-fisheries considerations sheets. Future challenges include integrating ensemble models and dealing with complex situations like the integration of split sub-stocks. Incorporating new stocks is a time-consuming process involving data collection, quality control and model development. It requires ongoing research and development, along with careful review by relevant working groups.

'Developing new areas' seeks to improve the understanding of mixed-fishery interactions in new areas. A development process already exists within ICES to aid the development of new area-based mixed-fishery considerations. There are two primary routes for initiating such developments: formal requests from external bodies (for example, the EU, Norway, UK) or informal interest within ICES. Since the level of region overarches all other levels, these other aspects need to be considered in the process, including: the species to include, the model to use, how to condition the model and determining the relevant scenarios to explore. The most recent example of development of a new area is that of the Irish Sea ecoregion. In the process of its development, and for other regions in the future, it was proposed that a more formal review process was desirable. Therefore, development of new regional mixed-fishery considerations involves an internal benchmark review, a review report and an external peer review. This process ensures the quality and reliability of the models and advice products.

Ongoing model developments are those in the Baltic Sea and the West of Scotland. Challenges for the Baltic Sea are the granularity of available data. For the West of Scotland, the main challenge is resource limitation, more specifically the availability of key expertise. Work on the region has been under development since 2012 but is still considered to be in the initial stages of development. This highlights the need for commitment from experts, stakeholders, and funders for the development of models for new areas.

Conclusions

This work has gone some way to begin addressing the uncertainty and sensitivity of the current ICES mixed-fisheries assessment models. The study uses case studies from across the North Sea, Celtic Sea and Bay of Biscay to identify the need for the inclusion of uncertainty and account for sensitivity within the models used to generate mixed-fisheries considerations. The differences in stocks, fishing behaviour, management and even assessment model in each of the case studies has identified that there is no "one size fits all" mixed-fisheries modelling approach that can account for uncertainty and sensitivity. Examining fleet and métier definitions highlights the need to address overall model structural uncertainty, particularly in terms of fleet dynamics models. Characterising uncertainty in mixed-fisheries models sheds light on the significance of input parameters. Within this, the study encountered, and where possible, overcame challenges in data availability and resolution. This study introduces conceptual frameworks for scenario evaluation, stock rebuilding, adding new stocks and developing models for new areas within mixed-fisheries models which identify a number of areas where additional amendments would be desirable to expand the purpose of the models. In terms of the frameworks, the first question going forward should be 'who is the end user of mixed-fisheries considerations', and the second 'what is it that is needed to support their requirements'. From a fisheries management perspective, the issue can be more associated with identifying where the majority of fishing mortality is occurring and identifying the main sources (fleets), both spatially and temporally. This issue is somewhat different to identifying by which species one or more fleet is chocked.

RÉSUMÉ EXÉCUTIF

La gestion des pêcheries de l'Union européenne (UE) est généralement guidée par des avis portant sur une seule espèce et des totaux admissibles de captures (TAC). Cette approche ne tient souvent pas compte des interactions et des vulnérabilités entre les stocks capturés ensemble, ce qui risque d'entraîner une surexploitation des stocks les plus vulnérables. Cette étude aborde les défis liés aux hypothèses sous-jacentes à l'application de l'approche des modèles d'évaluation des pêcheries mixtes au sein de l'UE.

En tenant compte de ces problèmes, cette étude examine les modèles de pêcheries mixtes qui intègrent les implications de la capture de multiples espèces au sein de multiples pêcheries avec différentes capturabilités et comportements ou objectifs de ciblage. Le concept de « pêcheries mixtes » a été activement développé au sein du Conseil International pour l'Exploration de la Mer (CIEM) depuis plus d'une décennie. Le CIEM fournit des considérations basées sur des scénarios en utilisant des modèles tels que les flottes et le modèle de prévision des pêcheries Fcube, ainsi que l'Évaluation de l'Impact Bio-Économique utilisant la Bibliothèque des Pêcheries dans R (FLR) (FLBEIA). Le CIEM produit des considérations pour la mer du Nord, la première éco-région pour laquelle le CIEM a développé des scénarios de pêcheries mixtes, la mer Celtique, les eaux ibériques, et le golfe de Gascogne. En 2022, le CIEM a étendu ses scénarios de pêcheries mixtes pour inclure la mer d'Irlande.

Cependant, les hypothèses sous-jacentes à ces modèles peuvent conduire à des scénarios de prises qui ne correspondent pas à la réalité, ce qui peut entraîner une sous-utilisation des stocks. L'étude actuelle visait à analyser ces hypothèses et leurs impacts, tout en impliquant une étroite collaboration avec le CIEM.

L'objectif était de fournir à la Commission Européenne (CE) des éclairages sur la fiabilité des scénarios de pêcheries mixtes du CIEM. À travers des études de cas dans la mer du Nord, la mer Celtique et le golfe de Gascogne, cette étude examine les incertitudes et sensibilités, aidant les décisions de politique européenne sur les opportunités de pêche et la protection des stocks.

Disponibilité des données

Les sources de données utilisées pour les analyses ont été recueillies auprès des États membres, du CIEM et du cadre de collecte des données de l'UE (DCF), chacun offrant un niveau de détail variable. Le principal défi était d'obtenir des données reflétant avec précision les activités des flottes à une résolution significative. Les interactions techniques ne peuvent être identifiées qu'au niveau du trait, pour lequel il manque actuellement des données complètes. Le système régional de base de données et d'estimation (RDBES) vise à remédier à cela, en reliant plusieurs sources de données pour assurer la cohérence. Cependant, sa résolution spatiale est limitée. Pour surmonter cette limitation, des ensembles de données spécifiques des États membres sont explorés, tout en respectant la sensibilité des données et les règles de confidentialité nationales.

Sensibilité et incertitude par rapport à la flotte

Dans le contexte de deux études de cas, la mer du Nord et la mer Celtique, les composants fondamentaux des modèles de pêcheries mixtes, à savoir les flottes et les métiers, ont été examinés. Ces composants ont évolué au fil du temps conformément aux directives du DCF, mais il reste une marge d'amélioration. Ces études de cas visaient à évaluer les définitions actuelles de flotte et de métier utilisées, suggérer des améliorations potentielles et évaluer l'impact de différentes agrégations de flottes et de métiers sur les prévisions de capture.

Dans l'étude de cas de la mer du Nord, l'analyse a exploré l'influence de différentes agrégations de flottes et de métiers, telles que les engins utilisés et les espèces ciblées, sur les prévisions de captures projetées. Alors que l'Analyse en Composantes Principales (ACP) a été utilisée pour évaluer l'impact de l'agrégation des données sur les profils de capture (compositions d'espèces similaires), il est apparu que l'ACP seule ne pouvait pas entièrement définir les flottes et les métiers. Des informations supplémentaires concernant la répartition des quotas, les caractéristiques techniques des navires et la capturabilité sont également nécessaires. L'étude a révélé que l'agrégation des données utilisées par le CIEM WGMIXFISH au niveau du pays et de l'engin avait un impact minimal sur la variabilité des données.. Cependant, relier les résultats de l'ACP et de l'analyse de cluster aux définitions de métiers utilisées dans le modèle WGMIXFISH de la mer du Nord a souligné le besoin de définitions plus détaillées dans des combinaisons spécifiques de flottes et de métiers, compte tenu de la variabilité de la composition des débarquements présente dans les strates d'entrée de ces métiers. Toutefois, tant que la distribution de l'effort de pêche est statique dans le modèle, la désagrégation des flottes en un plus grand nombre de métiers n'affecterait pas les prévisions projetées. Dans une distribution statique de l'effort de pêche, seule la création de flottes supplémentaires entraînerait une variation des prévisions.

De plus, l'étude a souligné l'importance de s'attaquer à l'incertitude structurelle des modèles, en particulier les modèles de dynamique des flottes (qui dictent l'utilisation de l'effort à travers les métiers en supposant des modèles comportementaux spécifiques). Il a été constaté que le choix du modèle de dynamique des flottes avait un effet plus prononcé sur les résultats que les définitions de flotte et de métier seules. Un modèle alternatif de dynamique des flottes a été exploré, offrant une plus grande flexibilité dans les proportions d'effort à travers les métiers, ce qui a conduit à une meilleure utilisation des quotas mais aussi à une diminution de la capture par unité d'effort (CPUE) en raison d'un accent sur les métiers avec de faibles capturabilités. L'adoption de contraintes d'effort historiques a résulté en des modèles comportementaux plus réalistes.

L'étude de cas de la mer Celtique s'est concentrée sur la définition des flottes et des métiers en utilisant des données hautement spatialement désagrégées. Cette approche visait à fournir une représentation plus précise de la dynamique de la pêche. Un exemple illustratif impliquait l'examen des interactions de la morue au sein de la flotte irlandaise de *Nephrops*. En exploitant des données issues de rapports de pêcheurs et d'outils spécialisés, l'étude a identifié des interactions entre espèces et évalué leur importance. Même au niveau du voyage et du rectangle ICES, les interactions entre *Nephrops* et morue ne pouvaient pas être dissociées dans une zone connue pour sa faible présence de morue (La Banc de Porcupine). L'aperçu clé ici était que l'acquisition de données plus spatialement désagrégées et de haute résolution est cruciale pour l'identification et la délimitation précises des flottes. Cela pourrait potentiellement changer notre perception des interactions techniques entre flottes et stocks, et pourrait se traduire par moins d'opportunités perdues en raison de l'élimination des motifs de « choke » artificiels (le « choke » étant, le résultat d'un stock à quota inférieur atteignant sa limite, empêchant la poursuite de la pêche pour des stocks à quota supérieur).

De plus, l'étude a introduit des simulations de Monte Carlo, qui ont échantillonné de manière stochastique les valeurs des paramètres d'entrée à partir de données historiques. Ces simulations ont montré que l'incertitude des paramètres affectait de manière significative les résultats du modèle. Des variations dans les captures prévisionnelles ont été observées sous différents scénarios d'effort, soulignant la nécessité que davantage de résultats de prévision des pêcheries mixtes soient accompagnés d'estimations robustes de la confiance pour assurer que les limitations des prévisions soient clairement communiquées, et que les domaines nécessitant une amélioration puissent être facilement identifiés, c'est-à-dire le niveau d'agrégation des données.

Les incertitudes dans les données d'entrée, telles que la conditionnalité de la capturabilité (le processus par lequel les valeurs de capturabilité pour les années futures sont choisies sur la base de certaines hypothèses des valeurs passées), peuvent être liées à des problèmes de qualité des données ou à des changements dans le comportement de la flotte, qui pourraient également être influencés par des différences spatiales dans la composition des captures. Le jeu de données actuel du CIEM pour la mer Celtique ne permet pas d'identifier de manière exhaustive de tels mécanismes. Il est donc impératif que ces questions en suspens soient évaluées sur une base nuancée, cas par cas. Ces limitations posées par le manque de données à haute résolution sont reconnues et soulignent l'importance de traiter ces questions dans les recherches et analyses futures.

Sensibilité et Incertitude par Rapport aux Prévisions

Dans le cadre de deux études de cas, la mer du Nord et le golfe de Gascogne, l'incertitude des modèles de pêche mixte a été caractérisée en se concentrant sur l'impact du conditionnement des prévisions. L'objectif était de comprendre comment les incertitudes des données historiques et des paramètres d'entrée affectent les projections du modèle. Les incertitudes des paramètres dans les prévisions ont été examinées et l'incertitude des résultats a été quantifiée pour permettre l'identification des paramètres les plus influents.

Les modèles de pêcheries mixtes impliquent de nombreux paramètres d'entrée, y compris la capturabilité, la distribution des efforts et les allocations de quotas. Ces modèles dépendent de données historiques, qui peuvent être sujettes à erreur, pour le conditionnement des paramètres. L'analyse de sensibilité est cruciale pour comprendre la relation entre les incertitudes des entrées et les variations des sorties. L'analyse de sensibilité globale (ASG) caractérise efficacement cette relation mais peut être exigeante en termes de calculs. Dans l'étude de cas du Golfe de Gascogne, l'ASG a été mise en œuvre pour évaluer la sensibilité de la capturabilité, de la part des quotas et de la proportion des efforts. Pour l'étude de cas de la Mer du Nord, une approche moins intensive en calcul a été adoptée, conduisant des analyses d'incertitude séparées pour la capturabilité, les proportions des débarquements et la proportion d'effort.

L'étude de cas du Golfe de Gascogne s'est concentrée sur la réalisation d'une analyse d'incertitude et d'une ASG pour les pêcheries démersales mixtes de la région, avec un accent particulier sur les flottes françaises et espagnoles. La capturabilité a été conditionnée en fonction des interactions interspécifiques au sein de chaque métier, en considérant des effets unidimensionnels par année et par stock. L'incertitude dans la proportion des efforts et des débarquements a été introduite à l'aide d'une distribution de Dirichlet (une distribution de probabilité multivariée). L'analyse ASG a ensuite caractérisé la variance de sortie en fonction des variances des facteurs d'entrée (la capturabilité a été séparée en sélectivité et intensité), y compris la considération des interactions entre les facteurs d'entrée. Trois scénarios dynamiques de flotte (effort moyen, captures maximisées, captures minimisées) ont été examinés, chacun avec des facteurs distincts affectant les résultats. Dans le scénario maximisant les captures, l'effort global dépendait principalement de l'intensité de la flotte à travers différents métiers, et l'interaction entre les facteurs d'entrée jouait un rôle significatif dans l'explication de la variance. Dans le scénario le plus restrictif (captures minimisées), l'intensité dans le métier le plus critique avait le plus grand impact, avec la part des quotas affectant la variance de sortie pour la plupart des stocks (à l'exception du chinchard). La probabilité qu'un stock devienne un point de « choke » pour l'effort de pêche a été particulièrement influencée par la répartition des quotas, bien qu'il ne s'agisse pas d'un facteur déterminant.

Pour l'étude de cas de la mer du Nord, en termes d'écart par rapport aux valeurs observées, les hypothèses actuelles, qui fixent des valeurs égales aux dernières données disponibles, fournissent généralement des prévisions non biaisées. Trois hypothèses

alternatives ont été testées, mais l'hypothèse actuelle a souvent été plus performante que les autres en raison d'un niveau d'incertitude plus faible. Les tests de sensibilité ont ensuite comparé les séries utilisant l'hypothèse actuelle avec les séries utilisant les valeurs réelles observées. Les hypothèses relatives à la capturabilité et à la proportion de l'effort ont eu un impact limité sur les stocks à quotas limitants (« choke ») et les stocks les moins limités (plus abondants), ce qui montre que les hypothèses actuelles donnent généralement de bons résultats pour ces paramètres. Les hypothèses relatives à la proportion de débarquement ont eu un impact significatif sur les effets de « choke », les données réelles montrant des effets de « choke » plus faibles. Il convient toutefois de noter que les difficultés liées au reconditionnement, notamment les différentes inclusions de stocks, les différences d'évaluation et la manière dont les avis historiques ont été utilisés, ont eu une incidence sur la précision des résultats. Pour évaluer avec précision les effets des paramètres sur les performances du modèle, il est conseillé d'adopter une approche plus complexe.

Interactions entre les stocks

Les interactions techniques, c'est-à-dire les interactions entre les activités de pêche et les stocks de poissons (spatiales et temporelles), constituent un autre composant crucial dans la modélisation des pêcheries mixtes. Les explications actuelles des interactions de stock dans les écorégions de l'ICES sont fournies dans des fiches de conseils, des sections de rapports de conseils et des Aperçus des Pêcheries au sein des écorégions de l'ICES où des conseils sont produits annuellement. Cependant, ces descriptions peuvent être améliorées, en particulier en termes de détails spatiaux et temporels plus fins. Une analyse des interactions de stock au niveau des rectangles de l'ICES et au niveau des voyages de pêche a été exécutée et des méthodologies pour explorer et analyser les interactions de stock dans les pêcheries mixtes sont introduites, avec un code disponible pour son application dans des projets futurs.

L'analyse des interactions entre les pêcheries mixtes a montré la complexité et la diversité des interactions techniques et des interactions entre les stocks, ainsi que la diversité des interactions entre les espèces et les stocks au sein des zones locales, des sorties et à travers les échelles spatiales et temporelles. Les interactions techniques et les mesures utilisées pour atténuer les pressions sur les stocks (telles que les changements d'engins ou les fermetures spatiales et temporelles) ont tendance à se produire à une échelle plus fine que les niveaux de flotte, de métier et de stock utilisés dans les modèles pour fournir des scénarios de pêche mixte. L'accès à des données à plus haute résolution permettrait probablement de mieux comprendre les schémas de pêche réalisés et réduirait l'impact d'une éventuelle interaction technique artificielle. Des visualisations ont été créées pour identifier les stocks importants, leurs liens avec les pratiques de pêche et les risques potentiels pour ces stocks. Toutefois, les limites des données, en particulier l'exclusion des espèces de moindre valeur commerciale, posent des problèmes pour comprendre pleinement ces interactions. La recherche d'un équilibre entre la modélisation détaillée, la capacité de calcul et les questions d'interprétation a été identifiée comme un élément crucial de la modélisation des pêcheries mixtes. Les recherches en cours visent donc à trouver des méthodes alternatives pour quantifier ces interactions techniques, et des efforts sont faits pour prendre en compte les stocks à TAC zéro et les espèces vulnérables dans les modèles. Ces efforts soulignent la nécessité d'une amélioration continue dans ce domaine. La question de savoir dans quelle mesure des données de plus haute résolution amélioreraient le résultat des scénarios de pêcheries mixtes reste en suspens. La robustesse des prédictions de capture des modèles et la sensibilité de ces prédictions peuvent varier considérablement en fonction des cas spécifiques. Par exemple, alors que certaines flottes et métiers peuvent être bien représentés dans les modèles actuels, d'autres pourraient bénéficier de plus d'analyses à des niveaux de désagrégation plus élevés.

Développement de Cadres Conceptuels

Le développement de cadres conceptuels a été exploré pour examiner comment ils pourraient être utilisés pour étendre les modèles existants de pêcheries mixtes. Quatre cadres ont été proposés : « évaluation de scénarios », « reconstruction des stocks », « incorporation de stocks supplémentaires » et « développement de nouvelles zones ».

L'évaluation de scénarios intègre des mesures techniques et relatives aux engins de pêche (telles que des changements d'engins) et des fermetures spatiales dans les évaluations des pêcheries mixtes, et vise à tenir compte des effets en aval de ces mesures sur la composition des captures, la pression de pêche, la dynamique des stocks, la viabilité de la pêche et les marchés.

Le cadre identifie les données, les méthodologies et les étapes nécessaires pour tenir compte de l'impact des mesures techniques basées sur les engins et les fermetures spatiales dans les projections prévisionnelles des pêcheries mixtes du CIEM. Il décrit comment les scénarios de gestion impliquant des mesures techniques ou des fermetures spatiales peuvent être évalués à l'aide des cadres de modélisation existants, tels que FLBEIA (actuellement utilisé par le CIEM) et DISPLACE, un modèle spatial des pêcheries destiné à favoriser la pêche durable et la planification de l'espace maritime, qui n'est pas actuellement utilisé par le CIEM.

La mise en œuvre de scénarios de gestion pour la sélectivité des engins et les fermetures spatiales nécessite des approches distinctes. Évaluer l'impact des changements d'engins implique de considérer les changements de capturabilité, ce qui peut nécessiter des données issues d'études d'essais d'engins ou de connaissances d'experts. Des défis se présentent lors de l'alignement des résultats des essais d'engins avec les modèles de pêcheries mixtes, en particulier concernant la structure en taille/âge et la représentation des espèces. Les changements d'engins peuvent également influencer l'allocation de l'effort de pêche, nécessitant une modélisation dynamique du comportement de la flotte.

En ce qui concerne les scénarios de gestion basés sur des fermetures spatiales, il est important de savoir que les modèles de pêcheries mixtes utilisés pour fournir des considérations de pêche mixte ne sont pas spatialement explicites. Cependant, les effets spatiaux peuvent être examinés indirectement en définissant des métiers représentant des zones spatiales distinctes. Le défi ici est que la désagrégation des métiers en unités spatiales discrètes peut être coûteuse sur le plan informatique et limitée par la disponibilité des données. Un autre aspect est que des modèles de dynamique de flotte sont nécessaires pour prédire comment l'effort de pêche serait réaffecté en réponse aux fermetures spatiales ou aux changements dans la distribution des stocks. L'incertitude dans les scénarios de gestion spatiale doit être abordée ; cela peut être fait par l'évaluation de stratégie de gestion (MSE).

Il a également été conclu qu'un alignement amélioré des informations biologiques et économiques est essentiel pour évaluer les impacts en aval ; qu'un investissement à long terme dans la recherche et le développement est nécessaire pour maintenir le progrès ; et que l'engagement des parties prenantes, y compris les processus de rétroaction, est crucial pour un développement significatif de scénarios.

La 'Reconstruction des Stocks', associée à l'allongement de la période de projection des prévisions, est un cadre permettant d'intégrer la dynamique de reconstitution des stocks dans les modèles de pêche mixte, afin de permettre la reconstitution des stocks à long terme. Les prévisions traditionnelles des pêcheries mixtes reposent sur des projections à court terme et des hypothèses statiques (telles que la répartition de l'effort entre les flottes), qui conviennent à la planification immédiate mais ne permettent pas d'évaluer la durabilité à long terme de la gestion des pêcheries. Il est donc essentiel d'introduire du dynamisme et de l'incertitude, qui peuvent être incorporés dans les modèles FLBEIA et Fcube.

Trois éléments principaux jouent un rôle crucial dans ce cadre : les stocks, les flottes et les avis de capture. Le cadre stipule que les stocks doivent être conditionnés de manière dynamique plutôt que statique et que les modèles d'exploitation biologique doivent tenir compte des changements dans la dynamique du recrutement, les paramètres biologiques et les modèles d'évaluation des stocks. En ce qui concerne la dynamique de la flotte, la capturabilité, les proportions d'effort et les parts de débarquement doivent également être soumises à des approches dynamiques. Il s'agit notamment des modèles de maximisation du profit et d'utilité aléatoire, qui peuvent être utilisés pour simuler les caractéristiques futures de la flotte. Il convient de noter que la dynamique du capital, qui représente l'entrée et la sortie d'unités de pêche dans les flottes, est importante mais difficile à modéliser. L'inclusion d'une procédure de gestion est également recommandée ; elle devrait inclure un estimateur reflétant l'état du stock et une règle d'avis pour générer un avis sur les captures. Si l'inclusion d'un composant de procédure de gestion doit être incorporée, cela devrait inclure un estimateur reflétant l'état du stock et une règle de conseil pour générer des conseils de capture. L'incertitude des paramètres biologiques et de la flotte, ainsi que des données, doit également être prise en compte ; il s'agit notamment de l'incertitude des processus, des observations, des modèles, des estimations, de la mise en œuvre et de l'incertitude institutionnelle.

Enfin, il est important de considérer que, pour évaluer la performance des approches de reconstruction des stocks, les statistiques de performance devraient idéalement se concentrer sur les indicateurs au niveau de la flotte. Cependant, puisqu'il n'y a pas d'objectifs spécifiques au niveau de la flotte, il n'est pas possible de définir des statistiques de performance en termes de niveau cible. Toutefois, des statistiques alternatives pourraient inclure la probabilité qu'un stock soit un stock à quota limitant «choke species», l'erreur de mise en œuvre dans les captures, le rendement total et la variation de l'effort total.

L'incorporation de stocks supplémentaires est un cadre pour la sélection et l'ajout de nouveaux stocks aux études de cas sur les pêcheries mixtes. Il passe en revue les méthodes existantes pour incorporer de nouveaux stocks dans des outils de modélisation tels que Fcube et FLBEIA, et met en lumière les exigences en matière de données et les limitations potentielles associées à l'inclusion de nouveaux stocks.

Pour répondre aux besoins croissants et diversifiés des considérations sur les pêcheries mixtes, le groupe ICES WGMIXIFSH a déjà développé plusieurs méthodologies et outils supplémentaires pour garantir que le groupe soit capable d'inclure différents stocks. L'inclusion de nouveaux stocks dans les considérations sur les pêcheries mixtes n'est pas statique, et devrait évoluer parallèlement aux améliorations des évaluations de stocks d'une seule espèce pour mieux saisir la dynamique des stocks de poissons. Le processus d'incorporation de nouveaux stocks nécessite un développement continu à travers des forums tels que ICES WGMIXFISH et une communication continue avec les évaluateurs de stocks, les développeurs de modèles et les groupes de travail sur mono-espèces.

Les directives de meilleures pratiques pour inclure de nouveaux stocks soulignent plusieurs critères, y compris l'importance commerciale, le degré d'interaction dans les pêcheries mixtes, et la gestion informatique. Les stocks avec des modèles de production excédentaire (catégorie 2 de l'ICES) peuvent déjà être inclus dans les modèles de pêcheries mixtes, avec la possibilité de les faire fonctionner dans des cadres de modélisation tels que Fcube et FLBEIA. Les stocks sans évaluations peuvent être inclus en utilisant une hypothèse constante de CPUE pour les prévisions à court terme, bien que cela soit principalement à des fins illustratives. Cependant, lorsque l'on souhaite introduire des stocks qui vont au-delà des écorégions définies pour les pêcheries mixtes, des défis se posent. Un exemple est le merlu dans le golfe de Gascogne, où une portion significative des prises se produit en dehors de l'écorégion. Des efforts sont alors nécessaires pour estimer et allouer les prises manquantes de tels stocks. Ces efforts peuvent être rendus plus cohérents à travers les cas. De même, des défis surgissent

lorsqu'il s'agit d'incorporer des stocks qui couvrent plusieurs études de cas. Dans de tels cas, des hypothèses spécifiques doivent être faites concernant la distribution des stocks, et le comportement de la flotte par rapport à ceux-ci. Les modèles qui incluent des stocks couvrant plusieurs zones d'écorégion (et donc des modèles de pêcheries mixtes) sont combinés pour exécuter des scénarios cohérents à travers les deux zones, en séparant les résultats pour les feuilles de considérations sur les pêcheries mixtes.

Les défis futurs incluent l'intégration de modèles d'ensemble et la gestion de situations complexes telles que l'intégration de sous-stocks divisés. L'incorporation de nouveaux stocks est un processus long qui implique la collecte de données, le contrôle de la qualité et le développement de modèles. Cela nécessite une recherche et un développement continus, ainsi qu'une révision attentive par les groupes de travail pertinents

Le 'développement de nouvelles zones' vise à améliorer la compréhension des interactions dans les pêcheries mixtes dans de nouvelles zones. Un processus de développement existe déjà au sein de l'ICES pour aider au développement de considérations sur les pêcheries mixtes basées sur des zones. Il existe deux voies principales pour initier de tels développements : des demandes formelles de la part d'organismes externes (par exemple, l'UE, la Norvège, le Royaume-Uni) ou un intérêt informel généré au sein de l'ICES. Étant donné que le niveau régional surplombe tous les autres niveaux, ces autres aspects doivent être pris en compte dans le processus, y compris : les espèces à inclure, le modèle à utiliser, comment conditionner le modèle et déterminer les scénarios pertinents à explorer. L'exemple le plus récent du développement d'une nouvelle zone est celui de l'écorégion de la mer d'Irlande. Dans le processus de son développement, et pour d'autres régions à l'avenir, il a été proposé qu'un processus d'examen plus formel soit souhaitable. Ainsi, le développement de nouvelles considérations sur les pêcheries mixtes régionales implique un examen interne de référence, un rapport de révision et un examen par des pairs externes. Ce processus garantit la qualité et la fiabilité des modèles et des produits de conseil.

Les développements de modèles en cours concernent la mer Baltique et l'ouest de l'Écosse. Les défis pour la mer Baltique résident dans la granularité des données disponibles. Pour l'ouest de l'Écosse, le principal défi est la limitation des ressources, plus spécifiquement la disponibilité de compétences clés. Le travail sur la région est en développement depuis 2012 mais est toujours considéré comme en phase initiale de développement. Cela souligne le besoin d'engagement de la part des experts, des parties prenantes et des bailleurs de fonds pour le développement de modèles pour de nouvelles zones.

Conclusions

Ce travail a contribué à aborder l'incertitude et la sensibilité des modèles actuels d'évaluation des pêcheries mixtes de l'ICES. L'étude utilise des études de cas à travers la mer du Nord, la mer Celtique et le golfe de Gascogne pour identifier le besoin d'inclure l'incertitude et de tenir compte de la sensibilité au sein des modèles utilisés pour générer des considérations sur les pêcheries mixtes. Les différences en termes de stocks, de comportement de pêche, de gestion et même de modèle d'évaluation dans chacune des études de cas ont identifié qu'il n'existe pas d'approche de modélisation des pêcheries mixtes "taille unique" pouvant tenir compte de l'incertitude et de la sensibilité. L'examen des définitions des flottes et des métiers souligne la nécessité de traiter l'incertitude structurelle globale du modèle, en particulier en termes de modèles de dynamique des flottes. Caractériser l'incertitude dans les modèles de pêcheries mixtes met en lumière l'importance des paramètres d'entrée. Dans ce cadre, l'étude a rencontré, et dans la mesure du possible, surmonté les défis liés à la disponibilité et à la résolution des données. Cette étude introduit des cadres conceptuels pour l'évaluation des scénarios, la reconstruction des stocks, l'ajout de nouveaux stocks et le développement de modèles pour de nouvelles zones au sein des modèles de pêcheries mixtes, identifiant un certain nombre de domaines où des modifications supplémentaires seraient souhaitables pour

étendre l'objectif des modèles. En termes de cadres, la première question à l'avenir devrait être "qui est l'utilisateur final des considérations sur les pêcheries mixtes", et la seconde "de quoi a-t-il besoin pour soutenir leurs exigences". Du point de vue de la gestion des pêches, la question peut être davantage associée à l'identification de l'endroit où se produit la majorité de la mortalité due à la pêche et à l'identification des sources principales (flottes), à la fois spatialement et temporellement. Cette question est quelque peu différente de celle d'identifier par quelle espèce une ou plusieurs flottes sont limitées.

1 INTRODUCTION

1.1 Background

At present, the majority of fishing opportunities for demersal stocks within the European Union (EU) are in the form of TACs (total allowable catches) based on single-species advice. Such advice does not consider the interactions between, or differences in, the variety or vulnerability of stocks that are often caught together. Following single-species advice for more abundant stocks without additional safeguards could result in a risk of overexploitation of the more vulnerable stocks within the same area.

The concept of 'mixed fisheries', and the need to consider the implications of capturing multiple species within multiple fisheries with different catchabilities and targeting behaviour or objectives is not new (e.g. Ulrich et al., 2011; Iriondo et al., 2012). Mixed fisheries is a topic of interest and active development within the International Council for Research of the Sea (ICES). ICES has been developing and providing scenario-based mixed-fisheries considerations for more than 10 years, supported by two dedicated ICES working groups (WGMIXFISH-ADVICE; WGMIXFISH-METHODS). In 2022, ICES presented mixed-fisheries scenarios for many of the ICES eco-regions focused on a number of demersal species¹, at which time the Irish Sea was added following a period of development and validation (ICES, 2022a).

The methods used in ICES to provide scenarios on mixed-fisheries considerations, are fleets and fisheries forecast model Fcube and Bio-Economic Impact Assessment using Fisheries Library in R (FLR) (FLBEIA). Both methods are based on FLR libraries (Kell et al., 2007). Fcube (Ulrich et al., 2011) was the first model used to provide scenarios and was specifically developed for this purpose. Fcube is currently only used in the assessment of mixed-fishery considerations within the Celtic Sea. FLBEIA (Bio-Economic Impact Assessment using FLR, Garcia et al., 2017) goes beyond mixed-fisheries and was developed to facilitate the bio-economic evaluation of management strategies under the management strategy evaluation (MSE) approach. FLBEIA is used to assess mixed fisheries within the majority of the ICES mixed-fishery ecoregions. The versatility of FLBEIA makes it the current preferred model for future mixed-fishery assessment developments. The models used within each ecoregion have a number of underlying assumptions that feed into the development of the predictions underpinning the mixed-fisheries scenarios presented.

During the 2021 annual EU-UK consultations² it was agreed there is a need for further analysis of the assumptions used to produce mixed-fisheries considerations to aid understanding of the uncertainty around, and impacts of, these assumptions. These assumptions could lead to situations where mixed-fisheries scenarios indicate the need for lesser or greater reductions in fishing opportunities than required in reality, leading to stock under-utilisation, and risk undermining the utility of mixed-fisheries scenarios in setting TACs.

Many of the issues and work within this study are also under consideration within ICES. As such, this study has been closely linked to the ICES advisory process, and the ICES groups developing mixed-fishery considerations, with a number of the study partners active within the ICES MIXFISH working groups.

¹ <https://www.ices.dk/advice/Fisheries-overviews/Pages/fisheries-overviews.aspx>

² Written record of fisheries consultations between the United Kingdom and the EU for 2021; paragraph 5(f)(v)

1.2 Objectives

The overall objective of this study is to provide the European Commission (EC) with insights into the robustness of mixed-fisheries scenario assumptions currently made within the ICES advisory process. This study has examined:

- a. assumptions that could result in false technical interactions by missing spatial and/or temporal aggregations by examining the sensitivity of models to input aggregations;
- b. assumptions associated with the adaptability of those exploiting the stocks through analysis of the sensitivity and uncertainty of model settings (such as constant effort proportions within a fleet);
- c. whether there are any inputs that should be included but are currently not considered (in terms of vulnerabilities or technical measures);
- d. how the outcomes of scenarios could change if an important stock (due to fishing or vulnerability) is not included in the mixed-fishery model; and
- e. the perception of scenarios over the longer term, with current provisions focusing solely on the following year.

Each of these assumptions and sensitivities have been explored within this study, and the outcomes are presented in the following sections of this report. Consideration of these outcomes could be used to support European policy decisions aimed at maximising fishing opportunities whilst ensuring protection of vulnerable stocks.

1.3 Scope of the study

The study has focused on providing case studies from three ICES mixed-fishery considerations areas – the North Sea, the Celtic Sea and Bay of Biscay – to demonstrate the impact of uncertainties and sensitivities on the interpretation of mixed-fisheries considerations. There are a number of differences between these three regions, making their examination within this study worthwhile. The most relevant difference is the type of modelling method and level of model development within projections for the mixed fishery. Modelling for the North Sea and Bay of Biscay is completed in FLBEIA, while Fcube is used for the Celtic Sea. In addition, the fleets fishing, stocks present, and stock assessment methods used within the three regions vary, providing a greater opportunity to explore various aggregation and assumption scenarios.

1.4 Structure of the report

Section 2 presents the 'data availability'. The results and outputs of the 'sensitivity to fleet' selection is provided in section 3, including case studies for the North Sea (3.1) and the Celtic Sea (3.2). Section 4 then presents results and outputs of the 'sensitivity to forecast', with separate case studies presented for the North Sea (4.1) and the Bay of Biscay (4.2). Section 5 considers 'stock interactions', including Interactions at the ICES rectangle level (5.1) and Interactions at the trip and haul level (5.2) and 'additional factors' (5.3). Section 6 looks at how the mixed-fishery models could be extended from their current format through development of conceptual frameworks. More specifically, a 'framework scenario evaluation' (6.1), a framework for 'stock rebuilding' (6.2), a framework for 'new stocks' (6.3), and lastly a framework developing 'new areas' (6.4).

Finally, sections 7 and 8 draw all the outputs together to provide a set of final conclusions and considerations for further development, respectively.

2 DATA AVAILABILITY

Data used within this study come from three main sources: EU Member States; ICES; and the EU Data Collection Framework (DCF), each source providing a tool by which to describe fishing activity at varying levels of resolution. All sources are described in ANNEX 1, in terms of accessibility, coverage and limitations. During the ICES second workshop on fisheries overviews (ICES WKFO2) a member of this consortium was able to access all available data sets to assess quality and consistency and a full summary of the data quality and consistency is available in the workshop report (ICES, 2023a). A summary of the data used within the study is given in Table 1.

The greatest challenge with any mixed-fisheries analysis is the acquisition of data at an appropriate resolution to accurately represent the fleet. Therefore, the remaining part of this section will focus on data available to achieve this. The appropriateness of the resolution is considered to be the level at which differences in catch composition created from the technical and biological interactions between fleets, gears and species can be detected (Ulrich and Andersen, 2004). Modelled technical interactions must account for the complex nature of fisheries, at a resolution that is meaningful to the end users/managers. This requires suitable fleet and métier definitions, identification and treatment of target / bycatch stocks and incorporation of gear-based selectivity, while accounting for fisheries dynamics (seasonality, closures, fisher decisions). These definitions also need to be meaningful and applicable to economic and social outcomes.

The true technical interactions can only be detected at the individual haul level, and there is currently no regulatory requirement, data-collection programme, or database that is able to provide a complete overview of such information in the EU. However, the current development of the Regional Database and Estimation System (RDBES) will provide the most comprehensive overview of fleet data, sampling information (at sea and biological), along with associated variables. It will also provide links to data collected by the EU for the Scientific Technical and Economic Committee for Fisheries (STECF) Fishery Dependent Information (FDI) and Annual Economic Report (AER) (i.e. fishing technique)³. In the near future the RDBES will provide a single platform from which highly disaggregated sampling data from ICES member nations can be extracted for use in single-species stock assessments, in mixed-fishery assessments, and to tie in with FDI data. Use of a single platform will provide better consistency and transparency across data sources. This consistency is key for any mixed-fisheries model where merging multiple data sources can lead to potential errors, gaps and bias in the data. The governance group for the RDBES development (WGRDBESGOV) anticipates that the new system will be under development until 2024, and operational for single-species advice by 2025. An important prerequisite for phasing out of the Regional Database (RDB; which was originally designed for the review of fisheries-sampling plans) and InterCatch⁴ is to demonstrate that the design of RDBES is able to provide sufficient support for current estimation protocols. An overview of how the RDBES data aligns with currently used fleet data (landings and effort) can be found in the ICES WKFO2 report (ICES, 2023a).

In addition to the technical interactions, the spatial resolution available in the RDBES is limited to ICES statistical rectangle, which may not capture more fine scale targeting behaviour. For this reason, a number of bespoke data sets provided by individual Member States are explored in section 3, including the sensitivity to fleet aggregation (3.2.1). These highly disaggregated data sets are built with the data collected by vessel monitoring systems (VMS). Given the highly sensitive nature of these data sets it is not possible to share the raw data, so a framework has been developed to analyse and share the data at a resolution that does affect national confidentiality rules.

³ https://dcf.ec.europa.eu/data-calls/aer_en#definitions

⁴ Web-based system to which national institutes from the Northeast Atlantic can upload national fish catches

Table 1: Summary of data used in this study.

Type	Sources	Accessibility	Year coverage	Limit of spatial resolution	Details
Single-species information	Advice sheet (Landings + discards)	Open to all	Varies per stock. Start of assessment time series until 2021	Stock level	Estimated total landing and discards (where available) per year can be taken from the ICES advice sheet. This data source is used as the baseline when comparing other data sources in this exercise. The ICES single-species advice sheets are considered the standard quality-controlled values as they are reviewed by data submitters, stock coordinators, single-species working groups, and advice-drafting groups. All other data sources will be compared to this to describe overall trends and typically account for adjustments such as misreports.
	Stock information	Restricted to WG * members or via special request to ICES	Varies per stock. Start of assessment time series until 2021	Stock level	This comes in the form of an FLStock object *, which contains the inputs and outputs of the single-species stock assessments and forecasts (WGBIE, WGCSE, WGNSSK *) in terms of fishing mortality pressure (F), spawning stock biomass (SSB) and catch (tonnes).
	Age and length structure	Restricted to WG members or via special request to ICES	Varies per stock. Grouping based on sampling design, data availability and model needs	Groups ICES divisions	This raised sample data is extracted from the ICES InterCatch *database and represents the best-available description of the age and length structure of the stocks and gears in question.

Study to assess the robustness of mixed-fisheries scenario assumptions

Type	Sources	Accessibility	Year coverage	Limit of spatial resolution	Details
Fleet	WGMIXFISH * fleet data (landings and effort)	Restricted to WG members or via special request to ICES	2009–2021	ICES Division	Age information (InterCatch), in combined with landings and effort information at the level of métier by WGMIXFISH to produce fleet objects, describing the general patterns of fisher behaviour at a very aggregated level. Landings and effort data are provided by year, quarter, country, ICES division, métier/gear and vessel length. However, not all species are available because the landings are aggregated by the species specifically requested in the annual ICES fisheries data call, all other species are aggregated under an 'OTH' species code.
	FDI (landings, discards and effort)	Restricted to expert working group / STECF members or via request to DCF and each Member State	2013–2021	ICES division and ICES statistical rectangle	Data supplied by DCF, submitted by EU Member States during and analysed during the STECF Expert Working Group on Fisheries Dependent Information (STECF-22-10). Catch, effort and landings tables were supplied to the consortium by the JRC. This data set provides information at the spatial aggregation level of ICES division and statistical rectangle. UK data not available from 2020 onwards. Therefore, a large proportion of the Celtic Seas fishing landings and effort data are missing.

Study to assess the robustness of mixed-fisheries scenario assumptions

Type	Sources	Accessibility	Year coverage	Limit of spatial resolution	Details
	Bespoke scripts	At a raw level accessibility is limited to an individual data owner (i.e. Member State)	Coverage varies based on sampling programmes	Logbook declarations and VMS pings	Several bespoke scripts were developed to facilitate the sharing of sensitive fisheries information at an aggregated level. See section 3 (3.2.1) where scripts were developed to aggregate and share VMS and logbook data required to identify finer technical interactions then were available in the currently used WGMIXFISH data call.
*WG = working group; FL Stock Object = a data object in R that is a representation of a stock assessment and contains the inputs and outputs of the single-species stock assessments and forecasts; WGBIE = Working Group for the Bay of Biscay and the Iberian Waters Ecoregion; WGCSE = Working Group for the Celtic Seas Ecoregion; WGNSSK = Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak; InterCatch = Web-based system, to which national institutes from the North East Atlantic can upload national fish catches; WGMIXFISH = Working Group on Mixed Fisheries.					

3 SENSITIVITY TO FLEET

The basic building blocks of all mixed-fisheries models are the fleet (or fleet segments), and the métier. The definitions of these building blocks have evolved over time and the most recent official definitions are set out in the DCF (Reg. (EC) No 949/2008⁵ and replaced by Commission Decision 2010/93/EU⁶). These definitions, shown below, have been adopted by ICES and have been applied within this study.

- **Fleet segment:** a group of vessels with the same length class and predominant fishing gear during the year. Vessels may have different fishing activities during the reference period but might be classified in only one fleet segment.
- **Métier:** a subset of a fleet consisting of a group of fishing operations targeting a similar (assemblage of) species, using similar gear, during the same period of the year and/or within the same area and characterised by a similar exploitation pattern.

A fleet should describe a physical group of vessels that share some physical traits and economic behaviours and execute similar activity that is meaningful to management. At present, WGMIXFISH defines fleets based on nationality, vessel size groups and aggregations of métier that use particular gear (i.e. French Otter trawlers 24–40 m in length). However, this grouping may not reflect the true diversity of fishing practices, potentially masking valuable information on polyvalent vessels that may combine trawling activity with potting or netting.

Métiers should describe the behaviour executed by a fleet at the level of the fishing operation (outcomes of a fishing operations at the level of trip, area and gear). Ideally this information should be available at the highest resolution possible and should contain information on species / species groups targeted so that the catch compositions of the fisher's intended behaviour is captured. This would provide a realistic measure of catchability for these stocks. In practice, fishing activity is extremely diverse, with no two hauls resulting in the same outcome. Further, it is often impossible to know the intended behaviour from a posteriori evaluation of catch compositions (ICES, 2018). In practice, WGMIXFISH uses the same métier classifications as those provided to the single-species working groups for catch estimates. The métiers provided are at DCF level 6 (gear, target species, mesh size range, selectivity device). In reality, they are grouped during the estimation process in national laboratories and by stock coordinators. Although these groupings have the advantage of providing consistency with the national sampling programmes used to estimate discards and size composition of catch, they are only a typology, and should be assessed for their relevance to the fishery and behaviour being executed to better define model inputs. Therefore, greater detail in terms of time (fishing trip level information) and space (highest resolution possible) are required to ensure that realistic and meaningful métiers are used.

By aggregating fishing activity into discrete homogenous fishing units, it is possible to reflect the true nature of a fishery (ICES, 2003). Homogeneity within a unit of fishing activity can provide more effective estimates of catch per species, directed fishing effort and partitioning of fishing mortality (Pelletier and Ferraris, 2000). However, it is important to ensure that the unit selected correctly captures the fishing activity within an area and that the right level of contrast is used to capture both spatial and temporal differences between the fishing units (Holley and Marchal, 2004; Mateo et al., 2017).

The section aims to evaluate the current fleet and métier definitions used, suggest potential improvements, and assess the impact of different aggregations of fleets and métiers on catch forecasts across two case studies: the North Sea and the Celtic Sea.

⁵ OJ L 346, 23.12.2008, pp. 37–88.

⁶ OJ L 41, 16.2.2010, pp. 8–71.

3.1 North Sea case study

The outputs presented here are based solely on the mixed-fisheries data as submitted to the ICES WGMIXFISH-advice. This decision was made based on the exploration of available data within section 2, which highlighted the discrepancies between the different data products available to this study. Although this limits the scope with respect to fleet/métier definitions, using a single data source (validated by WGMIXFISH) facilitates the interpretation of the results as there are no (potential) effects of using different data sets. Furthermore, starting from an existing mixed-fisheries model allowed to invest more effort in the development of alternative fleet dynamics models.

The data submitted to ICES Working Group on Mixed Fisheries Advice Methodology (WGMIXFISH-ADVICE) uses a similar stratification level as the data submitted to ICES for single-species stock assessments. Effort and catch/landings (by species) are submitted by country, quarter, métier DCF level 6, vessel length (following the Annual Economic Report definitions) and ICES subdivision, resulting in an extensive dataset. To reduce the number of strata (and potential fleet/métiers), the data are grouped into categories such that the variability of the data, describing the heterogeneity of the fishery, is maintained as much as possible.

In the current implementation of the North Sea mixed-fisheries model used by ICES, the starting point of the grouping into fleets and métiers was to match the definitions used in the cod long-term management plan (Council Regulation (EC) No 1342/2008⁷). Fleets were further split by country, and sometimes further by vessel length category depending on the availability of cost data from the Annual Economic Report and then the overall importance of the fleet in terms of total effort. Since 2012, more in-depth consideration has been given to the relevance of groupings of the fleet segments with regard to known national fishing patterns (detailed in ANNEX 2).

As a second step, and in order to reduce the number of categories, an aggregation threshold was used to identify 'small' métiers. A métier failing to catch 1.0% of at least one of the stocks considered was classified as small, and not considered as a separate métier but aggregated by fleet in one 'Other' métier (OTH). Further to this, fleets that contain only the OTH métier were aggregated into one single OTH fleet.

3.1.1 Framework for defining métier and fleet units

Data submitted to ICES WGMIXFISH (see Table 1 for details on this dataset) was used to conduct a Principal Component Analysis (PCA) and cluster analysis following the methodology as described in Moore et al. (2019). This multivariate analysis allows to group input data according to similarities across multiple input variables. In this case, the input variables represent the landings proportion of a selection of important demersal fish species (and Nephrops) in the North Sea for the years 2019-2021 (see ANNEX 3 for a detailed description of the input data).

This analysis was repeated multiple times for different grouping levels of the input data (Table 2 of ANNEX 3). These grouping levels included the ICES subdivision, the target species assemblage, vessel length, country, gear type, and mesh size used, and were selected as they are considered as important fishing activity descriptors that could inform about the fleet/métier structure in the North Sea.

The results of this analysis showed that the grouping of variables according to the aforementioned descriptors has little impact on the number of principal components and clusters required to explain a significant part of the variability in the landings composition (Figure 1 and Table 2 of ANNEX 3). For each grouping, approximately 19 to 22 clusters are retained to explain >90% of the variance, which indicates that a

⁷ OJ L 348, 24.12.2008, pp. 20–33

similar number of métiers, thereby ignoring the grouping into fleets and quota allocation across fleets, could be used to capture the main technical interactions of the demersal fisheries in the North Sea.

Linking those results to the current fleet and métiers definitions used by ICES WGMIXFISH in the North Sea showed a good level of agreement with about 70% of the non-other métiers belonging to one or two clusters (Table 3, 4, 5 of ANNEX 3). Only for a few métiers, a large discrepancy was found between the ICES definitions and the results of the PCA and cluster analysis which is likely related to the development of the demersal fishery over time and the inclusion of métiers targeting pelagic species that are difficult to describe with landings of demersal species.

3.1.2 Links to sensitivity uncertainty of forecast conditioning

The fishery dynamics in ICES mixed-fisheries projections are the outcome of three components:

1. fishing opportunities (set as quota) defined at the fleet level (based on historical landing volumes of the fleets) control how much a fleet can catch from each species;
2. métiers considered as the production units, harvest fish of which the catch composition is related to the species-specific catchabilities of the métier;
3. fishing effort, which is defined at the fleet level with fixed-effort proportions by métier, and the abundance of the resource.

The uncertainty of these components (quota shares, catchabilities and effort proportions) is addressed in section 4.1 In the following section, structural uncertainty with respect to the fixed effort proportion assumption is addressed by investigating the effect of alternative fleet dynamic models.

A consequence of the fixed effort proportion assumption is that mixed-fisheries projections are independent from the métier definition of a fleet, and that a fleet constituted with a single métier catches exactly the same as a fleet composed of two or more métiers given that the same input data are used to condition the fleet and métier(s). If effort proportions across métiers are fixed, a fleet behaves as a fleet with a single métier, where the catchabilities of that métier are equal to the average catchabilities of all métiers weighted by the effort proportions. Hence, if one would define a fleet with spatially disaggregated métiers, at for example the level of an ICES statistical rectangle, the assumption of fixed effort proportions would imply that the spatial distribution of that fleet is fixed and not reallocated according to the fishing opportunities of that fleet. Moreover, this assumption may result in some counter-intuitive results if a fleet is composed of métiers that are independent for at least one stock – as is the case for fleets of the ICES WGMIXFISH-advice North Sea model, which have métiers operating in the Eastern English Channel and the North Sea. In such cases, a fleet may be choked by a stock that is caught by a métier that operates in the English Channel (e.g. sol.27.7.d), while the fleet could still have quota left for North Sea stocks.

To avoid such unrealistic choking and allow fleets to adjust the effort proportions between métiers given their fishing opportunities, an alternative fleet-dynamics model has been implemented in the WGMIXFISH-ADVICE North Sea model. As a result, there is a linear relationship between catch and effort, assuming that all catches are taken at a single point in time during the year (the middle of the year in this case). This linear relationship between catch and effort allowed the optimal effort levels of métiers within a fleet to be found using linear programming. In addition, effort limits, quota, capacity limits or other constraints can easily be implemented in a linear programming model to increase realism of the fishery. Another advantage of linear programming is that it is computationally efficient, giving exact solutions in little time.

4. In this case a linear programming model was implemented with six different constraints that represent three different scenarios in terms of fleet-effort

proportions across métiers, the mathematical representations of which are given in ANNEX 4.

The first scenario, 'flex', does not constrain the effort proportions across métiers (only considers constraints 1 to 3). The second scenario, 'hist', uses the historical effort ranges (lower and upper limit of a métier's effort proportion) to constrain the effort proportions of a métier (considers constraints 1 to 3, and 5-6). The third scenario, 'fix', fixes the effort proportions at the average of the last three historical years (considers constraints 1 to 4). This third scenario is similar to the ICES WGMIXFISH 'min' scenario (where fishing stops for a fleet when the fleet's catch of the first quota species for that fleet meets the corresponding single-stock exploitation boundary). It should be noted that in each of the scenarios described here, the effort of a fleet is maximised, but constrained by a fleet's fishing opportunities in terms of quota so that none of the quota are overshot. As such, those scenarios represent three variants of the 'min' scenario.

3.1.3 Impact of alternative fleet-métier definitions

Given the differences with respect to the data sources identified in section 2, the mixed-fisheries model was conditioned with the mixed-fisheries data as used by the ICES WGMIXFISH. Using alternative datasets to condition fleets would hamper the interpretation of the results because differences in the results would likely be explained by both the variety in input data used and fleet/métier structure.

The fishery implemented in the FLBEIA model used for mixed-fisheries projections consist of two levels: fleets and métiers. The fleet level is constrained by both the management through catch limits (quota) and technical constraints, i.e. the capacity of the fleet (i.e. number of vessels, or total effort). In this study, the capacity constraint is set at an unrealistic high level, so that the upper level of fishing effort exerted by a fleet is never reached and effort is thus unconstrained. Therefore, the quotas by fleet are the sole constraint in the model. These quotas by fleet are defined according to the principle of 'relative stability', i.e. fleets receive a fixed proportion of the TAC of each species during the projection period of the simulation and are based on the average proportion of a fleet's landings to the total landings of a given stock over the last three years. This is a simplistic approach that is likely to be invalid when past TACs are not fully caught and would over/underestimate quota shares for some fleets; in addition, quotas are often implemented at the national level or by producer organisations, eventually with some flexibility between individual vessels (transferable quota systems), fleets or Member States (bilateral quota swaps). The métier level governs the actual technical interactions that exist in the fishery, defined as operational fishing strategies of a fleet. Each métier has its own catch composition (defined by the catchabilities and the métier-specific catch weights for the different stocks included in the projection).

In this study, we compare two alternative fleet and métier definitions of the ICES WGMIXFISH-ADVICE North Sea model with the original fleet-métier definition. The two alternative definitions comprise scenarios where (a) the fleets are similar to the original fleet definitions, but métiers are spatially disaggregated at the ICES subdivision level (except for German fleets), and (b) fleets are disaggregated according to the vessel length into four categories (> 10 m; $10 \text{ m} \leq 24 \text{ m}$; $24 \text{ m} \leq 40 \text{ m}$, and $> 40 \text{ m}$). For each of the fleet-métier definitions, the new fleet dynamics model is used to compare four scenarios: a status quo effort scenario, and three 'min' scenarios: (i) full flexibility of effort proportions across métiers ('flex'), (ii) effort proportions within the historical ranges of a métier's effort proportions ('hist'), and (iii) fixed-effort proportions based on historical values from the last three years ('fix'). The twelve scenarios are compared in terms of fleet effort and utilisation of the TACs.

In summary, there are limited differences between the projections of the three different fleet and métier definitions if the same fleet dynamics model is used; this is the status

quo effort scenario. In contrast, using the three alternative fleet dynamics models has more pronounced effects, as can be seen in Figure 1. In the North Sea mixed-fisheries projections for 2023, more flexible fleet dynamics result in a better uptake of the flatfish quota in both the North Sea and Eastern English Channel. There is also a shift in quota-prevailing choking species in the mixed-fisheries projections (Table 2), with fewer fleets choked by witch flounder in the more flexible-effort dynamics scenarios, and a shift towards mainly sole.

Table 2: Number of occurrences that a prevailing quota species is the choke species by disaggregation scenario. Species abbreviations: COD-NS = North Sea cod; HAD = haddock; NEP-6 = *Nephrops* FU6; NEP-9 = *Nephrops* FU 9; PLE-EC = English Channel plaice; POK = saithe; SOL-EC = English Channel sole; SOL-NS = North Sea sole; TUR = turbot; WHG-NS = North Sea whiting; WIT = witch flounder

Scenario	COD-NS	HAD	NEP-6	NEP-9	PLE-EC	PLE-NS	POK	SOL-EC	SOL-NS	TUR	WHG-NS	WIT
Min_fix_default	3	0	1	0	0	0	1	0	5	0	0	36
Min_fix_fleets_length	5	1	1	0	1	0	2	1	7	2	0	46
Min_fix_métiers_area	4	0	2	0	0	0	1	0	5	0	0	40
Min_flex_default	3	3	0	1	5	1	3	1	11	4	2	12
Min_flex_fleets_length	3	7	0	1	7	1	9	6	10	11	1	10
Min_flex_métiers_area	6	7	1	0	1	1	0	7	9	0	6	14
Min_hist_default	4	0	0	0	2	0	1	1	14	0	0	24
Min_hist_fleets_length	5	1	2	0	7	0	3	5	17	2	1	23
Min_hist_métiers_area	5	2	1	0	0	0	1	4	13	0	1	25
sq_E_default	3	0	1	0	0	0	1	0	5	0	0	36
sq_E_fleets_length	5	1	1	0	1	0	2	1	7	2	0	46
sq_E_métiers_area	4	0	2	0	0	0	1	0	5	0	0	40

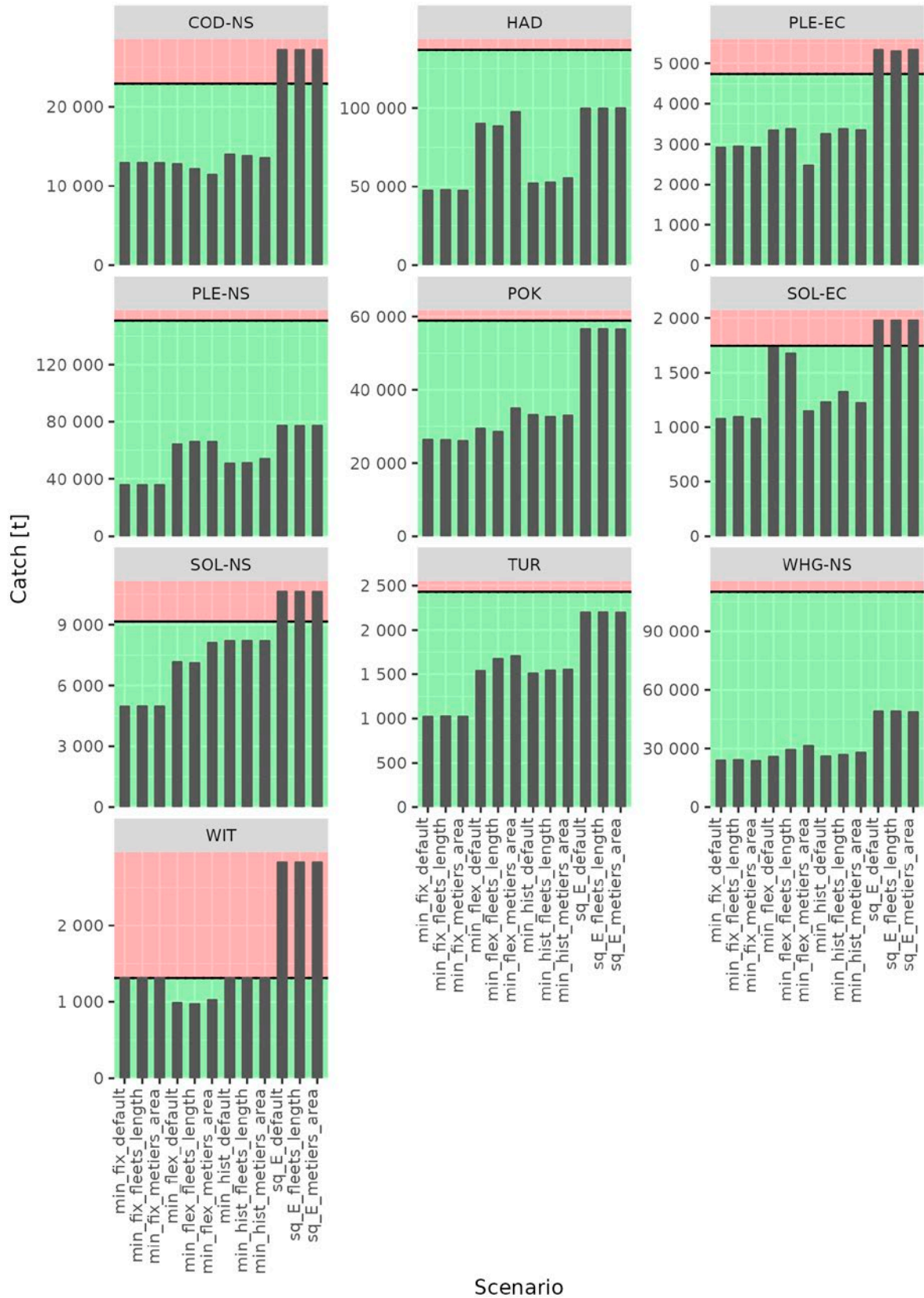


Figure 1: Catches of demersal North Sea stocks according to different mixed-fisheries scenarios. The horizontal line corresponds to the single-stock catch advice, with areas above and below the line representing potential over- and undershoot, respectively.

Disaggregating the fleets by vessel length category results in a wider spread of the choking effects across fleets (Figure 2). This can be interpreted as follows; some fleets experience stronger choking effects first, while others are choked later or experience fewer choking effects. Therefore, the distribution of ratio of the fleets' effort to the status quo effort (sqE) has a wider spread in the 'min_fix_fleets_length' scenario in the figure when compared to the 'min_fix_default' scenario. Nevertheless, the median effort level compared to the status quo effort level is very similar as with this aggregation level the effort ratio is distributed around 1 (Figure 2). This result is a logical consequence of combining multiple strata in a single fleet; if catch compositions and historical landings volumes differ for the strata, disaggregating those strata in multiple fleets will obviously result in fleets with catch opportunities and technical interactions that are more in line with the advice, and vice versa. Keeping the same fleets, but disaggregating the métiers has no effect if effort proportions across métiers are fixed. However, small differences may arise from métiers that are too small and are grouped in the OTH métier of a fleet.

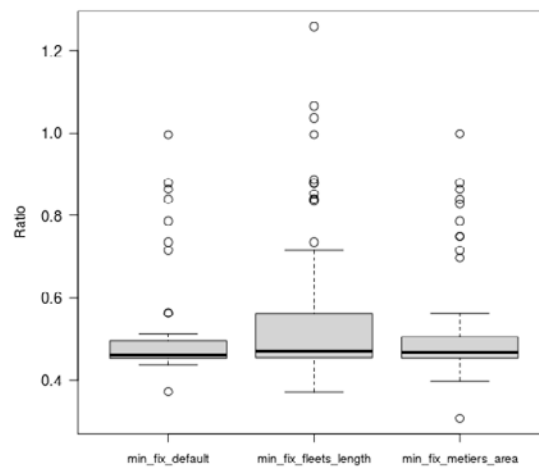


Figure 2: Effort compared to status quo effort levels by fleet for the three fleet-métier definitions under the fixed effort proportion scenario.

The fleet dynamics have stronger effects on a fleets' effort. Relaxing the constraint of fixed effort proportion results in increases in effort level for all fleets that comprise more than one métier. Removing all constraints in terms of effort proportions and allowing full flexibility results in effort levels that are on average similar to the sqE effort levels. If effort levels are constrained by the historical effort proportions, the overall median effort level by fleet is strongly reduced (to about 50% of the status quo). For fleets that fish with effort proportion ranging between the historical values, the reduction of the median effort level compared to status quo effort levels is less pronounced (about 12%). However, removing the constraints on the effort proportions reduces the overall catch per unit effort (CPUE) of the fleets (Figure 3). This is mainly the case for the 'flex' scenario and is a result of the objective function that seeks to maximise effort and is therefore favourable for métiers with low catchabilities. By constraining fleets to fish according to historical effort distributions, this effect is strongly reduced – indicating more realistic behaviour.

Another consequence of the increased flexibility in terms of effort proportions across métiers is that the number of choke species by fleet increases (Table 3). Fleets do not necessarily have to stop fishing if the first quota is depleted but are still able to fish with métiers that do not catch the first choke species.

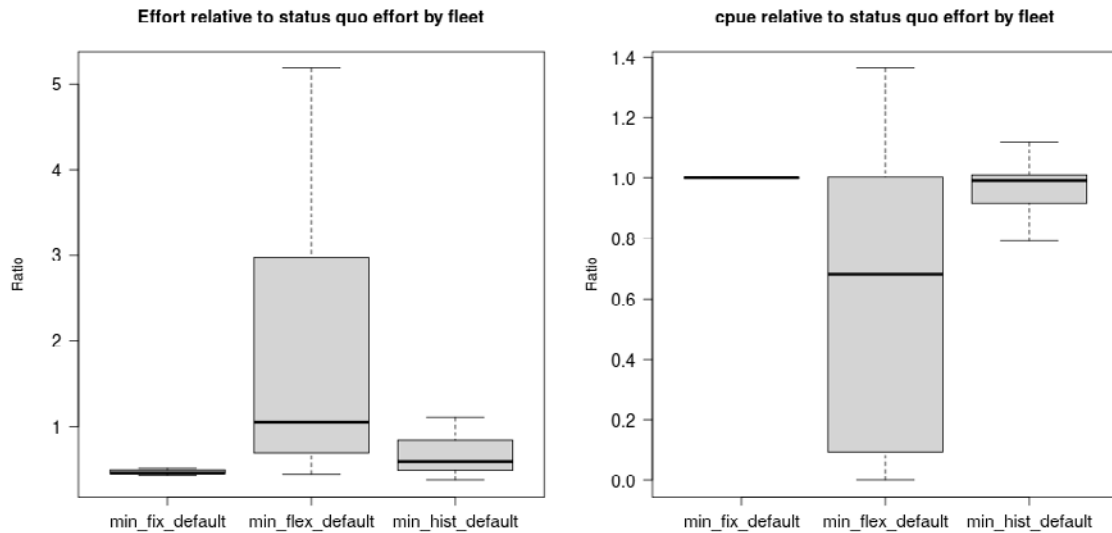


Figure 3: Effort (left) and CPUE (right) compared to status quo effort levels by fleet for the three alternative fleet dynamics models for the default fleet-métier definition.

Another consequence of the increased flexibility in terms of effort proportions across métiers is that the number of choke species by fleet increases (Table 3). Fleets do not necessarily have to stop fishing if the first quota is depleted but are still able to fish with métiers that do not catch the first choke species.

Table 3: Frequency table showing the number of choke species (1 to 5) by fleet for each scenario.

Number of choke species	1	2	3	4	5
min_fix_default	46	0	0	0	0
min_fix_fleets_length	66	0	0	0	0
min_fix_métiers_area	52	0	0	0	0
min_flex_default	12	18	12	3	1
min_flex_fleets_length	20	29	15	2	0
min_flex_métiers_area	11	19	14	8	0
min_hist_default	23	20	3	0	0
min_hist_fleets_length	32	30	4	0	0
min_hist_métiers_area	21	27	4	0	0

3.2 Celtic Sea case study

As only one of the four main countries fishing in the Celtic Sea was part of the consortium, all analysis was limited to the data currently available through WGMIXFISH, or Irish-specific data. However, work is ongoing at ICES, through the EU special request to ICES, which reflects the objectives of this study, enabling this study to work

collaboratively with those outside the consortium. The results of these more collaborative aspects will be presented under the special request report due in 2024 rather than within this report.

3.2.1 Framework for defining métier and fleet units

This analysis is an update of the work previously completed by the Celtic Sea subgroup at WGMIXFISH (Davie & Lordan, 2011; Moore et al., 2019; ICES, 2018). A multivariate analysis (PCA and hierarchical clustering) has been applied to identify homogenous groupings of métiers (presented in ANNEX 5). This framework is currently only applicable to métier definitions. Vessel-level information is required to define the fleet, and therefore fleets are not part of this discussion

This analysis indicates that current métier typology and grouping used in the Celtic Sea WGMIXFISH-ADVANCE model is sensible, and consistent with the previous findings (Moore et al., 2019, ICES, 2018). This indicates that at the resolution of year and ICES divisions, there is stability in the definitions used for métiers, and they maintain relevance to the current fishing patterns in the Celtic Sea. However, if new input data (e.g. spatially disaggregated) are used for mixed-fisheries projections in the future, it is a useful endeavour to explore the data using a PCA analysis, as presented here, before assigning fleet and métier definitions.

Ideally, high-resolution (spatial and temporal) trip-level data is required to define the most suitable métier for a specific mixed-fisheries case study. However, there is currently no such available data source within ICES and the EU. Issues of confidentiality currently hinder the collection and sharing of these data. To circumnavigate this issue, members of this consortium and the members of WGMIXFISH Celtic Seas subgroup are developing scripts that allow countries to merge and raise their own data to include high-resolution clustering of métiers and fleets segments that align with the AER. These data are derived from logbooks (EFLALO), VMS (TACSAT), and sales notes (AER), and will enable WGMIXFISH to identify real fleets (physical vessels), fisher behaviour (métier) and economic outcomes, while also reducing the chance of false-positive technical interactions (ICES, 2022b; ICES, 2023b). This work is under way beyond the scope of this study and will be reported as part of the response to the special request from the EU to ICES on this topic.

3.2.2 Impact of fleet–métier disaggregation

For the Celtic Sea case study there was no need to rerun the Fcube model to test the impact of new fleets, as no new fleets or métiers were identified from previous work. Future work will focus on defining fleets and métiers using highly spatial disaggregated data (see 3.2.1), at which point the Fcube model will be rerun with revised strata to determine the impacts. This is under way within the remit of the special request from the EU to ICES.

3.2.3 Impact of spatial disaggregation

WGMIXFISH produces mixed-fishery considerations using highly aggregated data, at the spatial level of ICES division. This level of aggregation does not always reflect the complexity of fisheries, or the impact of spatial or temporal dynamics on patterns in targeting behaviour and catch composition. This task explored the impact of spatial disaggregation on the chocking patterns of cod in the Irish *Nephrops* fleet. The objective was to identify the number and frequency of fishing trips operating within *Nephrops* Functional Units (FUs) that could be completely decoupled from any technical interactions with cod, the primary chocking species within the Celtic Seas mixed-fisheries model.

Despite the increased spatial resolution provided by this new data, it was not possible to completely decouple landings of cod and *Nephrops* on individual trips (see ANNEX 6).

The case study went on to further explore a single FU at the ICES statistical rectangle, the Porcupine Bank (FU 16) which is considered to be a highly targeted *Nephrops* fishery. However, even in FU 16, some technical interactions with cod persisted. As, in this case, it was not possible to completely decouple *Nephrops* trips from trips where cod was caught, there was no clear way to refine fleets with the current available levels of regulatory reporting. To create fleets that are not artificially choked by false technical interactions would require even more spatially disaggregated data. Therefore, the WGMIXFISH Celtic Seas subgroup is developing a framework (see 3.2.1) that will allow for the identification of technical interactions at a more spatially disaggregated level (VMS pings).

3.2.4 Impact of age-structured fleet and métier definitions

It is not currently possible to assess the impact of age-structured fleet and métier definitions on the mixed-fisheries forecasts produced for the Celtic Sea WGMIXFISH-ADVICE because the model used (Fcube) does not include age. In addition, the WGMIXFISH inter-benchmark in 2021 (IBPMIXFISH; ICES, 2021b) concluded that it was not possible to use FLBEIA for Celtic Seas advice purposes. When the FLBEIA model was applied in the Celtic Sea, several problems were encountered in reproducing the advice and forecast of mixed-fisheries scenarios. See Annex 7 for further details.

Once an age-based mixed-fisheries model can be fully implemented, it will enable WGMIXFISH to more accurately reflect the reality of mixed fisheries, providing the highest detail of technical interactions, and enabling us to account for the selectivity impacts of gears and targeting behaviour. For now, age-structured data is still produced annually as a step in the data-production process as the aim is to have all case studies using FLBEIA within the coming years. Although the transition to an age-structured fleet model would provide more tools with which to predict the impact of fleets on stocks, there are still a number of questions around the impact of the change on the quality of the data and the subsequent forecasts.

3.2.5 Links to sensitivity uncertainty of forecast conditioning

The effect of uncertainty of fleet and métier definitions on model behaviour has never been investigated, despite the possibility that poor estimates of strongly influential parameters may have large impacts on model performance. Understanding these impacts will enhance the quality of mixed-fisheries products. This work is currently being undertaken within WGMIXFISH-METHODS a summary of which is given in ANNEX 8

To date, the conclusions reached by WGMIXFISH-METHODS (ICES, 2023b) are that the generic set of methods developed by Cefas could be applied to the conditioning of any mixed-fisheries model and accommodate potentially noisy and poor-quality input data. These methods are already built into functions that can be readily applied to any data object in R that is a representation of amalgamated biological, assessment and fleet data (FLFleet object) and generate a performance log and diagnostics to screen for model fitting issues. Future work will improve the realism of forecasts, and will improve the robustness of model fitting, expanding the toolbox of user-friendly functions available. This work is ongoing and will be dealt with as part of WGMIXFISH-METHODS and the special request sent by the EU to ICES, to be published in 2024.

4 SENSITIVITY TO FORECAST

The main purpose of this section is to characterise the uncertainty in the projections of mixed-fisheries models as a function of uncertainty in forecast conditioning. This involves characterising the uncertainty of parameters in the forecast based on historical data; quantifying the uncertainty in the output indicators; and identifying the parameters that have the highest contribution to the output variance.

Mixed-fisheries scenarios provided by ICES are based on complex numerical models that, in addition to the parameters related to stock dynamics, also involve many input parameters corresponding to factors such as catchability, and proportions of effort between métiers for each fleet or quota distributions per fleet. These models are used to make short-term projections, and future values for these parameters are required for the projection period, namely the current year and the next year. Usually, average values of recent historical values are used to condition these parameters.

In the provision mixed-fisheries considerations, it is important to provide not only point estimates for model results but also confidence intervals as an indicator of the precision of the forecast. However, currently, uncertainty is not considered in the provision of mixed-fisheries considerations. In the simulation models used to generate mixed-fisheries scenarios uncertainty can be propagated into the output using Monte Carlo simulation, where probability distributions are used to condition the input factors. The model is then applied iteratively to different values sampled randomly from these probability distributions. The process of conditioning the probability distributions is known as uncertainty analysis. In turn, Global Sensitivity Analysis (GSA) examines how the uncertainty in the input factors translates to the uncertainty in the output. Subsequently, the research focus could be on the input factors that have the highest impact in the output variance.

The focus of the exercise was on the parameters directly related to catchability, quota-share and effort proportion. For this purpose, two case studies were selected. In the North Sea case study, uncertainty of the three parameters (catchability, effort proportion and quota share) was analysed, and alternative assumptions based on the outcome of sensitivity tests for the forenamed parameters were evaluated. In the Bay of Biscay case study, the more complex GSA approach was applied to assess the sensitivity of input factors.

4.1 North Sea

For the North Sea case study, three model input parameter types were scrutinised: catchabilities, effort proportions and the distribution of landings - henceforth landing proportion. The approach taken consisted of conducting sensitivity tests, whereby, for each of the three input parameter types, alternative assumptions ('scenarios') were to be proposed, based on an analysis of the historical values for these parameters. Mixed-fisheries projections were then run for the scenarios, and the output was compared to the base case. Because of the results of the historical values evaluation, no alternative assumptions were proposed and only the sensitivity of the status quo assumption was evaluated.

4.1.1 Review of current assumption and comparison with alternative assumptions

This section characterises the uncertainty associated with the assumptions made on future catchabilities, effort proportion and landing proportion when conditioning the North Sea mixed-fisheries model. For the three parameters, the same 'status quo' assumption is used, whereby the parameter values used for the projection period in the mixed-fisheries model (current year and next year) is set equal to the value in the last available data (one year before current year). Further details of the work can be found

in ANNEXES 9, 10 and 11, on the catchability assumption, effort proportion assumption and landing proportion assumption respectively.

The same approach was used for the three parameters. The uncertainty stemming from the assumption on the future parameter values was examined by computing retrospectively the values corresponding to the assumption for a given year, and comparing it to the actual value, based on the data. The analyses were based on data from the 2022 ICES WGMIXFISH meeting, which contained information on landings, effort and catchabilities per fleet and métier for the period from 2012 to 2021. The predicted values based on these assumptions were calculated for each fleet and each stock for the years 2017 to 2021 (in order to leave enough years to fit the AR1 and Im models – see below for details).

In addition to the assumptions used at WGMIXFISH, three alternative assumptions to the status quo assumption were tested. The assumptions tested were:

- sQ: the parameter values in year $y + 1$ (for a given fleet and a given stock) is based on the values observed for $y - 1$. This is the current WGMIXFISH assumption;
- Ave: the parameter values in year $y + 1$ (for a given fleet and a given stock) is based on the average of values for three previous years;
- Im: the parameter values in year $y + 1$ (for a given fleet and a given stock) is based on the prediction from a linear model fitted on the values for the years 2012 to the year $y - 1$;
- AR1: the parameter values in year $y + 1$ (for a given fleet and a given stock) is based on the prediction of an autoregressive model fitted on the values for the years 2012 to the year $y - 1$.

In order to compare the performance of the four assumptions in predicting the parameter values, different criteria were analysed: the prediction error was calculated for each data point, and the four assumptions were ranked on this basis. From this, the following performance descriptors were derived:

- the percentage of the data points (year/fleet/stock combination) for which each assumption ranked first;
- the average rank for each assumption;
- the average prediction error (mean absolute proportion error) for each assumption.

The main conclusion is that the current status quo assumption seems to provide a generally unbiased prediction for future parameter values (although some bias can occur for some stocks, (Table 7-Table 9). However, this assumption is associated with variable levels of uncertainty, on average, a mean error of between 20% and 50% but it can be higher. From a model perspective, any error on catchability or landing proportion will have an error of the same magnitude in the fishing effort (error of opposite direction for catchability, and same direction for landing proportions). Since the fishing effort is at the basis of the mixed-fisheries scenarios (e.g. 'min', 'max'), any impact on the effort will be translated in catches and reflect in the catch projections from the models, in a similar proportion. However, it is not possible to derive overall confidence intervals for the mixed-fisheries catch forecast simply based on the magnitude of the errors on the input parameters. In order to appropriately take into the interactions in the different levels of complexity of the model (multiple fleets and multiple stocks) it is necessary to use the model itself (see section 4.1.2).

There is also a large variability in these overall values. Overall, autocorrelation in error is negative, meaning that a larger error one year tends to be followed by a small error (or possibly of the opposite sign) the following year.

The assumptions alternative to sQ do not, overall, provide a better basis. The ranking of the assumptions gives a clear advantage to the currently used one. This means that although the parameters are difficult to predict, the best approximation for future values

are the latest observed ones. On a fleet-by-fleet basis, there is a small percentage of cases where an alternative assumption performs better than the one currently used by ICES. However, it does not seem realistic to use case-specific assumptions (e.g. the best-performing one for each fleet/stock combination), as the best assumption may vary from year to year, and this can only be assessed retrospectively. Finally, in some instances, none of the assumptions tested seemed appropriate, for examples for cases where abrupt changes in catchability occurred.

Regarding the landing proportions, the study also explored the use of an official database on quotas (before and after exchange) to formulate alternative assumptions for future TAC allocation between countries. Neither of the two alternative assumptions to predict future landing proportions based on quotas from FIDES provided a better basis than the one based on recent landing data currently used at ICES WGMIXFISH. The country initial quota percentages before exchanges are clearly not a good basis for assumptions on future landings proportions, as countries generally exchange large quantities to accommodate the needs of their fleets (to increase their fishing opportunities of their target stocks or anticipate the risk of being choked by certain stocks). Final quotas, those after exchange, were not a better basis either, as countries maybe still – consistently through the years – over-utilise, or, less likely, under-utilise, their fishing opportunities.

Table 4: Performance metrics for the assumptions on catchability. Where the scenarios are defined as: sQ – the parameter values in year $y + 1$ based on the values observed for $y - 1$; Ave – the parameter values in year $y + 1$ based on the average of values for three previous years; lm – the parameter values in year $y + 1$ based on the prediction from a linear model fitted on the values for the years 2012 to the year $y - 1$; AR1 – the parameter values in year $y + 1$ based on the prediction of an autoregressive model fitted on the values for the years 2012 to the year $y - 1$.

Assumption	Proportion of being best	Median relative error (%)	Mean rank
sQ	0.523	– 0.462	1.869
Ave	0.135	– 1.331	2.860
lm	0.252	– 1.392	2.432
AR1	0.189	– 1.811	2.839

Table 5: Performance metrics for the assumptions on effort proportions. Where the scenarios are defined as: sQ – the parameter values in year $y + 1$ based on the values observed for $y - 1$; Ave – the parameter values in year $y + 1$ based on the average of values for three previous years; lm – the parameter values in year $y + 1$ based on the prediction from a linear model fitted on the values for the years 2012 to the year $y - 1$; AR1 – the parameter values in year $y + 1$ based on the prediction of an autoregressive model fitted on the values for the years 2012 to the year $y - 1$.

Assumption	Proportion of being best	Median relative error (%)	Mean rank
sQ	0.615	0.064	1.762
Ave	0.176	– 0.167	2.753
lm	0.217	– 0.747	2.505
AR1	0.164	– 0.379	2.981

Table 6: Performance metrics for the assumptions on landing proportions. Where the scenarios are defined as: sQ – the parameter values in year $y + 1$ based on the values observed for $y - 1$; Ave – the parameter values in year $y + 1$ based on the average of values for three previous years; lm – the parameter values in year $y + 1$ based on the prediction from a linear model fitted on the values for the years 2012 to the year $y - 1$; AR1 – the parameter values in year $y + 1$ based on the prediction of an autoregressive model fitted on the values for the years 2012 to the year $y - 1$.

Assumption	Proportion of being best	Mean absolute percentage error (%)	Mean rank
sQ	0.553	37.9	1.8
Ave	0.157	43.4	2.7
lm	0.195	52.6	2.6
AR1	0.156	48.1	2.9

4.1.2 Model evaluation and sensitivity

The results of the review of the current assumptions and alternative scenarios highlighted that the status quo assumption in the North Sea mixed-fisheries model is the most robust compared to three other assumptions explored to configure future catchability, effort proportions per métier and landing proportions per fleet in the mixed-fisheries model. It is therefore of interest to test how this assumption affects the outcome of mixed-fisheries scenarios used within mixed-fisheries considerations.

One way to do this is to compare mixed-fisheries projections done using true parameter values with projections done using status quo assumption for these parameters. To have multiple points for comparison, the model can be run for five different starting years to produce five sets of results, both for the assumption and for the true parameter values.

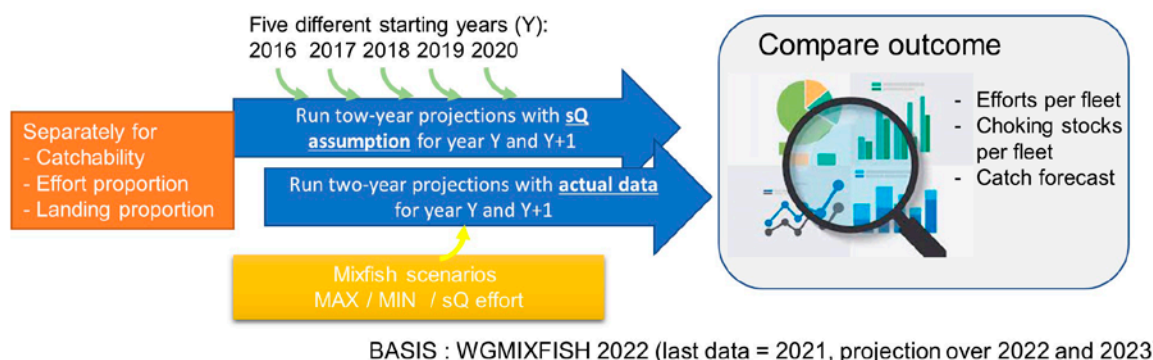


Figure 4: Retrospective approach to test the sensitivity of mixed-fisheries projections to the assumption made on key parameters for the North Sea case study.

Using the North Sea mixed-fisheries model conditioned in 2022, true values for catchability, effort and landings proportions are available up to 2021 (last data year). We performed a five-year retrospective analysis where a two-year projection was run starting at different historical time (years from 2020 to 2016 inclusive, Figure 4).

For each starting year, the model was run once with the parameter values unaltered (true values), and a second time after applying the status quo assumption, i.e. parameter values for the starting year and the following one were set equal to the value in the year preceding the starting year, as would be the case in a real situation for the last year of data available. This is similar to what is done when configuring the mixed-fisheries models to produce advice. Each of the runs above (five starting years, true vs. assumed parameters) were repeated for different mixed-fisheries scenarios.

To quantify the sensitivity of the model output to the assumptions on model configuration, we computed the difference in the catches (advice year) and the SSB (advice year +1) per retrospective run and per stock between the run using a status quo assumption and the run using the actual parameter value. In order to summarise the value of these errors across the five runs (retro years), the mean error (expressed in percentage) is calculated. In addition, we extracted the most- and least-limiting stocks for each scenario and compared the results for both assumptions.

For technical reasons, not all mixed-fisheries scenarios could be run in the sensitivity test of each parameter. The runs for which the sensitivity test could be done are given in Table 7 (see ANNEX 12 for explanations).

Table 7: List of runs performed to test the sensitivity of FLBEIA output to assumption on parameters.

Parameter	Catchability	Effort proportion	Landing proportion
Mixed-fisheries scenarios	Status quo effort	Status quo effort	'min' and 'max'

4.1.2.1 Results

The full set of results is presented in detail for each parameter in ANNEX 12.

For the fish stocks (Figure 5), the error in the projected catches was the smallest for the runs testing the sensitivity to the proportion of effort per métier, with projected catches using the assumption begin from -4% for witch flounder to 2% for saithe compared to the projected catches using the real effort proportions. For catchability, the sensitivity to the assumption was larger, and mainly positive, indicating the assumption of status quo catchability led to higher predicted catches than when the true catchability is used in the model. here, the projected catches using the status quo catchability assumption were between 2.5% (saithe) to close to 30% (haddock and whiting) higher than the catches obtained using the real catchabilities. The errors associated with SSB for the year after the advice year were smaller and mainly negative (as a consequence of the positive errors on catch in the advice year). The largest errors were observed for the test of sensitivity to the landing proportions. The sign of the error was different for the 'min' and the 'max' scenario. In the 'min' scenario, the assumption resulted in lower catches in the advice year by generally around 50% (i.e. projected catch using the assumption being on average half of the projected catches obtained using the actual landing proportions). Conversely, in the 'max' scenario, catches are higher with the assumption than with true values, with an even larger error (catches obtained using the assumption were higher, between 25% for cod and 80% for whiting, than using the real landing proportions). Consequently, errors of the opposite sign, but of a smaller magnitude are found for the SSB in the year after the advice year.

A possible explanation for this larger sensitivity could be that true landing proportions from the data correspond to the outcome of the activity of the fleets and therefore are representative for how each fleet has dealt with its potential quota limitations. Fleets can have managed to reduce choke effects by, for instance, increasing their quota for their potential limiting stock through exchange or transfer. It is therefore expected that when using the real (realised) landing proportion, the magnitude of the choke effects would be lower than from a forecast using status quo landing proportions. This would explain lower catches with the status assumption in the 'min' scenario. Conversely, the fleets are not likely to catch their full quotas for the stocks identified as least limiting; therefore, the proportion of landing for these stocks for the fleets for which they are least limiting are probably lower in reality than the ones based on the status quo assumption (and hence a higher forecasted catch in the 'max' scenario with this assumption).

For the three parameters, the mean percentage error (MPE) values for the *Nephrops* functional units (not shown here but available in ANNEX 12) were substantially higher than for the fish stocks. The sensitivity of the FLBEIA output is especially high for the landing proportion assumption, with an MPE larger than 100% for all stocks in the 'max' scenario. This is because the simulations use quotas per functional unit, while in reality a single quota is used for the whole of the North Sea. This adds an additional source of discrepancy between the real landing proportions and the ones based on status quo assumptions.

Finally, the perception on most- and least-limiting stocks can change considerably when the status quo assumption is used compared to when the true data are used (shown in ANNEX 12). This is especially the case when testing for the sensitivity to the landing proportion assumption, where very different sets of most- and least-limited species were obtained. Less differences were found for the test of the catchability assumption, while most- and least-limiting stocks were not very affected by the effort proportion assumption. This difference can be explained by the fact that the landing proportion is a key parameter to define the quotas of the fleets per stock, which ultimately determines which stocks will be most and least limiting for each fleet. In addition, for the last two parameters, only proxies for most- and least-limiting stocks were derived for this study, whereas in the case of the sensitivity to the landing proportion, the 'max' and 'min' scenarios were run, thus allowing the identification of most- and least-limiting stocks.

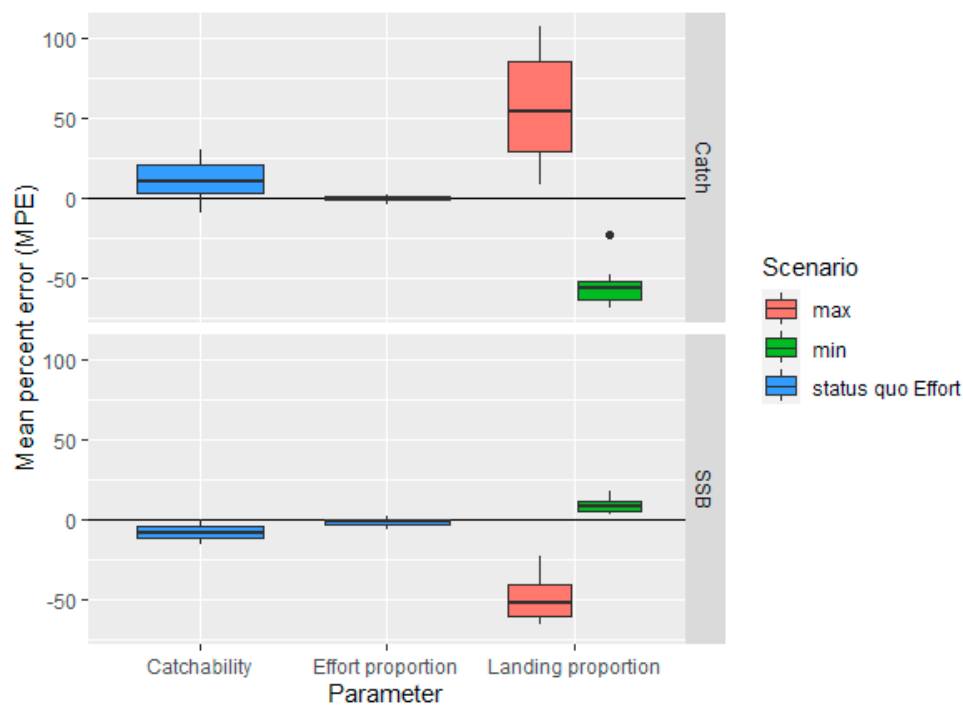


Figure 5: Sensitivity of FLBEIA output (catch in advice year and SSB the year after) to the assumptions made on future catchability, effort proportions and landing proportions. The sensitivity is measured by the mean percent error at the stock level. The boxplots depict the variability in the mean percent error amongst fish stocks for each parameter, and for different mixed-fisheries scenarios.

4.1.2.2 Discussion

Catchability

Use of the status quo catchability assumption might induce an error in catch and SSB advice estimates for the fish species in the North Sea model, varying on average between 0 and 30%, and 0 and 15% respectively. The catchability assumption does not

seem to induce large differences in most- and least-caught stocks per fleet, which might indicate that the choke and least-limiting stocks would be mostly well identified with the status quo catchability assumption.

Effort proportions

The status quo effort proportion assumption might induce an error in catch and SSB advice estimates for the fish species in the North Sea model varying on average between 0 and 4%, and 0 and 6% respectively. The effort proportion assumption hardly induces a difference in most- and least-caught stocks per fleet. This might indicate that the choke and least-limiting stocks would be mostly well identified with the status quo effort proportions assumption.

Landing proportions

Errors are larger as expected, because in this case the results are based on the 'min' and 'max' scenarios (set effort scenarios are not relevant for this parameter). The impact of the status quo assumption on this parameter does not only affect the calculation of forecasted catches and stock size for a given effort, but also the future effort itself. Indeed, in these scenarios, the efforts correspond to the lower and largest (for the 'min' and 'max' scenario respectively) of the efforts corresponding to the quota of each species, and these quotas are based on the landing proportions used.

The sensitivity of the mixed-fisheries forecast to the landing proportion assumption appears high. However, there is no obvious alternative to the status quo assumption. Explorations have been made using Fcube at WGMIXFISH (ICES, 2022b) in which actual quota shares (before or after exchanges) are used instead of a status assumption. This resulted in some noticeable differences. In particular, some fleets that were strongly choked by COD-NS with the status quo landing proportion assumption had actually underused their quotas (or traded them) in the recent years, and their actual quota share were much higher than assumed based on recent landing proportion. For these fleets, COD-NS was still choking when using quota shares as an assumption for future landing proportions, but for a much higher effort, and their catches were overall much higher. However, since it is impossible to predict annual exchanges and transfers, using quota shares does not seem to lead to a better assumption overall than using status quo landing proportion (see ANNEX 11).

4.1.2.3 Conclusions and observations

Not having reconditioned to exactly reproduce the previous mixed-fisheries considerations led to more issues than initially foreseen, and has resulted in limitations to the validity of the results presented here.

A first issue is related to the stocks included in the analysis for each métier. For a number of fleets, stocks are included in the catches of their métiers only for some years (the most recent ones). When running the model starting further back in time, those stocks remain in the list of stocks taken by these métiers, even though catches are 0. This leads to setting quotas for 0 catch for these stocks, which fully chokes the fleet (appearing as NA on the Figure 14 of ANNEX 12).

A second issue is that the runs were also parameterised using historical ICES advice to define the quotas of the fleets. The biological basis for the retrospective runs was the assessments available in 2022, which can differ substantially from the ones used back in time as a basis for both the single stock and the mixed-fisheries considerations (because of annual revisions in assessment perception or changes in methods after benchmarks). Therefore, it cannot be expected that most- and least-limiting stocks in this analysis correspond to those identified in the historical mixed-fisheries considerations.

Not having been able to fully recondition the model for each retrospective year might also be the reason for the unexpected results regarding most- and least-limiting stocks for the landing proportion assumption.

Reconditioning the model is very difficult, and would involve, for each retrospective run, a total reconstruction of each fleet-object (landing and discards at age per métier for each fleet, and corresponding effort), which is normally achieved after several days of work at each WGMIXFISH meeting. The stock object from the earlier assessments should also be used, and the corresponding assumption on future biology should be updated.

Since the lack of reconditioning is likely an additional source of discrepancy, it can be expected that the analysis presented here overestimates the sensitivity of the model output to the assumptions on configuration. However, it is not possible to establish the magnitude of this overestimation.

4.2 Bay of Biscay

The aim of this section was to conduct an uncertainty analysis and GSA on the Bay of Biscay demersal mixed-fisheries as a case study. The focus was on ensuring effective conditioning of the models to represent accurately the uncertainty in the output and characterise it using the GSA. The case study comprised data on the French and Spanish demersal fisheries operating in the Bay of Biscay. Input data was based on the available information from ICES WGMIXFISH 2022 (ICES, 2022c) and some improved information on Spanish fleet from the AZTI database, covering the period 2009–2021. A detailed description of the case study including the fleets and métiers available and an exploratory data analysis of catchability, effort share and quota share can be found in ANNEX 13.

As a proof of concept, the initial analysis focused on the analysis and conditioning of the two most important trawl fleets in terms of total landings. These were French bottom otter trawlers 10 to 24 m in length (FR_OTB_10<24m) and Spanish 24 to 40 m bottom trawlers (ES_OTB_24<40m). As the data time series should be as long as possible for this type of analysis, the longest data time series available for the Bay of Biscay mixed-fisheries case study was used, covering the years 2009 to 2021. Unresolvable data gaps occurred in the earlier part of the time series, limiting use to the years 2014 to 2021 in some instances.

4.2.1 Uncertainty analysis

4.2.1.1 Conditioning of the input factors

The focus was on the uncertainty conditioning of parameters directly related to catchability, quota-share and effort proportion. The catchability by fleet is calculated based on the model used for the simulation of catch production.

In the following sections, for simplicity, the subscripts for fleet and métier are omitted, but all the calculations occur at métier level. For a detailed description of the uncertainty conditioning is shown and the complete set of plots can be found in ANNEX 13.

During the process of conditioning catchability, focus was primarily on incorporating the effects of interspecies interactions that occur within each métier. To do so, catchability was decomposed in an intensity index that accounted for annual variability and a selectivity index that accounted for variability along ages. The uncertainty in the intensity, including, correlation in the intensity between species caught within the same métier, was modelled using a multivariate lognormal distribution. In case the multivariate lognormal produced outliers, i.e. values that differ greatly from observed intensities, we applied an envelope that constrained uncertainty estimates to the 95% confidence interval of observed intensities per stock.

The uncertainty associated with selectivity, on the other hand, was derived from a statistical model in which age was incorporated as an explanatory variable. The resulting uncertainty sometimes fell out of the observed selectivity; thus, we applied an envelope that constrained uncertainty estimates to the 95% confidence interval of observed selectivity levels.

To introduce uncertainty in the effort proportion, a multivariate probability distribution that models jointly the proportion of effort exerted in each métier was used. For quota share the same probability distribution was used, but in this case the proportion of the TAC assigned to each fleet was modelled.

Mixed-fisheries simulations were carried out under the following effort scenarios:

- max: fleet activity stops when the quota for all stocks is consumed;
- min-exhom: fleet activity stops when the quota for any stock is consumed, excluding horse mackerel that has zero catch advice for 2023, but not zero TAC;
- sq_E: fleet activity is the average of the most recent three data years.

4.2.1.2 Results

The impact of fleet parameter uncertainty on model outputs varied depending on the effort scenarios considered (Figure 6 and Figure 7). The larger variation is observed in the 'max' scenario, both in terms of expected effort and forecasted landings.

Extremely large efforts were simulated in the 'max' scenario (Figure 6) compared to status quo effort are due to cases with very low simulated catchabilities for some stocks, mainly hake and megrim.

Regarding forecasted landings, very little variation is observed in most of the scenarios, except for the 'max' scenario, where very larger variation is observed (but still much lower than variation observed for effort in this scenario). This variation in forecasted landings is probably coming from the uncertainty in catchability coupled with the technical interactions among different stocks.

Very similar results were obtained for the Spanish 24 to 40 m bottom trawlers (ES_OTB_24<40m). For a complete description see ANNEX 13.

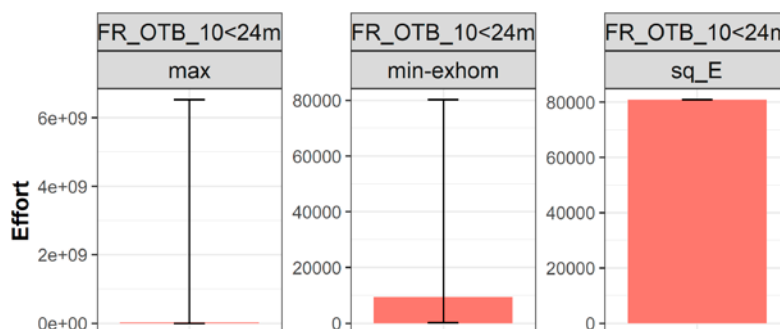


Figure 6: Variation in effort for the French bottom otter trawlers 10 to 24 m in length (FR_OTB_10<24m), given uncertainty in stocks' catchability, effort proportion by métier and quota shares by fleet and stock under alternative mixed-fisheries scenarios. Bars represent median estimates and vertical lines the 90% confidence intervals. Different scales are used because of the big differences observed between scenarios

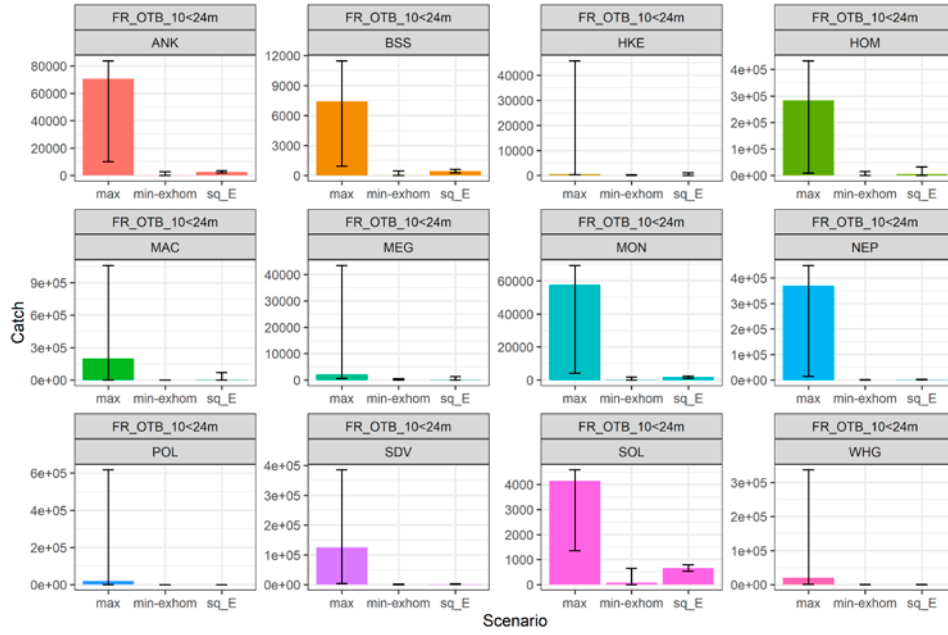


Figure 7: Variation in catches by stock for the French bottom otter trawlers 10 to 24 m in length (FR_OTB_10<24m), given uncertainty in stocks' catchability, effort proportion by métier and quota shares by fleet and stock under alternative mixed-fisheries scenarios. Bars represent median estimates and vertical lines the 90% confidence intervals

4.2.2 Global sensitivity analysis

GSA consists of the characterisation of the output variance of simulation models as a function of the variance in the input factors (Saltelli et al., 2008) (Figure 8). The difference between GSA and the common sensitivity analysis considered in most of the analysis of simulation studies (one factor at a time, OAT, sensitivity analysis) is that GSA considers interaction between input factors. In complex simulation models, the contribution of input factors to the output of the model is usually governed by its interaction with other input factors. Hence, OAT approaches underestimate the impact of input factors on the simulation results (Saltelli et al., 2019).

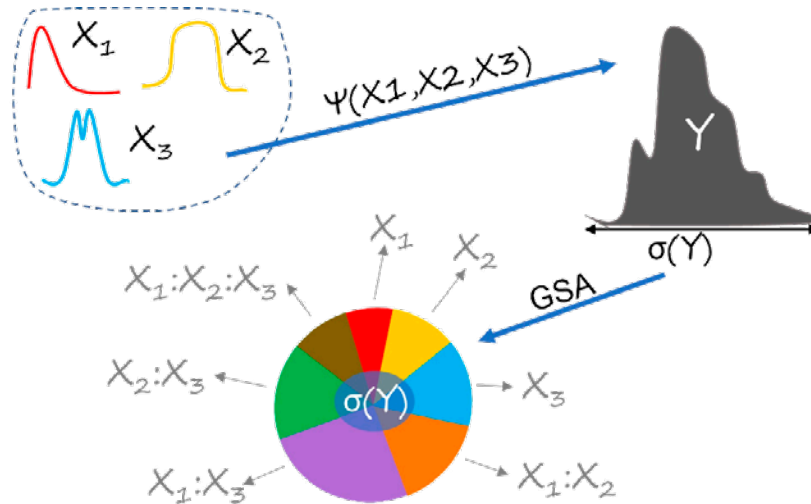


Figure 8: Graphical representation of GSA. X_1 , X_2 and X_3 represent the input factors for the GSA and ψ the simulation model, Y the output variable of the model, $\sigma(Y)$ the variance of the output and the coloured circle represents the partition of $\sigma(Y)$ as a function of the input factors and all their possible interactions.

GSA is very computationally demanding. To save computational time, only two indices are calculated: first-order and total-effect indices. The meaning of the indices is explained below and the mathematical details of their derivation and calculation can be found in ANNEX 13.

- First-order indices represent the amount of variance, in percentage terms, explained by each of the input factors isolation.
- Total-effect indices represent the amount of variance, in percentage terms, that is explained by the corresponding factor in isolation (first-order) and in interaction with all the other factors.

In this analysis we have followed the approach and guidelines presented by Garcia et al. (2021).

4.2.2.1 Results

In this report we focus on the results for the Spanish trawler fleet; results for the French fleet can be seen in ANNEX 13. The results are based in 5,000 based simulations that correspond to 175,000 iterations in total (5,000 iterations multiplied by the number of effective number of input factors (33) plus 2). We analysed three same fleet dynamic scenarios analysed in the uncertainty analysis in the previous section (sq_E, min_exHOM and max).

The total effort in the 'max' scenario depended mostly on the intensity exerted by the fleet in each of the métiers (Figure 9). Furthermore, the variance was mainly explained by the interaction between input factors. The quota share of some stocks in isolation explained some of the output variance. This happened because these stocks were the less-restrictive stocks for the fleet in some cases. In the 'min' scenario the most important input factor was the intensity in the 'DEF' métier that is the most important métier for the fleet. In this case, most of the variance was explained by the input factor in isolation. In this scenario the quota shares had higher impact and the impact was similar for all the stock except for ANK. For HOM the impact was almost zero because it never limited the effort of the fleet.

In the scenario where the effort was fixed 'sq_E' and the 'max' scenario (scenario where the fleets continue fishing until the last quota is exhausted) the only input factor that had a significant impact in the output variance of the stock catches was the intensity with which the stocks were caught (see ANNEX 7). The remaining factors had some marginal impact, especially quota share. The main difference between scenarios was that while in the 'sq_E' scenario the variance was explained almost exclusively by the input factors in isolation, in the 'max' scenario most of the variance was explained by interaction among factors. In the 'sq_E' scenario, the effort level, the variable that is directly related to the catch level, was fixed as an input parameter; hence the interaction between the input factors was low.

In the 'min_exHOM' scenario the variable with the highest impact was the intensity exerted in the most important métier (Figure 9). Furthermore, in most of the cases, most of the variance was explained by the input factor in isolation. In this case the quota share of all the stocks, except horse mackerel (HOM), had a significant impact on the output variance. The amount of variance explained by the input factor in isolation and in interaction with other factors depended on the stock.

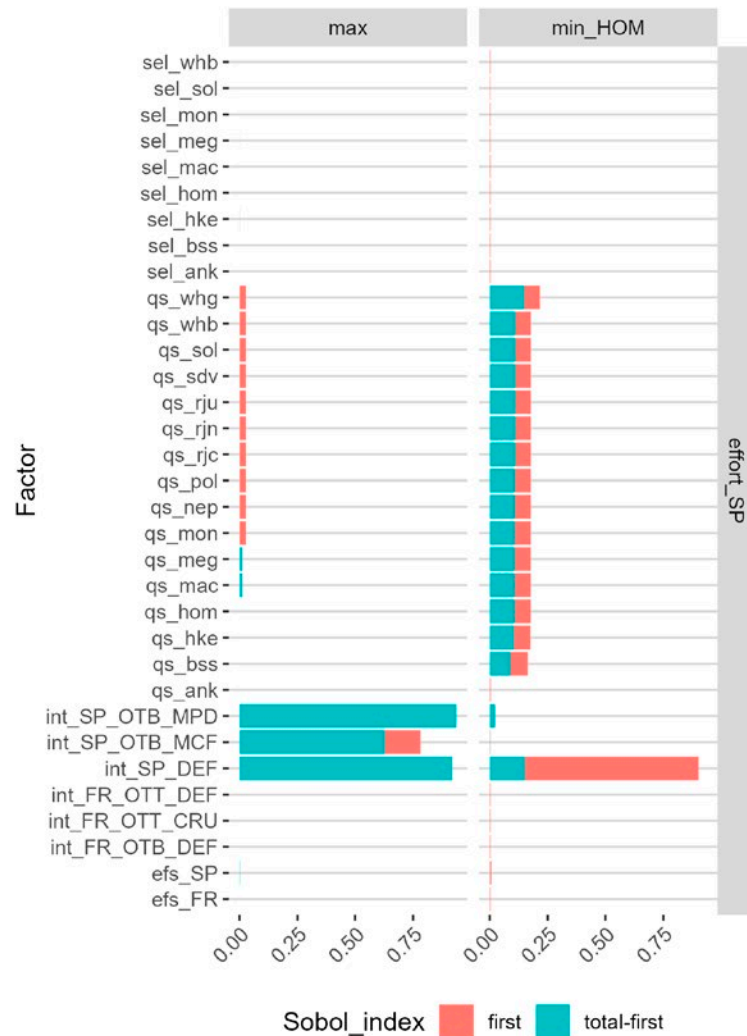


Figure 9: Global sensitivity indicators for the Spanish trawling fleet effort under 'max' and 'min' scenarios. The red bar corresponds to the first-order index and the whole bar, red plus blue, to the total index

The probability of being a choke stock was the variable that was affected by more input factors (Figure 11). As expected in this case, the quota share explained a significant proportion of the variance. The selectivity had little impact on catch and effort variables, however it had some significant impact in this case. The impact was almost always of first order, i.e. the interaction of selectivity with other input factors had minimal impact on the output variance. The effort proportions also had a significant impact in this case, in particular for white anglerfish, hake and smooth-hounds. The values around 0.25 and 0.15 for anglerfish, smooth-hounds and whiting are likely related to a convergence issue and do not indicate a real impact on the choking effect.

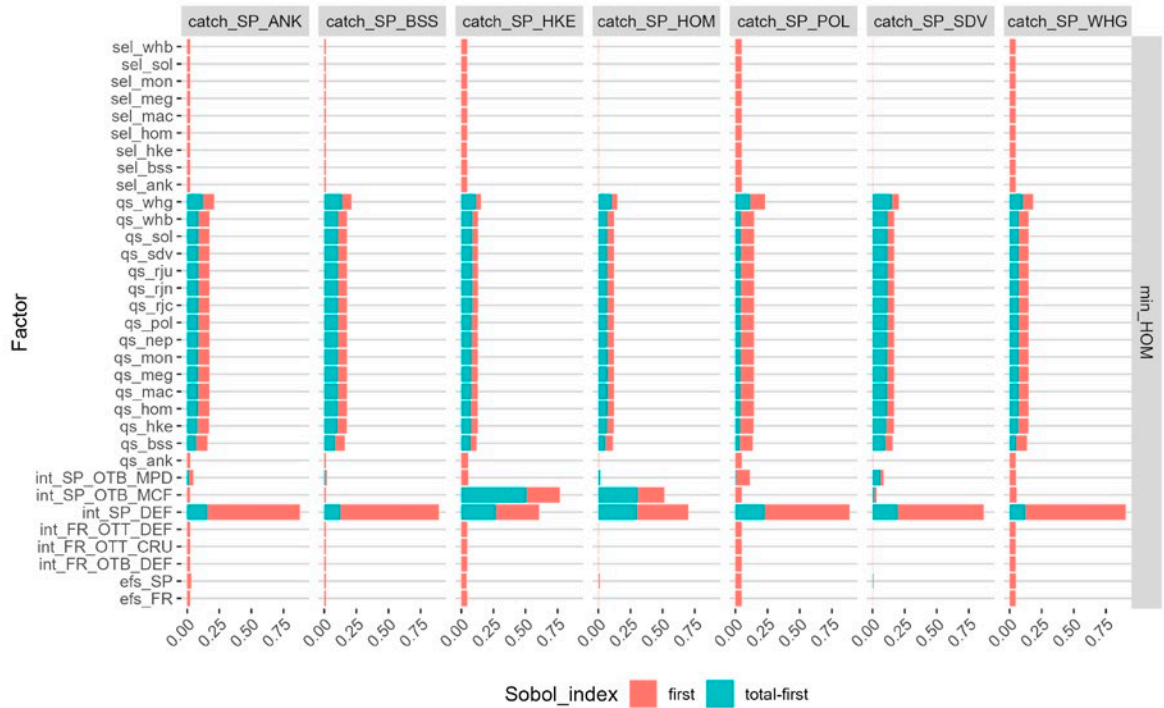


Figure 10: Global sensitivity indicators for the Spanish trawling fleet catch under 'min' scenario. The red bar corresponds to the first-order index and the whole bar, red plus blue, to the total index

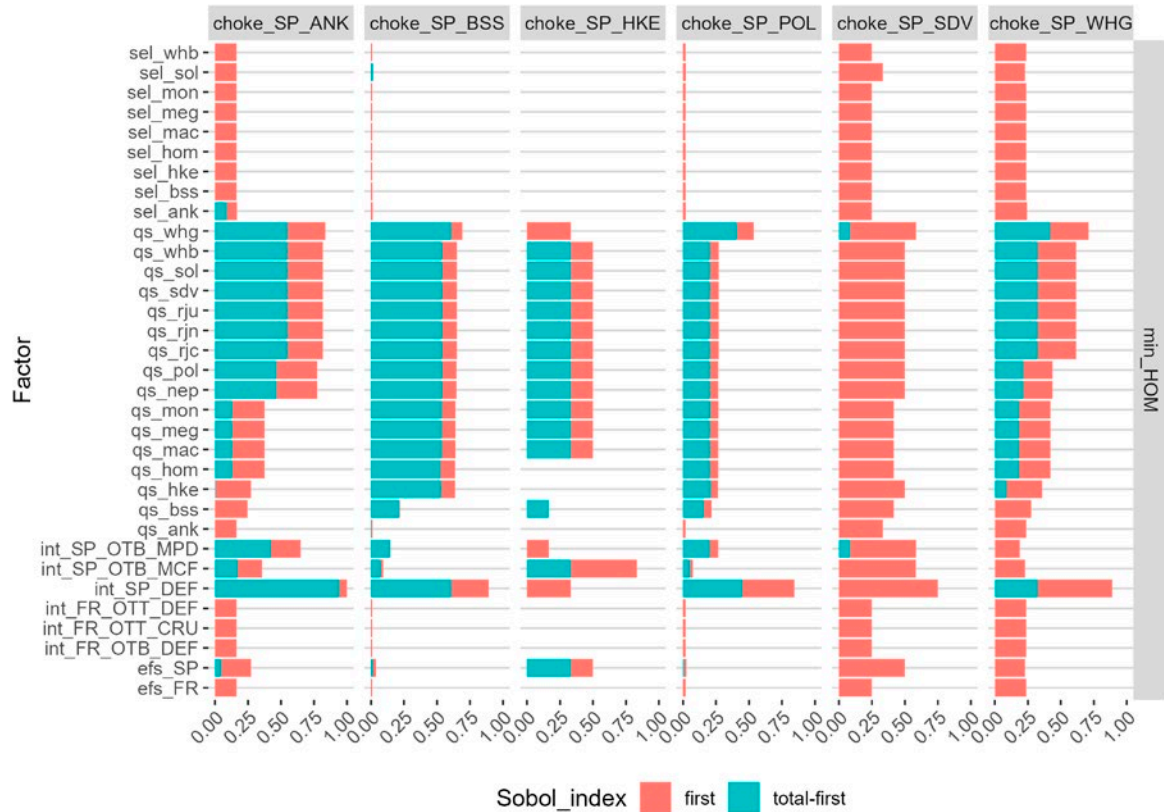


Figure 11: Global sensitivity indicators for the Spanish trawling fleet probability of being a choke stock under 'min' scenario. The red bar corresponds to the first-order index and the whole bar, red plus blue, to the total index

4.2.2.2 Conclusions and observations

The uncertainty conditioning approach estimates uncertainties in selectivity and intensity in two steps, extracting the intensity before modelling the selectivity. In the future, intensity and selectivity could be estimated simultaneously. The key problem would be to propose an appropriate model that accounts for the correlation among different species' intensities. As a further step, intensities could be modelled using a time-series-oriented approach (e.g. AR1 or random walks) so that predictions in one year depend on the predictions in the year before.

Introduction of uncertainty provided a better representation of plausible future situations. In a deterministic approach, a single stock is identified as the choke stock for each fleet in the landing obligation scenario. However, several stocks had similar probability of choking the fishery but were hidden in the deterministic approach.

The intensity with which the stocks are caught in each métier were the input factors that had the highest impact in almost all the output variables analysed. The variance in the intensity input factors was high. In fact, the confidence intervals were forced to be within the range of historical observations. The high uncertainty in the intensity could have conditioned the results, giving prominence to this variable to the detriment of the rest.

The selectivity had only little impact. The role of selectivity in the model is to give age structure to the catches but does not affect the volume. Thus, in the short term, where catch structure and biomass are not analysed, it makes sense that selectivity has no impact. However, in long-term simulations, when there is a feedback loop between the stock biomass and exploitation pattern, selectivity could have a significant impact. At present the output variables are not structured by age, however, should this be introduced it is likely that the impact of selectivity would be even higher.

Quota share explained a significant part of the output variance for some variables, especially in the event of strict compliance with the landing obligation ('min_HOM' scenario), but the amount explained was low in general. The low observed variability in the input data and the high variability in the intensity input factor could have led to a downplay of the importance of this input factor. Quota share was conditioned based on the historical catches instead of real quotas; therefore, including the uncertainty in the process of quota trading could be interesting.

Garcia et al. (2021) conducted a GSA in the Iberian Waters mixed-fisheries demersal system and found that effort-share was the most important input factor. However, in this case study, effort proportion among métiers had very limited impact. Garcia et al. (2021) applied the same variability to all the input factors, which likely over-estimated the variance in this variable and as a result its relevance was over-estimated. This contradiction highlights the importance of conditioning the uncertainty properly.

5 STOCK INTERACTIONS

'Technical interactions' is the term used to represent interactions between a fishing activity and the fished stocks, and forms the basis of any mixed-fisheries modelling. Therefore, for a robust model, it is key to understand the interactions between fish stocks caught in mixed fisheries.

Stock interactions within the ICES ecoregions where advice is produced annually are well explained in the corresponding advice sheets, advice report sections and Fisheries Overviews. However, there is still room for improvement, especially at a finer scale at both a spatial and temporal level. The work described in this section is a new detailed analysis of stock interactions at ICES rectangle level and fishing trip level.

The following sections present methodologies for exploration and analysis of stock interactions within mixed fisheries in the future. The examples presented were developed within the R environment (R Core Team, 2023) and all the code to run these methods for other datasets or ecoregions have been made available for use⁸.

The outcomes of the work described in this section are the results of a close collaboration between this study and several ICES working groups (notably ICES WKFO2 and ICES WGMIXFISH-METHODS) with contributions ranging from conceptualisation to code development in both directions. The reader is also referred to the ICES WKFO2 report (ICES, 2023a) for a number of alternative visualisations not included in this section.

5.1 Interactions at the ICES rectangle level

One of the key priorities of future mixed-fisheries models is an increased spatial disaggregation of the fishery to better account for spatial heterogeneity in terms of catch compositions. This could allow managers to identify areas with high choking risks, as well as more-favourable fishing grounds in terms of mixed-fisheries considerations. Typically, maps are produced that show the spatial variation in terms of catch compositions. Nevertheless, no single map can meet the interests of all end users, whose interests are likely to differ in terms of species diversity, fishing fleets, time frame or region. Therefore, more tools with interactive features are required to address this gap.

Currently, ICES and WGMIXFISH are developing such an interactive tool that will allow end users to explore catch compositions and effort distributions of fleets in space and time through a Shiny application⁹. Developing such an app is time consuming and requires specific programming skills and is beyond the scope of this study. However, members of the consortium have actively participated in the conceptualisation of this tool, and further developments via their participation in ICES WGMIXFISH.

The tool that is being developed uses FDI effort and landings data at the ICES statistical rectangle level by ICES ecoregion. Users can query the data via a dashboard by defining the following parameters: time frame (year range), vessel length categories (the categories used by the AER), gear types, mesh ranges and a selection of species. After filtering the data, 4 plots are shown that highlight the spatial landings composition for the selected input data by ICES statistical rectangle (i.e. the relative proportion of the colours in each grid cell), the spatial distribution of fishing effort, and the Pearson correlation between the landings and effort of the selected species and fleets, respectively.

Figure 12 shows an example of graphs that generated by the development version of the Shiny application. Developments are ongoing and aim to include visualisation of mixed-fisheries projections, as well as review some of the methods to, for example, calculate correlation statistics.

Alternatively, trip data can be used to prove information about technical interactions at the ICES rectangle level using a method similar to that described in 5.2 below. Figure 10 shows the number of trips in which a species had the highest share in terms of landings, as well as the share of other species in each of these trips in ICES rectangle 30E4. This gives a view, by strata, of how variable targeting is with respect to the main species caught, as well as the co-occurring species in each of those strata.

⁸ https://github.com/IrishMarineInstitute/STARMixFish/tree/main/lot_2/TASK_4/ and https://github.com/ices-taf/2023_WKFO2/

⁹ https://github.com/ices-tools-dev/mixfish_fo_app_dev/tree/main

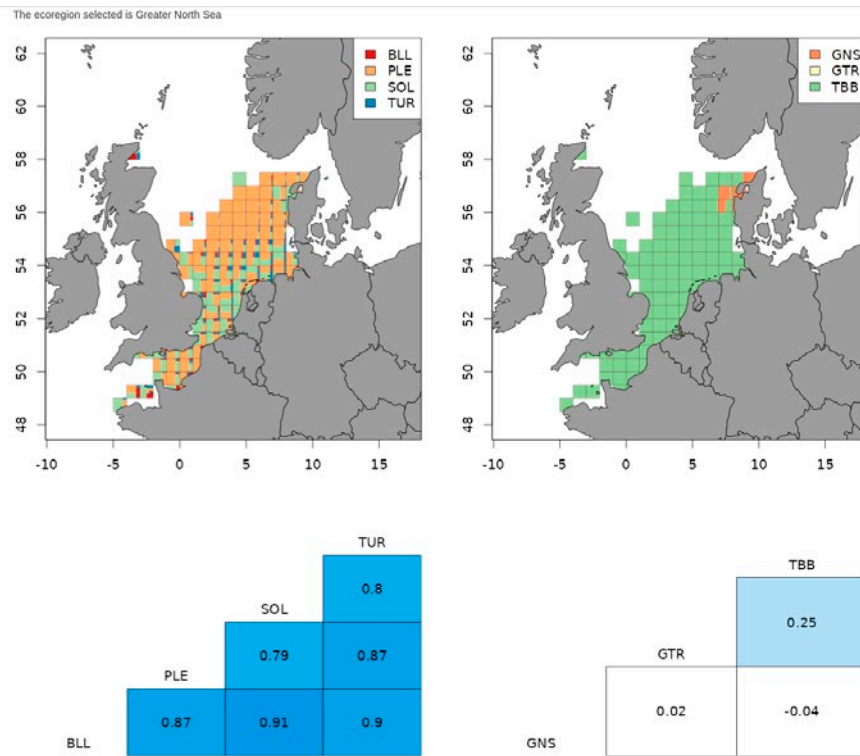


Figure 12: Screenshot showing the graphs (species composition in the landings for the selected species and fleets by ICES statistical rectangle, top-left panel: effort proportions by ICES statistical rectangle for the selected fleets; top right: correlation between the landings and effort with respect to the selected input data; bottom left/bottom right) created in the development version of the Shiny app developed in the framework of the ICES mixed-fisheries considerations

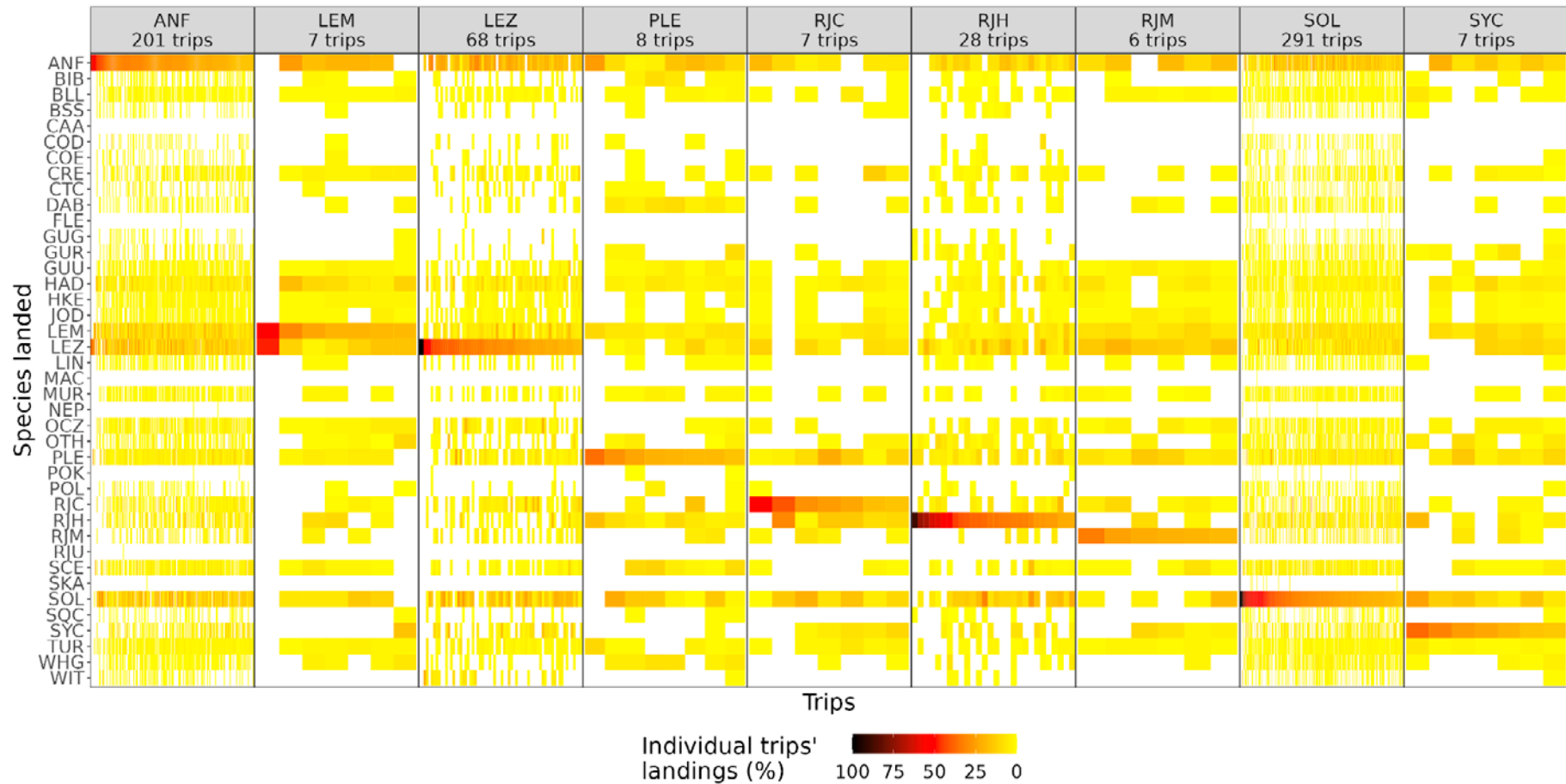


Figure 13: Targeting behaviour and catch composition by trip ordered by targeting for the Belgian beam trawl fishery targeting demersal species using mesh size 70-99 mm (TBB_DEF_70-99 m tier) operating in ICES statistical rectangle 30E4 in the Celtic Sea. Species abbreviations: ANF = anglerfish; BIB = bib; BLL = brill; BSS = seabass; CAA = wolffish; COD = cod; COE = conger eel; CRE = edible crab; CTC = common cuttlefish; DAB = dab; FLE = flounder; GUG = grey gurnard; GUR = gurnard; GUU = tub gurnard; HAD = haddock; HKE = hake; JOD = John dory; LEM = lemon sole; LEZ = megrim; LIN = ling; MAC = mackerel; MUR = Surmullet; NEP = *Nephrops*; OCZ = octopus; OTH = 'other'; PLE = plaice; POK = saithe; POL = pollack; RJC = thornback ray; RJH = blond ray; RJM = spotted ray; RJU = undulate ray; SCE = king scallop; SKA = skates and rays; SOL = common sole; SOC = sockeye salmon; SYC = small-spotted catshark; TUR = turbot; WHG = whiting; WIT = witch flounder.

5.2 Interactions at the trip and haul level

Trip-based data (e.g. from electronic logbooks or sales notes) were used to create new visualisations highlighting the variability in target behaviour and catch composition between individual fishing trips.

First, landing proportions at the trip level, or alternatively at a more disaggregated level such as the ICES subdivision, or statistical rectangle within a single trip, were calculated. From the landing proportions, trips were classified according to the dominant species in terms of landing composition. This classification enables trips to be grouped according to the 'target' behaviour (i.e. the species with the highest share in the landings). It also enables visualisation of how variable targeting is between trips of similar strata (e.g. gear, métier and/or ICES subdivision or rectangle).

Next, for each trip the catch composition is calculated. A colour code is used to indicate the proportion of the species in the landings (where black indicates high proportions and yellow indicates low proportions) at trip level. As such, the graphs show the variability in catch composition of trips with a certain targeting behaviour, as well as the relative number of other species caught alongside 'target' species. To aid visualisation, trips targeting species that contribute less than 0.5% to the total number of trips are excluded from the figure, and rare species are grouped in an OTH category. Such disaggregated visualisations are possible for many strata, and future work should focus on the development of interactive tools that allow users to explore strata of interest.

Figure 13 at the ICES statistical rectangle level, section 5.1, Figure 14, and ANNEX 14 show examples of the developed visualisation for a selection of Irish and Belgian fleets. For the Irish fleets, Figure 14 shows that catches of the bottom otter trawlers are mixed. Most of the bottom trawling trips target *Nephrops* effectively (shown by the dominance of black/dark-red colouring for *Nephrops* in the *Nephrops* panel). A number of trips targeting *Nephrops* also target anglerfish, comprising 25% of the catch, and a number of other species are also caught, i.e. megrim, haddock, hake, sole and witch. However, other bottom trawling trips targeting anglerfish, haddock, megrim or whiting are more mixed – for these trips, black is not the dominant colour and the yellow indicates that many other species are caught at lower proportions.

Study to assess the robustness of mixed-fisheries scenario assumptions

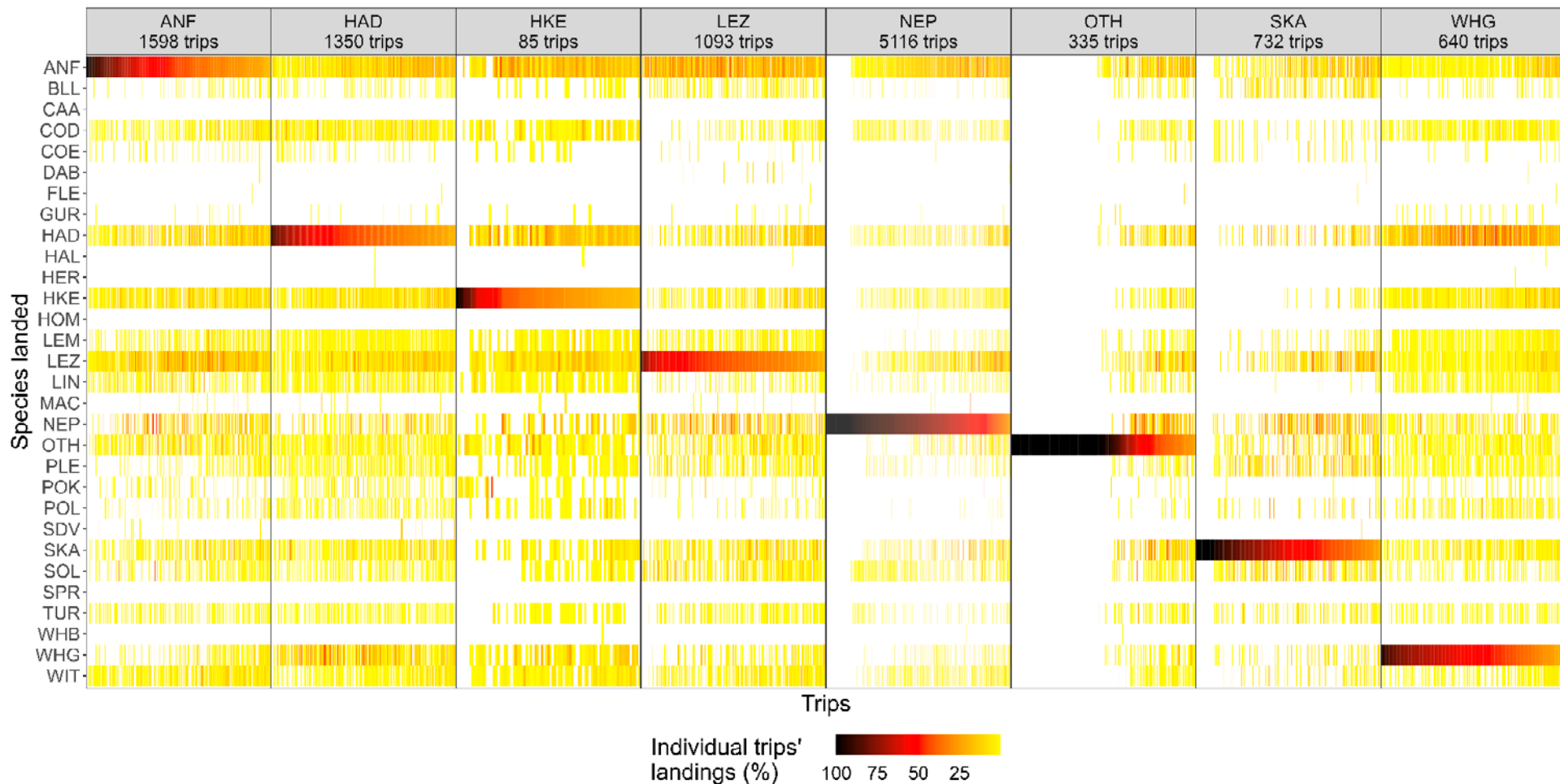


Figure 14: Targeting behaviour and catch composition by trip ordered by targeting of Irish bottom otter trawl gear (OTB) across all areas. Species abbreviations: ANF = anglerfish; BLL = brill; CAA = wolffish; COD = cod; COE = conger eel; DAB = dab; FLE = flounder; GUR = gurnard; HAD = haddock; HAL = halibut; HER = herring; HKE = hake; HOM = horse mackerel; LEM = lemon sole; LEZ = megrim; LIN = ling; MAC = mackerel; NEP = *Nephrops*; OTH = 'other'; PLE = plaice; POK = saithe; POL = pollack; SDV = smooth-hounds; SKA = skates and rays; SOL = common sole; SPR = sprat; TUR = turbot; WHB = blue whiting; WHG = whiting; WIT = witch flounder.

5.3 Additional factors

Within this study the investigation of ICES rectangle and trip-level interactions has highlighted further the diversity of interactions between species and stocks within localised areas, within and between trips. These interactions vary with spatial and temporal scale, along with the type of fishing activity carried out (the technical operation of the fishing activity – e.g. gear type). A number of alternative visualisations have been prepared, developed by Consortium members attending ICES WKFO2, and based on the ICES mixed-fisheries data used for the mixed-fisheries considerations. These alternative visualisations are intended to show interactions between stocks and fisheries, subsets of which are detailed below.

Figure 15 presents a subset of the technical interactions between métiers and stocks across the Bay of Biscay ecoregion. The full figure, and visualisations for the Celtic Sea and North Sea case study areas are presented in ANNEX 15 with additional ecoregions made available via web link¹⁰. Each visualisation allows identification of the important stocks within an ecoregion and the métiers landing them. The plot depicts the proportion of each stock landed within an ecoregion by métier, whereby columns sum to the total proportion of a stock landed in that ecoregion, totalling 1 if the ecoregion is the same, or larger than the stock area. Métiers are ordered according to their proportional importance within the area (summing the stock proportion landed by that métier). The métiers shown within the ecoregion are limited to those accounting for a proportion of at least 0.01 of stock landings within the area. This removes those métiers with very minor contributions from the visualisation to prevent overwhelming the plot with métiers of little impact within the area. The darker the colour of the cell, the greater the proportion of landings reported for a stock by a métier. The Bay of Biscay example presented below (Figure 15) has an interesting combination of stocks solely caught in the area and others with the majority of landings outside the ecoregion. The most important métier is OTB_DEF_>=70, which shows a diverse diversity of stocks caught. The OTB_CRU_>70 unsurprisingly catches most of the *Nephrops* (nep.fu.2324), with comparatively little contribution from any other métiers.

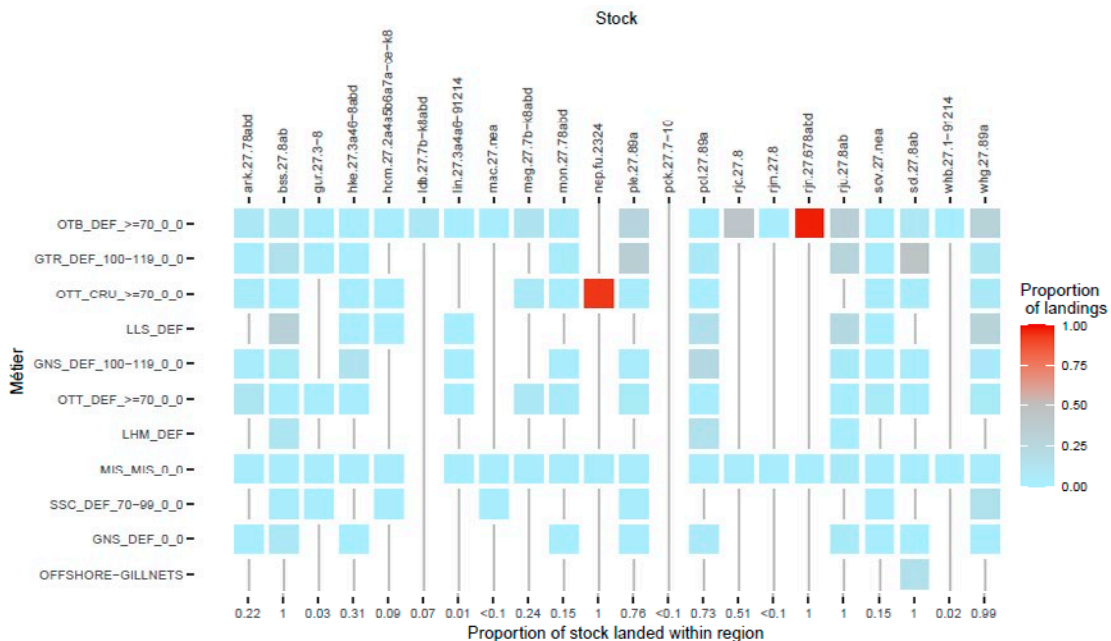


Figure 15: Subset of technical interactions between stocks and métiers within the Bay of Biscay in 2021

¹⁰ https://github.com/ices-taf/2023_WKFO2/tree/main/ToR_B/figures

An additional method of visualising interactions would be identifying high choking risks within an ecoregion, prepared by combining the degree of technical interactions (the number of strata in which species y is caught together with species x, divided by the number of strata in which species x is caught) and the ratio of the catch to the scientific advice released by ICES.

Figure 16 provides a subset of a such a visualisation for the Celtic Sea. The full visualisation and a North Sea example are given in ANNEX 16 and more detailed figures have been made available¹¹. Each panel shows a stock and the proportion of stocks caught together with this stock. The height of the bars shows how frequently a stock appears in strata of the stock shown in the title of each panel, while the colour of the bar indicates the ratio between the catch and scientific advice of a stock. Stock in red indicate stocks with a zero scientific advice. Noting that the numbers presented are the “encounter probability” and not related to landing volumes.

In the Celtic Sea for example, in around 45% of the strata where sole 7.e is caught, Celtic Sea hake and whiting are also caught, but the percentage of the scientific advice caught is very different in each of them (40% and 140% respectively), making only whiting a potential choke species for sole; additionally, around 40% of sole 7.e is caught together with Celtic Sea cod, where the red colour of the bar indicates that Celtic Sea cod has a zero-catch advice.

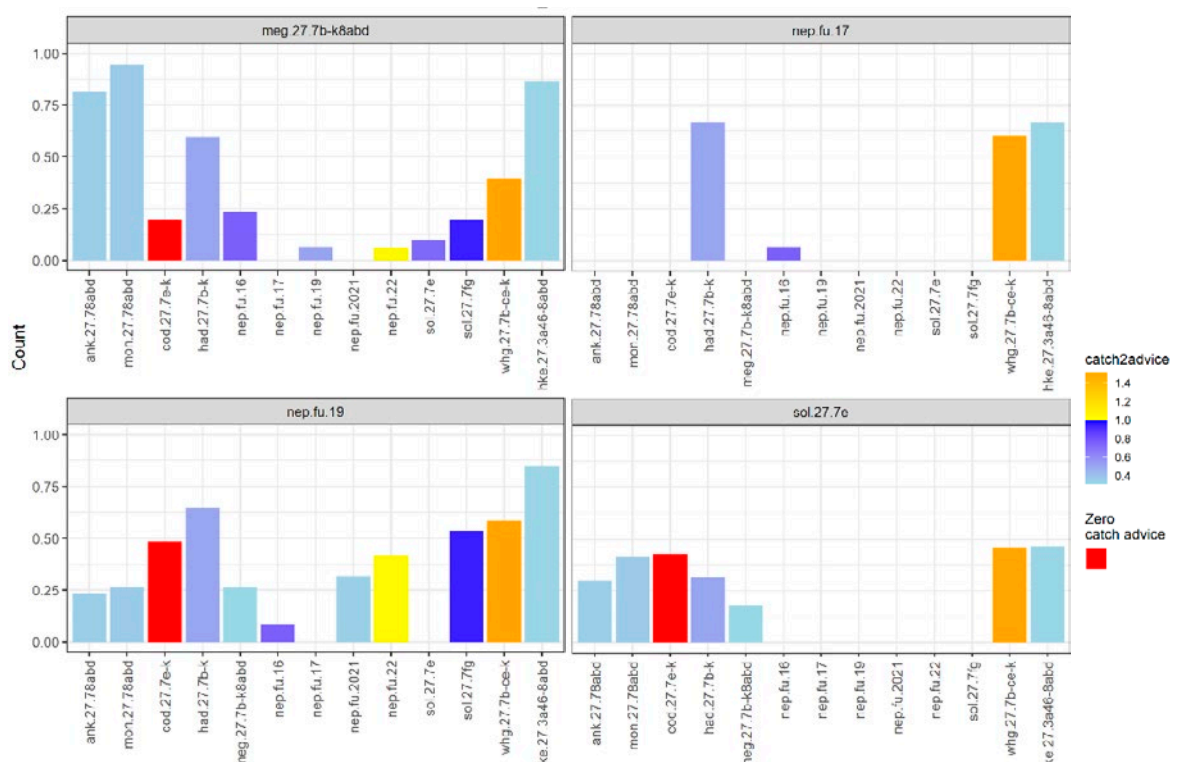


Figure 16: Subset of technical interactions between stocks and choking risk (catch uptake versus advice) for a selection of demersal fish stocks in the Celtic Sea for 2021.

Many trips have been shown to land 15 or more species, adding great complexity to the interactions. At present, none of the mixed-fishery assessments include all species. In most cases this will be as a result of the species inhabiting the same space and having varying degrees of susceptibility to the type of fishing operation. It should be noted that the investigations were carried out on landings data, which will bias the perception of interactions by excluding species with no commercial value.

¹¹ https://github.com/ices-taf/2023_WKFO2/tree/main/ToR_B/figures

Investigations into the impact of fleet and métier selections within the mixed-fishery models have shown that a balance is needed between the detail included to adequately represent the fishing operations, the impact on stocks as a result of interactions, and computational and interpretative limitations.

Technical interactions, and the measures used to alleviate pressures on stocks (such as gear changes or spatial and temporal closures) tend to occur at a finer scale than the fleets, métiers and stock levels used within the models to provide mixed-fishery scenarios. This is also linked to the granularity at which data is collected, particularly age, length and discard data that would prevent model disaggregation to the level required to enable scenarios to detect subtleties to alleviate pressures. The level of data granularity required to generate ICES mixed-fisheries scenarios for reducing pressure on vulnerable stocks is currently not feasible: if a vulnerable stock is considered to be a stock for which a zero TAC has been set, any métier in which that stock is caught is instantly choked, the result being the 'min' scenario. To work around this, ad hoc scenarios have been developed to test outcomes for a zero TAC stock by special request, where the constraints within the scenario have been adjusted. An example of this was the technical request made to ICES to provide advice on potential catches of zero-catch-advice stocks given fishing opportunities for target stocks. For Celtic Sea cod, three additional scenarios were provided using the Celtic Sea mixed-fishery model. Including catches: 1 – based on haddock fished at a level equivalent to maximum sustainable yield (FMSY); 2 – based on haddock fished at FMSY lower (MSY estimates are often given as a point estimate and a range of fishing mortalities may be associated with generating the MSY estimate, FMSY lower is the lower, more conservative, estimate of the range); 3 – based on haddock fished at an intermediate level between FMSY and FMSY lower (ICES, 2022c).

If single-species assessments are available, vulnerable stocks – defined as those stocks with impaired recruitment, or classified as an endangered threatened and protected (ETP) species – could be included within the assessment models. More and more category 3 assessments (ICES, 2016) are being developed for elasmobranchs for example, which could then be included within the models and within the scenarios. The restrictions here are the time required to include large numbers of these stocks, complexity of the resultant model, and what is wanted from the resultant scenarios. The outcome for many would be similar or the same as the outcomes for zero TAC stocks. At that point, the question of what is needed by the end user should become the primary focus to determine whether the current mixed-fishery assessment methods are what is required, or whether some alternative may be more appropriate, i.e., identifying ways to decouple, where possible, technical interactions.

The ICES WGMIXFISH group highlights that there is a need to develop and apply methods that can describe the strength of technical interactions between stocks, both quantitatively and qualitatively, to provide information about the impact of fisheries on the management outcome for other stocks. This alternative is being investigated intersessionally by several ICES member institutions, looking at developing spatially explicit clustering. Further information can be obtained from the 2023 ICES WGMIXFISH-METHODS report (ICES, 2023b).

6 FRAMEWORK DEVELOPMENT

This section considers how mixed-fishery assessment models could be extended from their current format. This is done through development of conceptual frameworks. The current mixed-fishery models are under continuous development to find ways to more accurately represent the real world in order to provide the best projections of the implications of mixed-fisheries considerations on stocks caught together. This information can then be used to identify impacts of management measures, and provide a scientific grounding for variations to these measures as necessary.

6.1 Scenario evaluation

Implementation of technical and spatial measures can have direct impacts on the composition of catch (e.g. Cosgrove et al., 2019; Browne et al., 2021), which in turn can have impacts on fishing pressure, stock dynamics, economic viability of a fishery and markets. There is a growing need to incorporate these downstream impacts into our understanding of mixed fisheries. If operationalised, it would allow scientists and stakeholders to explore long-term impacts of proposed and implemented measures. On this basis, the main objective of this section was to develop a conceptual framework detailing how gear and technical measures might be accounted for in mixed-fisheries assessments. Mixed-fisheries models could be used to evaluate alternative management scenarios, including technical measures (i.e. gear changes) or spatial closures.

This framework has identified the data, methodologies and steps that would be needed to be able to take account of the impact of gear-based and spatial technical measures within ICES mixed-fishery projections. Additionally, the framework outlines how such management scenarios could be evaluated through the mixed-fisheries models that are currently used for producing advice considerations. This framework will be developed around FLBEIA, which can already be used to develop scenarios able to account for gear-based technical measures. Although the FLBEIA model is not yet used to produce advice in all ICES mixed-fisheries considerations ecoregions (the Celtic Sea is currently within Fcube), the code and models do exist, and will be used to aid development of the conceptual framework. This framework could be operationalised within ICES.

6.1.1 Baseline scenarios

The implementation of any scenario around management measures requires two quite different approaches: one for gear selectivity and another for spatial closures. These two approaches are detailed below.

6.1.1.1 Selectivity measures

Assessing the impact of mesh-size changes or selectivity devices such as escape panels in trawl gears can be done in mixed-fisheries models if some pre-conditions are met.

First, information needs to be available on how gear changes affect a métiers' selectivity through changes in catchability. Such information is typically obtained from gear trial studies, or alternatively, expert knowledge can be used. Such information needs to represent a relative change of the new catchability value compared to the existing value.

In practice, several difficulties often arise when transferring results from gear trial studies to mixed-fisheries models. One needs to be able to match the gear and mesh size used in the study to the métiers used in the mixed-fisheries models. In case of aggregated métiers (i.e. those that represent a wide mesh-size range) this is difficult. The amalgamation of the fine-scale métier structure within the current mixed-fisheries models may limit effective implementation of gear changes when the gear change is too subtle to be detected within a larger métier grouping.

The second difficulty of gear trial studies is that they often provide information about changes in catch efficiency with respect to the size structure of a species. If the size category of such studies does not correspond with the size structure used in the mixed-fisheries models, post-processing of those results is required according to the size/age structure of the mixed-fisheries model. In most cases, a change from length (gear trial study) to age structure (mixed-fisheries projections) is needed, requiring information on growth parameters. In the case of age-aggregated mixed-fisheries models, if no such aggregated estimate is available, the catchability of a métier can only be changed with respect to the selectivity of the fishery (at the stock level).

Another shortcoming that may arise from using gear trial studies to parametrise selectivity is that the study needs to inform the model on the changes in all species considered in the mixed-fisheries model. However, in practice, gear trial studies are often targeted on a limited number of (commercially important) species, and the trial fishing grounds are often therefore chosen as a function of the species of interest with potentially a limited number of catches of other species (and thus information on change in selectivity) relevant for the mixed-fisheries models.

Gear changes are also likely to affect the tactical behaviour of fishers in terms of spatio-temporal fishing effort allocation, or gear/mesh-size used. If a gear change results in a loss of commercially important species and makes a métier less profitable, it is likely that the fleet affected would allocate relatively more effort to alternative métiers if possible. It is important to consider such changes in fleet dynamics in mixed-fisheries models that can be done through either a scenario analysis (where effort proportions of a fleet are set according to some predefined values) or the implementation of a dynamic model of effort proportion allocation. Ideally, this would include some optimisation procedures as presented in section 3, eventually including some economic factors in the objective function.

Finally, there may be uncertainty around the new catchability estimates if, for example, uncertainty estimates are available from gear trial studies, or if multiple studies are available with diverging results. Ideally, such uncertainty needs to be integrated in the mixed-fisheries projections (see section 4) and assessed through an MSE framework.

6.1.1.2 Spatial closures

The mixed-fisheries models that are used for advice are not spatially explicit, though the effect of spatial management measures could be investigated implicitly by defining métiers that represent distinct spatial areas. As such, all spatial effects are captured through the catchabilities of the métiers, where a métier that fishes in an area with low density for a certain species would be characterised by a low catchability for that species, and vice versa for that métier with exactly the same technical properties. Hence, the catchabilities would capture both technical gear and vessel characteristics, and the spatial heterogeneity of the stock (although, cannot strictly speaking be called catchability in this case as the term also includes density of the stock).

In theory, fleets/métiers can be disaggregated to the spatial level of the data, e.g. a métier by ICES statistical rectangle. However, from a practical point of view there are a number of caveats that would need to be considered, as highlighted below.

Disaggregating métiers into more discrete spatial units could result in a high number of métiers, which may come at a computational cost. Therefore, it is advisable to limit the number of métiers by grouping spatial strata according to similarities in catchabilities. Alternatively, new software should be developed that is more performant in terms of fleet/métier dimensions than the current software used for mixed-fisheries projections. Furthermore, there is currently a limited number of datasets available that would allow the definition of such spatially disaggregated métiers. The FDI database, and future RDBES database, provide both landings and effort at the ICES statistical rectangle level; nevertheless, information on discards or age-disaggregated catch information are

limiting the usability of these datasets, and assumptions on how to impute these data gaps should be made to address these data gaps. Alternatively, national databases could be used to inform spatially disaggregated métiers; however, this is often hampered by data protection regulations in terms of commercial sensitivity and confidentiality.

Disaggregating métiers to account for spatial variation would only have an effect if effort proportions across métiers used within the models are not fixed. This requires the implementation of fleet dynamics models that allow predictions of where fishing effort would be reallocated in case of spatial closures, or changes in spatial distribution of fish stocks. Such fleet dynamics could rely on the optimisation of an economic objective (e.g. profit) by fleet, or more heuristic decision rules. In addition, constraints should be defined so that the catches in a particular area (e.g. ICES statistical rectangle) cannot be larger than the biomass in that area. This could be done by assigning biomass shares to each spatial units based on, for example, species distribution models fitted on survey data.

Disaggregating métiers and adding alternative fleet dynamic models is likely to have an impact on the level of uncertainty, either through the data used to condition métiers (for example to reflect spatio-temporal variation in species distribution) and structural uncertainty through the assumptions related to fleet dynamics. Ideally, these sources of uncertainty should be considered when assessing spatial management scenarios with mixed-fisheries models through MSE.

6.1.2 Conclusions and observations

There are a number of modelling frameworks available that could be used to develop management scenarios around technical measures and spatial closures, such as FLBEIA (Garcia et al., 2017) and DISPLACE (a spatial model of fisheries to help sustainable fishing and maritime spatial planning; Bastardie et al., 2013). These modelling frameworks are data hungry and require many streams of data to answer the pertinent biological and economic questions. In recent years, a number of advancements have improved the alignment of biological and economic information supplied under the DCF, aligning FDI and AER (STECF, 2023a). Improvements in the alignment of fleet segments reported to both data calls, along with the availability of the fishing fleet segment variable in the RDBES, will provide an internally consistent baseline from which to build fleets that are capable of assessing downstream impacts.

Parameterisation of these complex models and scenarios requires a multidisciplinary team, incorporating skills in modelling, fisheries stock assessment, economics, gear technology, and social science. Occurrence of such forums is on the increase, with cross-team collaborative research-project working groups within ICES (WGMIXFISH, Working Group on Economics (WGECON), WKMIXFISH) and expert working groups within STECF (STECF, 2023b). However, to ensure momentum in development is maintained, long-term investment in research and development is required.

6.2 Rebuilding stocks

Currently, mixed-fisheries considerations are based on a two-year forecast of stock assessment model-output and catch-and-effort data at métier level. This is because, in single-stock short-term forecasting, everything is considered constant in the projection period. Although this assumption is considered valid in the short term, to evaluate stock rebuilding in the long term it is necessary to introduce dynamism and uncertainty to the projection.

The FLBEIA model (Garcia et al., 2017) used in most of the mixed-fisheries case studies was built for long-term simulations and has all the elements needed to run long-term mixed-fisheries simulations. In fact, it has already been used to analyse the performance of management strategies in a mixed-fisheries framework (see Garcia et al., 2019; Garcia et al., 2021). In comparison, the Fcube model was built to run short-

term projections, but it is possible to extend it to run long-term projections in specific cases.

The steps required to extend both models to produce mixed-fisheries considerations in order to analyse stock rebuilding in the long term are shown in Figure 17 below. The first step is to define the dynamics of the processes that form the system. The system can be divided in three main components: the stocks, the fleets and the catch-advice components. In turn these three components are formed by several processes. To simulate these processes into the future a mathematical model is needed to describe their evolution along time, the system dynamics. Furthermore, as the knowledge about system dynamics is limited and there is high natural variability in these processes the long-term simulations should include uncertainty in most of the processes.

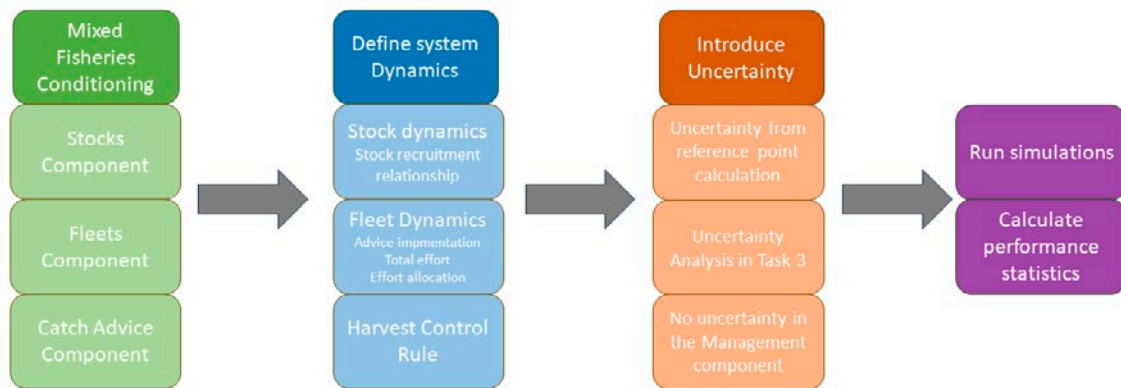


Figure 17: Conceptual diagram with the steps required to run long-term simulations from mixed-fisheries model conditioning

In this section we list the three processes that need to be modelled in long-term simulations and a detailed description of system dynamics modelling and uncertainty conditioning can be found in ANNEX 17.

- **Stock dynamics:** This component describes the evolution of stock populations over time. In the base case the populations are usually projected forward using an extension of the stock assessment model used to estimate historical abundance and exploitation level. In addition, in the case of length and age structured models, and stock recruitment model needs to be defined to project the population forward. Uncertainty in stock dynamics is already considered in the calculation of the reference points and it represents a good starting point to introduce uncertainty when analysing stock rebuilding. Data limited stocks represent a particular challenge and data-limited approaches that represent the existing uncertainty adequately are needed.
- **Fleet Dynamics:** The main processes to dynamically model the fleet component are the total effort, the effort share among métiers, the quota share and catchability. Total effort and effort-share are usually calculated within the same model and several models are available in the literature. The simplest approach is to use an effort share based on historical observations and to calculate the total effort based on the quota-share of the stocks. For quota-share and catchability mechanistic models are not available and approaches based on trends in historical data should be used. The conditioning of uncertainty of the fleet component has typically been overlooked and the approach described in ANNEX 12 represents a good starting point.
- **Management procedure:** In the management procedure the main component is the harvest control rule (HCR) which calculates TACs based on the status of the stocks. In the simplest case, the HCR can use the stock status directly from the biological operating model. In more complex cases, a full feedback approach can be used where an observation model for data and an assessment model to obtain stock status estimates are used. An intermediate approach could be a short cut approach

where some error is added to the stock indicators in the biological operating model to mimic the assessment model error. FLBEIA is able to simulate any of these approaches. There are many HCRs already available, and implementing new ones is considered to be easy.

When running long-term simulations the number of iterations required and the number of years in the projection are both important factors. Whereby the model is allowed to run until a steady state is reached, which depends on the lifespan of the stocks. The number of iterations is usually no fewer than 1000. Mixed-fisheries models are complex models that require a large amount of computational time when running several iterations and projecting several years. Thus, analysing stock rebuilding with mixed-fisheries models would require a high-performance computing system such as a cluster with various nodes.

The final requirement associated with long-term projections is the need to include performance statistics. In mixed-fisheries models performance statistics need to summarize the performance of the fleet in addition of the performance of the stocks. As there are no specific objectives at fleet level, it is not possible to define performance statistics that measure the achievement of the target. However, there are useful performance statistics that could be calculated at both the stock and fleet level. All of which can be calculated annually and then select specific years or calculate the mean of the indicator along different time periods. In relation to stock level these would be:

- The Probability of being below Blim
- Ratio between fishing mortality and fishing mortality target
- Total catch
- Depletion level or other indicator of relative biomass
- Inter annual variability in catch

In relation to fleet level these performance statistics could include:

- Probability of being a choke stock.
- Implementation error in catches at stock and fleet level. Implementation error arises naturally in mixed-fisheries models as reaching all the catch quotas simultaneously is impossible. The difference between the catch quotas and the real catches provides an idea of the use of fishing opportunities at fleet level.
- Total yield.
- Variation in total effort.

6.3 Incorporating additional stocks

A framework to include new stocks in mixed-fisheries models is presented in detail in ANNEX 18.

The key factors to consider when including a new stock in mixed-fisheries models are the economic importance of the stock, its relevance for the mixed fisheries in terms of technical interactions with the other stocks in the model, and the availability of a stock assessment and catch and effort data. When including new stocks, there is generally a trade-off between improving the description of the mixed fisheries under consideration and including potential new choke stocks, and a decreasing ability to appropriately model the dynamics of the new stocks. Therefore, adding more stocks to better describe the technical interactions in the fisheries would at some point be of limited interest if the dynamics of the stocks to be added cannot be modelled (as they are likely to lack an assessment). The number of stocks that can be included is also necessarily limited, as the models need to be updated every year and the work this represents has to be manageable.

Adding stocks with an analytical assessment or a biomass based assessment is in principle technically straightforward, as the mixed-fisheries models have been

developed for that purpose. The models were developed to accommodate stock with age-based assessment (category 1), and the frameworks were extended to biomass dynamics stocks (partly during the DRuMFISH project (EASME, 2018)). However, the increasing complexity of the stock assessment tools used at ICES, represents a challenge for the incorporation of these stocks. For example, the number of stocks for which the advice is based on stochastic forecast has increased, and this cannot be reproduced in the current mixed-fisheries models. The conversion of (age-) length-based assessments (for example conducted using stock synthesis) to simple age-based stocks used in the mixed-fisheries model can be problematic. New types of models, such as the new multi-stock assessment for Northern Shelf cod also represent new challenges for the Mixed Fisheries groups.

6.4 Developing new Areas

ICES currently covers a number of mixed-fisheries regions within its mixed-fisheries assessment process. However, a number of additional areas would benefit from an increased understanding of the mixed-fishery interactions and implications of changing stock health on the fleets and fisheries operating within an area, for example the west of Scotland. A development process already exists within ICES to aid the development of new area-based mixed-fishery considerations.

The flow diagram below (Figure 18) highlights the development process to clarify the current process, providing the sequence of events. The detail of what occurs within the various decision diamonds is given within ANNEX 19. There are two primary routes into initiating development of a new area of assessment: a formal request made to ICES from an external body (like the EU, Norway, UK); or informally, where interest generated within ICES or through other research and development indicates that such an assessment would aid a possible future management issue (horizon scanning). Many of the current assessments have originated from the informal route along with a large part of the mixed-fisheries methodology development, which results from the commitment of individuals to carry out research and development work intersessionally. Much of the new Irish Sea assessment development has occurred within this intersessional space.

The development of new regional mixed-fishery considerations is a lengthy process from the initial stages of identifying a need for an assessment, through the collation and quality checking of data, to model development, and finally peer review and benchmarking.

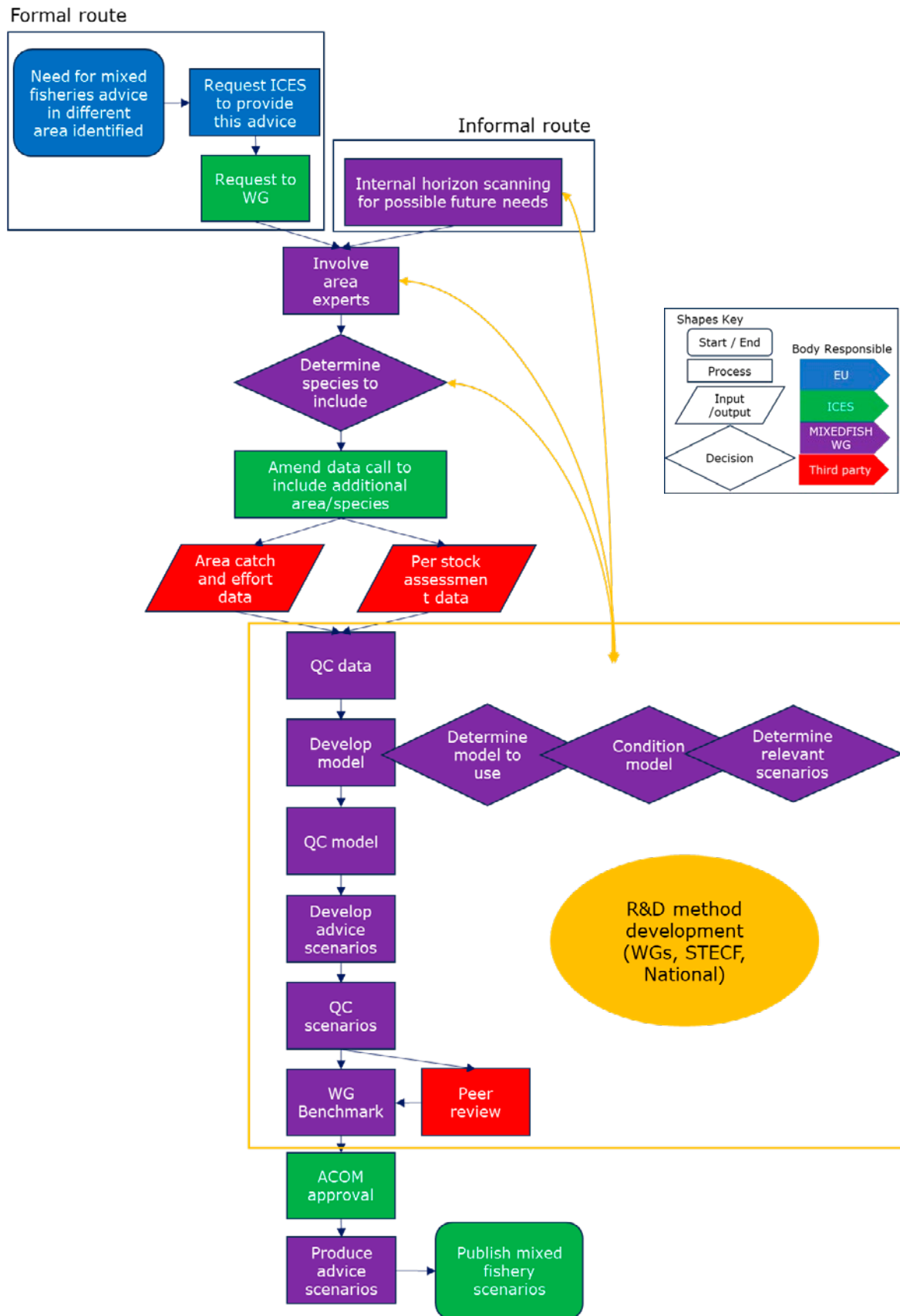


Figure 18: Flow chart of current development process for generating mixed-fisheries considerations for a new area

The most recent example of assessment development is the Irish Sea ecoregion, released by ICES in 2022. This outlined mixed-fisheries scenarios, based on advised catches for cod, haddock, *Nephrops* and whiting in the region. Mixed-fishery scenarios are based on minimum, maximum, and status quo effort scenarios for the aforementioned stocks, with the addition of plaice and sole¹². The process followed in developing the model and advice for this region was presented to ICES WGMIXFISH in 2022. This was agreed by the group to be an example of best practice for generating advice for new regions. The below highlights the additional steps the assessment went through prior to its acceptance by ICES. The information was kindly shared by the key developer of the new Irish Sea mixed-fisheries assessment, Ruth Kelly (AFBI).

The Irish Sea mixed-fisheries Fcube model was developed in conjunction with WGMIXFISH over a period of four years (2019-2022), and model developments were documented in the WGMIXFISH report over this period. Each meeting of the WGMIXFISH over this period enabled those scientists working on the Irish Sea model to benefit from the expertise, analyses, code and experiences encountered in the development of assessments for other ecoregions.

Prior to the acceptance of the Irish Sea assessment, there was no formal requirement for a model benchmarking mixed-fisheries products. However, in the case of the Irish Sea, and for other regions, it was proposed that a more formal review process was desirable. Therefore, the following steps were followed prior to issuing the first advice product for the Irish Sea:

1. an internal WGMIXFISH model review meeting was held (benchmarking with other ecoregions);
2. a review report and stock annex were written;
3. the review report, draft stock annex and fully reproducible model code were sent to an external expert by ICES for review and approval (external peer review).

On 22 August 2022, 15 members of the WGMIXFISH group attended the WGMIXFISH benchmark review. The presentations and report of the meeting covered: model background, software, data sources, treatment of *Nephrops* functional units, fleet and métier definitions, ability to reproduce advice and advice scenarios for 2022 (with estimated values for *Nephrops* used where surveys and advice were not yet available). The draft stock annex was also included as an appendix to the report for external review. These documents, along with fully reproducible model code, were made available to the external reviewer on the ICES SharePoint, and the reviewer was selected and contacted by the ICES professional officer for WGMIXFISH.

The peer review in mid-September 2022 allowed sufficient time for the model and advice product to be included in the WGMIXFISH advice meeting in October 2022, and advice production in November 2022 (ICES, 2022c; ICES, 2022f; ICES, 2022g). This process ensured a high degree of model scrutiny and external quality assurance prior to publication of the ICES advice product. WGMIXFISH deemed the development process a good template for the development mixed-fisheries considerations for new regions.

6.4.1 New model developments

6.4.1.1 Baltic Sea

WGMIXFISH-METHODS is currently looking at developing a model for the Baltic ecoregion. Work is at a very early phase, i.e. the group is examining and reviewing the data available for use in development. Currently, data for the ecoregion is submitted to the ICES data call at a gear resolution of 'active' or 'passive'. It has been highlighted

¹² <https://doi.org/10.17895/ices.advice.21532950>

(ICES, 2022b) that the level of granularity in the data is currently insufficient for development of an assessment for this ecoregion.

6.4.1.2 West of Scotland

West of Scotland has been under consideration for production of a mixed-fishery assessment intermittently since 2012. In 2013, the WGMIXFISH-METHODS group began an application of the Fcube methodology. While it was stated that 'significant progress was made' (ICES, 2013), the group considered that there was no certainty the expertise for the West of Scotland was going to be available going forward, and concluded there was no clear route to transitioning to the regular provision of mixed-fisheries considerations for the region (ICES, 2013).

In subsequent years, a West of Scotland extension to the North Sea Fcube model was trialled. The latest trial was in 2020, when the WGMIXFISH-METHODS group presented results from an updated North Sea – West of Scotland (NS–WoS) implementation of Fcube (ICES, 2021a). The group reproduced and updated the older implementation with what was in 2020 the most recent data available at the time (2019 data). This version used the same setup and data processing as the North Sea implementation and included West of Scotland cod, West of Scotland whiting, *Nephrops* from functional units 11–13 and the more widely distributed anglerfish and megrim.

At that time, the group believed it would be worthwhile to continue to develop the inclusion of West of Scotland stocks into the mixed-fisheries considerations. Since then, the North Sea implementation focus within WGMIXFISH-METHODS has been to develop a North Sea FLBEIA model, and the West of Scotland inclusion has been put on hold.

In terms of next steps for the NS–WoS mixed-fishery assessment in relation to the flow chart (Figure 18), the assessment development is in its infancy. The first step will need to be commitment from experts to ensure that there is sufficient availability, particularly from Marine Scotland Science (MSS) and the Agri-Food and Biosciences Institute (AFBI). From there, the focus will need to be on a review of the species to be included, and further development of the model. The group highlighted a number of focal points for the model development process (ICES, 2021a), which will need to be considered after the current Fcube NS–WoS model has been converted into an FLBEIA model. Focal points to be considered include:

- a need to consider a mixed fishery of the two herring stocks covering these areas;
- the most appropriate method for defining, conditioning and modelling behaviour.
- the behaviour of fleets in the minimum and maximum scenarios, where fleets may be restricted by fishing on North Sea stocks by West of Scotland quota and vice versa and stop fishing completely, whereas in reality these fleets would continue to fish in the other area;
- review of the intermediate-year assumptions.

7 CONCLUSIONS

Traditionally, single-species advice is considered when setting total allowable catch limits, however single-species advice does not account for the technical interactions that occur in mixed fisheries. When multiple stocks are caught together, overexploitation of the more vulnerable species, or missed fishing opportunities due to choking poses issues. To overcome these, mixed-fisheries models have been considered, which integrate the implications of capturing multiple species within multiple fisheries with different catchabilities and targeting behaviour or objectives. ICES provides scenario-based considerations focused on the use of two models at present: Fcube and FLBEIA.

This study investigates the implications of assumptions and decisions made within these models to provide ICES mixed-fishery considerations. Specific case studies are used to examine the impacts of changes to the design of fleets and métiers, the settings used within the models, and how these models could be extended in terms of stocks or areas through the development of frameworks. The work in this study is closely linked to the current workstreams of the ICES WGMIXFISH, and part of the work presented was done in collaboration with members of this group, and the members of ICES WKFO2 in relation to stock interactions. Mixed-fisheries is a high-priority topic within ICES, and has been under development for more than 10 years. Within that context the current study provides a focal point for further research and development.

7.1 Data availability

Modelled technical interactions must account for the complex nature of fisheries, at a resolution that is meaningful to the end users/managers. This requires input data to be available at a level able to detect fisheries dynamics (seasonality, closures, fisher decisions). This is, as a minimum, at the métier level with information on both target and bycatch stocks, and where possible gear-based selectivity information. The data used within this study come from three main sources that offered a varying level of detail: Member States (trip level), ICES (métier level), and the EU DCF in the form of the STECF FDI data (spatially disaggregated, statistical rectangle level). The main challenge was obtaining data that accurately reflect fleet activities at a meaningful resolution. The study has been constrained by the data available. A tailored data request, in which additionally disaggregated data would be requested from all relevant nations within the North Sea, Celtic Sea, and Bay of Biscay, was not possible. In consequence, the scope of case studies within each area has been dictated by the data made available within the timeframe of the study.

Particular issues were encountered within the Bay of Biscay data, which showed missing information for some Member States in earlier years. This required shortening of the time series to reduce the impact of such missing information. No other particular issues were identified in the remaining case study areas.

Technical interactions can only be identified at a very fine scale, the preference being at the individual haul level. The impact of using haul level data compared to courser scale data to identify interactions is currently not identifiable. In an Irish example using trip level data at the statistical rectangle, decoupling species interactions was not possible. Work is ongoing to look at the possibility of using VMS level data for this purpose. However, there are very few datasets available at such a fine scale because these are often not recorded during a fishing trip. Trip-level data can be made available in some instances within a Member State but is compounded by confidentiality issues of sharing such data either with other Member States or in a public arena. The developing RDBES aims to partially address this, linking multiple data sources for consistency. However, it is unlikely that haul- or trip-level data will be available for all data types used within the mixed-fishery assessment models and its spatial resolution is limited.

To overcome this limitation, bespoke datasets from Member States, based on VMS, EFLALO and AER data are being explored.

7.2 Assessment of model uncertainty and sensitivity

The basic building blocks of all mixed-fisheries models are the fleet (or fleet segments), and the métier. At present, ICES WGMIXFISH defines fleets based on nationality, vessel size groups, and aggregations of métier that use particular combinations of gear and target assemblage. Fishing activity is extremely diverse, with no two hauls resulting in the same outcome, and as such an incorrect grouping within mixed-fishery assessments can mask valuable information on interactions between stocks.

This study has reviewed the appropriateness of the input fleet and métier groupings through two case studies, one in the North Sea, the other in the Celtic Sea. A PCA analysis within each case study based on the ICES WGMIXFISH advice data provided useful insights into the input data, and showed which different strata could be grouped together to help simplify the mixed-fisheries models used. However, the PCA cannot be used directly to define fleets and métiers. This requires additional information on how quotas are distributed according to fishing vessels, as well as (technical) characteristics of fishing vessels that provide information on the different fishing strategies fishing vessels have (e.g. switching between mesh size, or gear, or spatial differentiation).

In the North Sea case study, different grouping levels of the input data resulted in a similar amount of clusters (ranging from 19-22) that could explain more than 90% of variability. This has a good level of agreement with current fleet and métiers definitions used by ICES WGMIXFISH in the North Sea. However, because for a few métiers large discrepancies were observed still, the analysis highlighted the need for more detailed definitions in specific fleet-métier combinations used within the ICES WGMIXFISH model.

The structural uncertainty with respect to the fixed-effort proportion assumption was addressed by investigating the effect of alternative fleet dynamic models. It was found that the choice of fleet-dynamics model had a more pronounced effect on outcomes than fleet and métier definitions alone. The cumulative effect marginally exceeded the effect of the fleet dynamics alone, likely related to the input data used. An alternative fleet-dynamics model was explored, applying three differing constraints, offering greater flexibility in assigning effort proportions across métiers. Limited differences between the projections of the three different fleet and métier definitions were observed when applying the standard fleet-dynamics model. In contrast, using alternative fleet-dynamics models has more pronounced effects, leading to improved quota utilisation; however, because of an emphasis on métiers with low catchabilities, this also lowered catch rates in terms of CPUE. The adoption of historical effort constraints resulted in more realistic behavioural patterns.

In the Celtic Sea case study, analysis was constrained by the number of consortium members participating in the study, with several of the key fishing nations not represented. The PCA revealed a consistency in identified métiers between this current application and that previously completed by Moore et al. (2019). As a result, no additional runs of the Celtic Sea Fcube model were completed. Instead, focus was concentrated on defining fleets and métiers using highly spatially disaggregated data. This approach aimed to provide a more accurate representation of fishing dynamics. An illustrative example involved examining cod interactions within the Irish *Nephrops* fleet. By harnessing data from fishers' reports and specialised tools, the study identified species interactions and assessed their significance. At the ICES statistical rectangle level, it was not possible to decouple the landing of cod and *Nephrops* on individual trips. The key insight here was that acquiring more spatially disaggregated data (at the level of VMS pings) is crucial for the accurate identification and delineation of fleets.

Additionally, propagation of fleet parameter uncertainty in mixed-fisheries forecasts was carried out via an ICES development study that introduced Monte Carlo simulations to stochastically sample input parameter values from historical data. This method of propagating uncertainty has been developed in such a way to allow application to the conditioning of any mixed-fishery model. The impact of fleet-parameter uncertainty on model outputs was reported to have varied depending on the stock and the effort scenarios considered and could be greatly affected by technical interactions (ICES, 2023b). Variations in forecasted landings were observed under different effort scenarios, underscoring the necessity for more-precise data in specific areas of mixed-fisheries forecasting. For instance, cod is the chief limiting stock in the Celtic Sea and very little variation was observed under the 'min' scenario; the scenario where fishing stops for a fleet when the fleet's catch of the first quota species for that fleet meets the corresponding single-stock exploitation boundary. However, technical interactions with haddock and whiting in many métiers means that uncertainty in catchability translates to large variation in the forecasted landings under the haddock and whiting scenarios.

The question as to the extent to which higher resolution data will improve the output of the mixed-fisheries scenarios remains outstanding. The robustness of catch predictions and the sensitivity of these predictions are believed to vary significantly depending on the specific case studies. For instance, while some fleets and métiers may be well-represented in current models, others could benefit from more granular analysis and disaggregation. Additionally, uncertainties in input data, such as catchability conditioning, may be linked to data quality issues or shifts in fleet behaviour, which could also be influenced by spatial differences in catch composition. The current aggregation level does not allow for a comprehensive identification of such mechanisms. Therefore, it is imperative that these outstanding questions be evaluated on a nuanced case-by-case basis and generalizations are hard to be made. In theory, very disaggregated métiers would likely increase the solution space, and thus result in higher uptake of fishing opportunities. If you would assume that fishers exactly know what they are going to fish (and ignore causal relationships) at the haul level, it is likely that a solution exists where fishers can select those hauls that result in a 100% uptake of their quota. However, the issue of causality may become important when disaggregating métiers to very granular levels (i.e. ICES rectangle or fishing trip) although this is very hard to test. Two case studies, the North Sea and the Bay of Biscay, were used to investigate the impact of uncertainty in the conditioning of mixed-fisheries model forecasts. Parameter uncertainties in forecasting were examined, and output uncertainty quantified in order to enable identification of the most influential parameters. The intention was to understand how uncertainties in historical data and input parameters affect model projections.

The mixed-fisheries models involve numerous input parameters, including catchability, effort distribution and quota allocations. These models rely on historical data, which may be error-prone, for parameter conditioning. Sensitivity analysis is crucial for understanding the relationship between input uncertainties and output variations. GSA efficiently characterises this relationship but can be computationally demanding. Within the Bay of Biscay case study, GSA was implemented to assess the sensitivity of catchability, quota share and effort proportion. For the North Sea case study, a less computationally intensive approach was adopted, with separate uncertainty analyses for catchability, landings proportions, and effort proportion.

For the North Sea case study, sensitivity tests were conducted for the three model input parameter types – catchabilities, effort proportions and landing proportion – with a view to proposing alternative assumptions ('scenarios') based on an analysis of the historical values for these parameters. In terms of deviation from the observed values, the current assumptions, setting values equal to the last available data, generally provide unbiased predictions. When tested against the alternative assumptions, the assumption currently used by WGMIXFISH often outperformed them.

Sensitivity tests for the North Sea case study then compared runs using the current assumption to runs using the actual observed values. Catchability and effort proportion assumptions had limited impacts on choke and least-limiting stocks, highlighting that current assumptions generally perform well for these parameters. The landing proportion assumption had significant impacts on choke effects, with real data showing lower choke effects. However, challenges with reconditioning, including varying stock inclusions, differences in assessments, and the way the historical advice was used, affected the accuracy of the results. To accurately assess the effects of the parameters on model performance, a more complex approach is necessary.

The Bay of Biscay case study focused on conducting an uncertainty analysis and GSA for demersal mixed fisheries in the region, with a particular focus on French and Spanish fleets as proof of concept. Introduction of uncertainty provided a better representation of plausible future situations. As opposed to a deterministic approach, where a single stock is identified as the choke stock for each fleet, in the current approach multiple stocks with a similar probability of choking the fishery were identifiable.

The intensity with which the stocks are caught in each métier were the input factors that had the highest impact in almost all the output variables analysed. It needs, however, to be stated that the high uncertainty in the intensity could have conditioned the results, giving prominence to this variable to the detriment of the rest. Selectivity had the smallest impact. However, in long-term simulations, when there is a feedback loop between the stock biomass and exploitation pattern, selectivity could have a significant impact, especially if age-structured outputs are introduced.

The current findings do not neatly align with the findings for the Iberian Waters mixed-fisheries demersal system by Garcia et al. (2021). There it was found that effort–share was the most important input factor. However, in this case study, effort proportion among métiers had very limited impact. This contradiction highlights the importance of conditioning the uncertainty properly.

7.3 Stock interactions

‘Technical interactions’ is the term used to describe the interactions between a fishing activity and the fished stocks and forms the basis of any mixed-fisheries modelling. Therefore, for a robust model, it is key to understand in detail the interactions between fish stocks caught in mixed fisheries. Stock interactions within the ICES ecoregions where advice is produced annually are well explained within the materials published by ICES. However, there is still room for improvement on this description, especially at finer scale at both spatial and temporal levels. Indeed, one of the key priorities of future mixed-fisheries models is to increase the spatial disaggregation of the fishery, to better account for spatial heterogeneity in terms of catch compositions. Such a development could allow managers to identify areas where spatial decoupling may be possible and focus on areas where the main source of catches occur in order to reduce mortality of more vulnerable stocks (those with poor stock status) whilst reducing choke risks in the wider of the fleet.

In collaboration with ICES WKFO2 and WGMIXFISH the work conducted within this study brings a new detailed analysis of stock interactions at ICES rectangle level and fishing-trip level. In the case of aggregated data sources that depict interactions at the stock level, a single figure can tell a story in terms of catch/landing proportions by métier, importance of a stock in an ecoregion, or probability of co-occurrence in the landings across different strata by ecoregion. However, visualising technical interactions at more disaggregated levels is more complicated because the number of strata increases exponentially with the number of factors used to disaggregate the data source. This has been shown by the visualisation of trip-level and ICES statistical rectangle data, in which great variability in the targeting behaviour and catch composition is observed between trips within strata. There is a higher spatial and temporal variability than included within

models at present. No two trips were the same. A balance required between the detail included to adequately represent the fishing operations, the impact that has on stocks as a result of interactions, and the computational and interpretative limitations. A point will be reached where the resolution is so granular that model outputs are not useful to the end user (e.g. managers).

Inclusion of stock interactions need not only be through the assessment models. Information, useful to managers, can also be obtained through visualisation of data. section 5 provides an overview of collaborative visualisation development between this study and ICES, providing useful information on the scale of interactions between fishing operations and stocks varying in location, time, and type. The development of interactive methods to view this information is currently under way at ICES, particularly at the ICES statistical rectangle scale, which will provide an excellent tool for examining species and gears spatially and temporally.

7.4 Framework Development

It is acknowledged that the mixed-fishery assessment models are a continual 'work in progress' as the level of understanding, skill and technology develops. At the same time, the fisheries, fleets and management are evolving, and the mixed-fishery assessments need to reflect this. Within section 6 on Framework Development, a number of frameworks are presented for how the information gleaned within this study could be incorporated into mixed-fisheries assessment modelling. Here, four aspects have been considered:

- development assessments for additional areas (6.4, Developing new Areas);
- methods to include additional stocks (6.3, Incorporating additional stocks);
- inclusion of technical and spatial measures (6.1, Scenario evaluation);
- lengthening the forecast period (6.2, Rebuilding stocks).

ICES currently covers a number of mixed-fisheries ecoregions within its mixed-fisheries assessment process. However, there are a number of additional areas that would benefit from an increased understanding of the mixed-fishery interactions and implications of changing stock health on the fleets and fisheries operating within an area. The development of a mixed-fishery assessment is time-consuming, and ICES is currently developing best practice guidelines to follow for such development. This study provides an outline of the development process and highlights areas where important decisions are made, provides an overview of the process undergone in the most recent ecoregion to have been developed (the Irish Sea), highlights the difficulties the Baltic region is experiencing and suggests what would be needed for the continuation of a West of Scotland assessment (noting that the current view of ICES MIXFISH is that West of Scotland be incorporated within the North Sea assessment).

In addition to the inclusion of new areas, ICES is currently developing best practice guidelines to cover the inclusion of new stocks. This study includes an overview of the current practices for inclusion of new stocks into the mixed-fishery assessments, with details of how this could be extended (section 6.3). The aim is to build on the guidelines being developed and outline a framework by which new stocks are selected and added to a mixed-fisheries assessment. To this end, this study reviews existing methods to include new stocks in Fcube and FLBEIA, highlights data requirements, and includes a discussion on the potential limitations and research needs.

Often, selection of stocks for inclusion in a mixed-fishery assessment is based on data and single-species assessment availability, management needs, and expertise in the room. However, the exclusion of data-poor species could result in missed management goals, or bias in understanding of pressures on an ecoregion. Therefore, to produce more-useful management tools, all relevant stocks should be captured by a model, and not just those stocks most readily available. However, this has its own limitations – one of which being the current best practice quality control for all WGMIXFISH advice

products, which is the teams' ability to reproduce the single-species advice forecast. This means that, in the absence of an analytical stock assessment and forecast, there is currently no defined basis to include data-poor stocks (data assessment category 3–6; ICES, 2016) or stocks with no advice. This study includes a possible method for including these stocks based on assuming a constant catch rate (constant CPUE). However, because of the need to assume constant biomass, it might only be possible to include these stocks for 'illustrative' purposes, meaning that they are not used in the computation of the effort per fleet, and therefore cannot become choke species. Whether a species chokes a fleet or not is the primary point of interest to fishery managers, making it one of the main reasons to include, more vulnerable, stocks within mixed-fishery considerations.

However, a growing number of stocks in ICES with category 2 assessments (such as SPiCT) could be included thanks to the DRuMFISH project (EASME, 2018). Running of category 2 assessments inside Fcube considerably increased the running time, which proved to be a major issue when conducting long-term simulations but was acceptable when producing the short-term forecast as used in the mixed-fisheries considerations. Computational limitations for these stocks were less of an issue for FLBEIA.

The process of including new stocks requires good communication between WGMIXFISH and the stock assessor, collection of all current data, quality control reviews, and clear definitions of limitations and assumptions. This is time-consuming, and work cannot always be completed in one advice year. Incorporation of new stocks takes intersessional research and development, along with development at WGMIXFISH-METHODS before it can be approved for use in the production of mixed-fishery considerations. The inclusion of each new stock also changes the structure and dynamics of the fleet and model. This may also require the development of specific scenarios and time spent by WGMIXFISH-METHODS and WGMIXFISH-ADVICE reviewing the revised products to ensure that the outcomes of the scenarios are logical and meaningful. There is no one-size-fits-all in terms of assessment model or advice product. Time and human capacity are currently the key limiting factors when incorporating additional stocks.

This study also looks at possibilities for developing the existing assessment models to provide additional context to evaluate impacts of management, such as technical and spatial management measures, and potential for management measures to rebuild stocks. This was achieved via development of two conceptual frameworks.

In relation to the inclusion of technical and spatial measures, there is a growing need to incorporate downstream impacts of these into our understanding of mixed fisheries. If operationalised, this would allow scientists and stakeholders to explore long-term impacts of currently implemented and proposed future measures. The framework has identified the data, methodologies and steps necessary to account for the impact of gear-based and spatial technical measures. Two separate approaches are presented, both focused around extending the FLBEIA model. Additionally, the proposed framework outlines how such management scenarios could be evaluated through the assessment models that are currently used to provide mixed-fishery considerations.

The drawback of integration of such measures is the level of data disaggregation needed to be able to detect impacts as observed within this study. The drawbacks to using highly disaggregated métiers (or strata) are the likely additional manual processing and computational costs, which could reach prohibitive levels. It is therefore advisable to limit the number of métiers, by grouping strata according to similarities in catchabilities to maintain a realistic level of processing and computational cost. Alternatively, new software could be developed that reduces the computational demand of increased granularity of fleet/métier dimensions.

An additional requirement when including gear and spatial technical measures is the finer-scale data that is needed for the development of segment-level stratification to detect fishing associated with the relevant technical and or spatial measures to be

assessed. It was found that data at the fine scale required is not often available. The future RDBES database may alleviate this in terms of landings and effort; however, availability of discards and/or age-disaggregated catch information will remain limiting factors for the development of fine-scale strata. Specifically in relation to technical measures, in practice, several difficulties often arise when transferring results from gear-trial studies to mixed-fisheries models. In such cases, one needs to be able to match the gear and mesh size used in the study to the métiers used in the mixed-fisheries models. In case of aggregated métiers, which might represent a wide range of mesh sizes, matching métiers can be difficult. The métier structure of the current mixed-fisheries models may turn out to be a limitation to effective implementation of gear changes.

In order to provide outputs associated with evaluating stock-rebuilding measures, the duration of the current model projection functionality would need to be extended. At present, the assessment models projects two years into the future, with the use of fixed variables within projections. Although this assumption is considered valid in the short term, to evaluate stock rebuilding strategies it is also necessary to introduce dynamism and uncertainty into the projection. This would allow dynamic changes in all forecast settings, particularly catchability, effort proportions between métiers and quota shares. However, from a technical perspective, the models used can be extended easily.

The steps required to extend the models used to produce mixed-fisheries considerations to analyse stock rebuilding in the long term are presented. The first step towards running long-term projections is to define the dynamics of the processes that form the system. The system can be divided in three main components: the stocks, the fleets and the catch advice. The processes that should be modelled in each of these components in order to run long-term simulations have been identified, along with where and how uncertainty should be introduced. In relation to dynamic models, the major work would be in the conditioning of the stock-recruitment relationship, the fleet dynamic model, in terms of effort allocation among métiers and total annual effort, and the HCRs to provide the catch advice. A full MSE approach would require introducing the assessment model within the simulation; for many stocks this would imply a huge amount of work to prepare the algorithm and a huge amount of computational time. For uncertainty conditioning, at least in the base case, that of the biological component should be based on the conditioning of the single-stock models used to calculate reference points. For the fleet component, the uncertainty conditioning carried out in section 3 could be used as a basis.

An overarching theme that is applicable to the development of all forementioned frameworks is that stakeholder engagement is a key aspect of this development. Stakeholders are central to the development of meaningful management scenarios that could be produced with mixed-fisheries models. Forums such as WKMIXFISH (ICES, 2023d) are essential to collecting some of the information. Annual iterative feedback processes will need to be developed to ensure progress can be aligned with requirements.

8 CONSIDERATIONS FOR NEXT STEPS

Mixed fisheries is a high-priority topic for development within ICES, and will continue to be for the foreseeable future. Many of the investigations carried out within this study represent a point on a larger development scale, and these developments should be continued. More specifically, these include those within the joint EU-UK request sent to ICES, and those of ICES WGMIXFISH. There is a number of limitations to the further progressive development of mixed-fishery assessment and advice that have relevance to this study but also go beyond its capacity. These can be broadly summarised into four categories.

1. The current form of mixed-fishery assessment within ICES has tended to develop as a result of needs to answer specific questions around the consequences to a particular stock. Each ecoregion has had its own focal requirements originating from management questions. This includes consideration of cod stocks and associated recovery management. Greater clarity of the end-user requirements of mixed-fishery considerations will be needed to enable harmonisation between ecoregions, and future development of mixed-fishery models to encapsulate these requirements.
2. The majority of case study investigations would have been aided by a dedicated data call, which was not possible within the timeframe of this study. This would need to be a data call in which additional disaggregated data would be requested from all relevant nations within the North Sea, Celtic Sea and Bay of Biscay, including EU Member States and third countries to ensure sufficient representative coverage can be achieved.
3. As the interest in the use of mixed-fisheries considerations increases beyond ICES, there is a need to continue supporting research and development of the mixed-fisheries assessment models under development. This should incorporate a greater complexity of métiers, stocks and scenario projections, and ways to reduce human and computational time commitments. This can be facilitated by adopting and implementing many of the aspects described as part of the framework development.
4. As the priority of mixed fisheries grows within ICES and beyond, there is a need for additional technical staff to support the research-and-development process needed to progress the topic.

The following considerations provide more specific requirements associated with further development of mixed fisheries within Europe.

8.1 Data availability

The considerations associated with data availability are cross-cutting, and would benefit all aspects of continuing work carried out within this study.

- As stated in the more general terms, a data request with data disaggregated, ideally at the trip level, would be requested from all relevant nations within the North Sea, Celtic Sea and Bay of Biscay, both within the EU and beyond to ensure sufficient representative coverage can be achieved. It would also be preferable to have access to VMS ping data to further investigate the spatial element of classifying strata for inclusion into mixed-fishery models.
- Long time series of complete data are needed to obtain a good representation of uncertainty and an effort should be made to complete and extend the existing time series in the historical period. There were many gaps in the data used for the uncertainty conditioning in the Bay of Biscay case study into the sensitivity of forecasting. These gaps made it difficult to distinguish between real zeros and lack of data. The distinction has big implications because it has a big impact on the conditioning of catchability, for example. Time constraints made it impossible to identify the real nature of all the gaps. For some stocks this significantly reduced forecasted catchability and it had a non-desirable impact in the uncertainty analysis.

8.2 Assessment mode uncertainty and sensitivity

The following considerations are additions to those already listed in 8.1.

- Further refine the definition of the strata (fleets and métiers) used within mixed-fishery models, giving consideration not only to landings but also quota, technical and socio-economic aspects. Wherever possible, this should be done at a finer spatial scale than DCF métier level 6. This level is considered insufficient to decouple fisheries, such as decoupling targeting *Nephrops* on the Porcupine Bank from cod targeting at an ICES statistical rectangle level.
- Develop and integrate more-realistic fleet dynamics models in future mixed-fisheries models to more accurately account for changes in fishing opportunities and spatially disaggregated model projections.
- Continue the development of the effect of uncertainty of fleet and métier definitions on model behaviour via use of the Monte Carlo simulation method developed within WGMIXFISH. This would be focused to improve the realism of forecasts, such as the use of auto-regressive functions to constrain sampled projection values, as well as improve the robustness of model fitting and expand the toolbox of user-friendly functions. This work will be dealt with as part of WGMIXFISH-METHODS and the special request sent by the EU to ICES, to be published in in 2024.
- With respect to the model conditioning, explore alternative approaches or data sources to better predict future landing proportions, especially in cases where quota exchanges and transfers significantly affect these proportions.
- Future investigations that compare the projection runs that have status quo parameter assumptions with projection runs that use the observed values for the parameters should consider reconditioning of the model. Reconditioning the model to exactly reproduce the mixed-fisheries considerations in past years is necessary to get a sense of model sensitivity to the conditioning of forenamed parameters. Currently, only the observed values available from the most recent mixed-fisheries considerations are used.
- Correlation among stocks' catchability arises at haul level. However, mixed-fisheries models are conditioned at métier level, and the correlation between the catchability (intensity) was derived at this more aggregated level. It could be interesting to calculate correlation among stock catchabilities at haul level and compare them with the correlations obtained in this analysis to check for similarity. Alternatively, it could be interesting to analyse options for using existing data at the haul level to improve conditioning at the métier level.
- The GSA results are highly sensitive to the uncertainty conditioning. In this case, the variance in the intensity was limited because the model used produced over-wide confidence intervals that extended beyond the historical observations. This behaviour could be related to the lack of long-enough time-series data and the selected model itself. Further research is needed to extend the time-series data and improve the models used in the uncertainty conditioning.
- Time constraints meant that convergence of the indices has not been analysed. However, Garcia et al. (2021) used 10 000 base interactions with a more complex model and observed that the sensitivity indices were fairly stable from 2 000 iterations on. In their analysis they used Sobol sequences to speed up convergence (Renardy et al., 2021). The work here attempted to use Sobol sequences in this analysis; however, it was not possible to transform Sobol sequences to constrained sampling of intensity. The sensitivity indices showed little variability in some cases (quota-share indices for example), the reason for such pattern could be related to convergence issues and should be examined in further analysis.

8.3 Stock interactions

- The complexity of technical interactions lends itself to interactive visualisation tools that allow the end user to specify the information of interest; this can be fishing operation style, stock, spatially or temporally specific. Development of interactive

tools is becoming more mainstream and ICES is moving towards this method of information dissemination. The continued development of the spatially explicit tool described within the current study is in line with this evolution..

- In order to further investigate stock interactions for vulnerable stocks, the meaning of vulnerable should be determined.
- Further develop current mixed-fishery modelling methods (or alternative models) to allow incorporation of spatially and temporally disaggregated strata that are treated within the model at an appropriate scale, e.g. a smaller than annual time step.

8.4 Framework development

Considerations for the four framework development topics are detailed below. Three overarching considerations were identified, which apply to each framework.

- Further develop mixed-fishery assessment models to enable more advanced integration, and/or less computationally demanding methods of processing greater granularity of fleets/métiers and stocks.
- Feed into and support the developing ICES WGMIXFISH best practice guidance, particularly in relation to the development of assessments for additional areas and methods to include additional stocks.
- A key aspect of this development is stakeholder engagement. This is central to the development of meaningful management scenarios. Forums such as WKMIXFISH (ICES, 2023d) are key to collecting some of the information. Annual iterative feedback processes will need to be developed to ensure progress can be aligned with requirements.

Specific considerations in relation to Scenario evaluation (6.1):

- Technical and spatial measures can be considered with the current mixed-fisheries models but would likely require assumptions on the input data to condition fleets and métiers in case of technical changes. Besides, such analysis would benefit from more realistic fleet dynamic models, as such measures are likely to affect the profitability of the fleets.

Specific considerations in relation to Rebuilding stocks (6.2):Rebuilding stocks

- FLBEIA uses Cobb–Douglas production function, a function widely used in economic literature to describe production in diverse economic activities, to relate catch and effort. It has been shown that when the stocks are at low biomass levels, the dynamic of this function and the Baranov production function, the most popular function to calculate catch as a function of effort in age-structured models, are significantly different. A Baranov approach should be implemented in FLBEIA to ensure full replicability of single-stock approaches. This development would benefit long-term simulation approaches, and short-term projections used in the generation of mixed-fisheries considerations.
- Intra species correlation in the intensity parameter at métier level has been modelled using data at métier level. However, the correlation arises at haul level. However, an attempt should be made to use haul level data to improve the conditioning of the uncertainty.
- Dynamic modelling and uncertainty conditioning require long time-series data to provide a good basis for inference into the future. Thus, the time series available should be extended.
- Alternative fleet dynamic models that are able to replicate the past adequately and are appropriate for forecasting are needed. The development of a hindcasting module that allows identification of what works better in the historical period would be useful.
- HCRs used to provide advice for category 3 stocks should be implemented in FLBEIA.
- Some of the exemptions of the landing obligation are already implemented in FLBEIA but have not been tested extensively. More testing is needed to validate the model.

9 ANNEXES

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- ANNEX 2: OVERVIEW OF NORTH SEA FLEET DISTINCTIONS USED IN THE ICES WGMIXFISH ADVICE NORTH SEA MODEL
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- ANNEX 4: MATHEMATICAL REPRESENTATION OF CONSTRAINTS USED IN TESTING NORTH SEA CASE STUDY LINKS TO SENSITIVITY UNCERTAINTY OF FORECAST CONDITIONING
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ANNEX 1: OVERVIEW OF THE FLEET AND MÉTIERS DEFINITION USED IN THE ICES WGMIXFISH ADVICE NORTH SEA MODEL

The below table provides an overview of the fleet and métiers definition used in the ICES WGMIXFISH advice North Sea model, as well as the strata used to condition the métiers. The columns 'n cluster' and 'NA cluster' indicates the number of clusters to which the strata belong, and indicate strata that could not be matched to a cluster, respectively.

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
BE_Beam<24	BT2.4	2	TBB_DEF_100-119_0_0_all / 4 / 10-24 & TBB_DEF_70-99_0_0_all / 4 / 10-24	2	0	9887
BE_Beam<24	BT2.7D	1	TBB_DEF_70-99_0_0_all / 7D / 10-24	1	0	10013
BE_Beam<24	beam_oth.4	1	TBB_CRU_16-31_0_0_all / 4 / 10-24	1	0	1193
BE_Beam>=24	BT1.4	1	TBB_DEF_>=120_0_0_all / 4 / 24-40	1	0	42960
BE_Beam>=24	BT2.4	2	TBB_DEF_70-99_0_0_all / 4 / 24-40 & TBB_DEF_100-119_0_0_all / 4 / 24-40	2	0	25868
BE_Beam>=24	BT2.7D	1	TBB_DEF_70-99_0_0_all / 7D / 24-40	1	0	19997
BE_Otter	OTH	6	OTB_DEF_32-69_0_0_all / 4 / 24-40 & OTB_DEF_32-69_0_0_all / 4 / 10-24 & OTB_DEF_32-69_0_0_all / 7D / 24-40 & OTB_DEF_32-69_0_0_all / 7D / 10-24 & OTB_CRU_70-99_0_0_all / 7D / 10-24 & OTB_CRU_70-99_0_0_all / 7D / 24-40	2	0	317
BE_Otter	TR1.4	4	OTB_DEF_>=120_0_0_all / 4 / 24-40 & OTB_DEF_100-119_0_0_all / 4 / 24-40 & OTB_DEF_>=120_0_0_all / 4 / 10-24 & OTB_DEF_100-119_0_0_all / 4 / 10-24	2	0	7866
BE_Otter	TR2.4	4	OTB_CRU_70-99_0_0_all / 4 / 10-24 & OTB_CRU_70-99_0_0_all / 4 / 24-40 & OTB_DEF_70-99_0_0_all / 4 / 10-24 & OTB_DEF_70-99_0_0_all / 4 / 24-40	2	0	16366

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
DK_<10towed	OTH	6	OTB_CRU_32-69_0_0_all / 3AN / <10 & OTB_DEF_>=120_0_0_all / 3AN / <10 & SDN_DEF_>=120_0_0_all / 3AN / <10 & OTB_DEF_>=120_0_0_all / 4 / <10 & SDN_DEF_>=120_0_0_all / 4 / <10 & OTB_CRU_70-99_0_0_all / 4 / <10	4	0	3668
DK_<10towed	TR2.3AN	1	OTB_CRU_90-119_0_0_all / 3AN / <10	1	0	2170
DK_Otter<24	OTH	4	OTB_CRU_32-69_0_0_all / 3AN / 10-24 & OTB_CRU_32-69_0_0_all / 4 / 10-24 & OTB_DEF_>=120_0_0_all / 3AN / 10-24 & OTB_CRU_16-31_0_0_all / 3AN / 10-24	3	0	19448
DK_Otter<24	TR1.4	1	OTB_DEF_>=120_0_0_all / 4 / 10-24	1	0	39193
DK_Otter<24	TR2.3AN	1	OTB_CRU_90-119_0_0_all / 3AN / 10-24	1	0	77522
DK_Otter<24	TR2.4	1	OTB_CRU_70-99_0_0_all / 4 / 10-24	1	0	3769
DK_Otter>=24	OTH	7	OTB_CRU_32-69_0_0_all / 3AN / 24-40 & OTB_CRU_32-69_0_0_all / 4 / 24-40 & OTB_CRU_70-89_2_35_all / 3AN / 24-40 & OTB_CRU_70-89_2_35_all / 3AN / >=40 & OTB_CRU_16-31_0_0_all / 3AN / 24-40 & OTB_CRU_16-31_0_0_all / 4 / 24-40 & OTB_CRU_16-31_0_0_all / 4 / >=40	3	0	3453
DK_Otter>=24	TR1.3AN	2	OTB_DEF_>=120_0_0_all / 3AN / 24-40 & OTB_DEF_>=120_0_0_all / 3AN / >=40	1	0	7374
DK_Otter>=24	TR1.4	2	OTB_DEF_>=120_0_0_all / 4 / 24-40 & OTB_DEF_>=120_0_0_all / 4 / >=40	1	0	98338
DK_Otter>=24	TR2.3AN	2	OTB_CRU_90-119_0_0_all / 3AN / 24-40 & OTB_CRU_90-119_0_0_all / 3AN / >=40	2	0	11152
DK_Otter>=24	TR2.4	2	OTB_CRU_70-99_0_0_all / 4 / 24-40 & OTB_CRU_70-99_0_0_all / 4 / >=40	2	0	6251
DK_Seine	TR1.3AN	4	SDN_DEF_>=120_0_0_all / 3AN / 10-24 & SSC_DEF_>=120_0_0_all / 3AN / 24-40 & SSC_DEF_>=120_0_0_all / 3AN / 10-24 & SDN_DEF_>=120_0_0_all / 3AN / 24-40	4	0	50991

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
DK_Seine	TR1.4	4	SDN_DEF_>=120_0_0_all / 4 / 10-24 & SSC_DEF_>=120_0_0_all / 4 / 24-40 & SSC_DEF_>=120_0_0_all / 4 / 10-24 & SDN_DEF_>=120_0_0_all / 4 / 24-40	3	0	28839
DK_Static	GN1.3AN	7	GNS_DEF_>=220_0_0_all / 3AN / 10-24 & GNS_DEF_>=220_0_0_all / 3AN / <10 & GNS_DEF_100-119_0_0_all / 3AN / 10-24 & GNS_DEF_100-119_0_0_all / 3AN / <10 & GNS_DEF_120-219_0_0_all / 3AN / <10 & GNS_DEF_120-219_0_0_all / 3AN / 24-40 & GNS_DEF_120-219_0_0_all / 3AN / 10-24	3	0	24214
DK_Static	GN1.4	9	GNS_DEF_>=220_0_0_all / 4 / <10 & GNS_DEF_>=220_0_0_all / 4 / 24-40 & GNS_DEF_>=220_0_0_all / 4 / 10-24 & GNS_DEF_100-119_0_0_all / 4 / <10 & GNS_DEF_100-119_0_0_all / 4 / 10-24 & GNS_DEF_120-219_0_0_all / 4 / <10 & GNS_DEF_120-219_0_0_all / 4 / 24-40 & GNS_DEF_120-219_0_0_all / 4 / 10-24 & GNS_DEF_100-119_0_0_all / 4 / 24-40	3	0	66846
DK_Static	OTH	5	LLS_FIF_0_0_0_all / 3AN / <10 & LLS_FIF_0_0_0_all / 3AN / 10-24 & LLS_FIF_0_0_0_all / 3AN / 24-40 & LLS_FIF_0_0_0_all / 4 / 10-24 & LLS_FIF_0_0_0_all / 4 / <10	3	0	936
EN_<10	GN1.4	1	GNS_DEF_all_0_0_0_all / 4 / <10	1	0	2081
EN_<10	GN1.7D	1	GNS_DEF_all_0_0_0_all / 7D / <10	1	0	4912
EN_<10	GT1.7D	1	GTR_DEF_all_0_0_0_all / 7D / <10	1	0	2309
EN_<10	OTH	19	TBB_DEF_70-99_0_0_all / 7D / <10 & GTR_DEF_all_0_0_0_all / 4 / <10 & LLS_FIF_0_0_0_all / 4 / <10 & LLS_FIF_0_0_0_all / 7D / <10 & OTB_CRU_32-69_0_0_all / 4 / <10 & OTB_SPF_32-69_0_0_all / 4 / <10 & MIS_MIS_0_0_0_HC / 4 / <10 & MIS_MIS_0_0_0_HC / 7D / <10 & OTB_CRU_100-119_0_0_all / 4 / <10 & OTB_DEF_>=120_0_0_all / 4 / <10 & OTB_DEF_100-119_0_0_all / 4 / <10 & OTB_PEL_100-119_0_0_all / 4 / <10 & OTB_DEF_>=120_0_0_all / 7D / <10 & OTB_CRU_100-119_0_0_all / 7D / <10 & OTM_SPF_32-69_0_0_all / 4 / <10 & OTB_CRU_32-69_0_0_all / 7D / <10 & OTB_SPF_32-69_0_0_all / 7D / <10 & MIS_MIS_0_0_0_HC / 6A / <10 & FPO_CRU_0_0_0_all / 6A / <10	6	4	4994

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
EN_<10	TR2.4	4	OTB_CRU_70-99_0_0_all / 4 / <10 & OTB_DEF_70-99_0_0_all / 4 / <10 & OTB_SPF_70-99_0_0_all / 4 / <10 & OTB_MOL_70-99_0_0_all / 4 / <10	3	1	12229
EN_<10	TR2.7D	4	OTB_DEF_70-99_0_0_all / 7D / <10 & OTB_CRU_70-99_0_0_all / 7D / <10 & OTB_MOL_70-99_0_0_all / 7D / <10 & OTB_SPF_70-99_0_0_all / 7D / <10	3	0	2627
EN_<10	pots.4	1	FPO_CRU_0_0_0_all / 4 / <10	1	0	996
EN_<10	pots.7D	1	FPO_CRU_0_0_0_all / 7D / <10	1	0	40
EN_Beam	BT1.4	3	TBB_DEF_>=120_0_0_all / 4 / >=40 & TBB_DEF_>=120_0_0_all / 4 / 24-40 & TBB_DEF_>=120_0_0_all / 4 / 10-24	2	0	54177
EN_Beam	BT2.4	3	TBB_DEF_70-99_0_0_all / 4 / 24-40 & TBB_DEF_70-99_0_0_all / 4 / 10-24 & TBB_DEF_70-99_0_0_all / 4 / >=40	2	0	34572
EN_Beam	BT2.7D	2	TBB_DEF_70-99_0_0_all / 7D / 24-40 & TBB_DEF_70-99_0_0_all / 7D / 10-24	1	0	3403
EN_Beam	OTH	2	TBB_CRU_16-31_0_0_all / 4 / 10-24 & TBB_CRU_16-31_0_0_all / 4 / >=40	2	0	31
EN_Otter24-40	OTH	4	OTB_DEF_>=120_0_0_all / 6A / 24-40 & OTB_DEF_>=120_0_0_all / 6A / 24-40 & OTB_CRU_100-119_0_0_all / 6A / 24-40 & OTB_DEF_100-119_0_0_all / 6A / 24-40	3	1	254
EN_Otter24-40	TR1.4	5	OTB_DEF_>=120_0_0_all / 4 / 24-40 & OTB_DEF_>=120_0_0_all / 4 / 24-40 & OTB_CRU_100-119_0_0_all / 4 / 24-40 & OTB_CRU_100-119_0_0_all / 4 / 24-40 & OTB_DEF_100-119_0_0_all / 4 / 24-40	3	0	24568
EN_Otter24-40	otter_oth.4	2	SSC_DEF_All_0_0_All / 4 / 24-40 & SDN_all_0_0_all / 4 / 24-40	1	1	97
EN_Otter24-40	otter_oth.7D	2	SSC_DEF_All_0_0_All / 7D / 24-40 & SDN_all_0_0_all / 7D / 24-40	1	1	41
EN_Otter<24	OTH	7	OTB_CRU_32-69_0_0_all / 4 / 10-24 & OTB_SPF_32-69_0_0_all / 4 / 10-24 & SSC_DEF_All_0_0_All / 4 / 10-24 & SDN_all_0_0_all / 4 / 10-24 &	3	2	1641

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
			SSC_DEF_All_0_0_All / 7D / 10-24 & OTB_CRU_70-99_0_0_all / 6A / 10-24 & OTB_DEF_70-99_0_0_all / 6A / 10-24			
EN_Otter<24	TR1.4	7	OTB_CRU_100-119_0_0_all / 4 / 10-24 & OTB_CRU_100-119_0_0_all / 4 / 10-24 & OTB_DEF_>=120_0_0_all / 4 / 10-24 & OTB_DEF_>=120_0_0_all / 4 / 10-24 & SDN_DEF_>=120_0_0_all / 4 / 10-24 & OTB_DEF_100-119_0_0_all / 4 / 10-24 & OTB_MOL_100-119_0_0_all / 4 / 10-24	4	1	14084
EN_Otter<24	TR1.7D	1	OTB_DEF_>=120_0_0_all / 7D / 10-24	1	0	41
EN_Otter<24	TR2.4	4	OTB_CRU_70-99_0_0_all / 4 / 10-24 & OTB_CRU_70-99_0_0_all / 4 / 10-24 & OTB_DEF_70-99_0_0_all / 4 / 10-24 & OTB_DEF_70-99_0_0_all / 4 / 10-24	2	0	31104
EN_Otter<24	TR2.7D	2	OTB_DEF_70-99_0_0_all / 7D / 10-24 & OTB_CRU_70-99_0_0_all / 7D / 10-24	2	0	1085
EN_Otter>=40	OTH	4	OTB_DEF_>=120_0_0_all / 6A / >=40 & OTB_DEF_>=120_0_0_all / 6A / >=40 & OTB_DEF_70-99_0_0_all / 4 / >=40 & OTB_SPF_70-99_0_0_all / 4 / >=40	3	0	1506
EN_Otter>=40	TR1.4	3	OTB_DEF_>=120_0_0_all / 4 / >=40 & OTB_DEF_>=120_0_0_all / 4 / >=40 & OTB_DEF_100-119_0_0_all / 4 / >=40	3	0	36534
EN_Pelagic	pelagic.4	2	OTM_SPF_32-69_0_0_all / 4 / >=40 & OTM_SPF_32-69_0_0_all / 4 / 10-24	2	0	248
EN_Pelagic	pelagic.6A	2	OTM_SPF_32-69_0_0_all / 6A / >=40 & OTM_SPF_32-69_0_0_all / 6A / 10-24	1	1	13
EN_Pelagic	pelagic.7D	1	OTM_SPF_32-69_0_0_all / 7D / >=40	1	0	14
EN_Static	GN1.7D	1	GNS_DEF_all_0_0_all / 7D / 10-24	1	0	149
EN_Static	OTH	9	GNS_DEF_all_0_0_all / 4 / 10-24 & GNS_DEF_all_0_0_all / 4 / 10-24 & GNS_DEF_all_0_0_all / 4 / 24-40 & GTR_DEF_all_0_0_all / 4 / 10-24 & LLS_FIF_0_0_0_all / 7D / 10-24 & GTR_DEF_all_0_0_all / 7D / 10-24 & LLS_FIF_0_0_0_all / 4 / 10-24 & LLS_FIF_0_0_0_all / 4 / 24-40 & FPO_CRU_0_0_0_all / 6A / 10-24	6	1	1821

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Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
EN_Static	pots.4	2	FPO_CRU_0_0_0_all / 4 / 10-24 & FPO_CRU_0_0_0_all / 4 / 24-40	1	1	117
EN_Static	pots.7D	1	FPO_CRU_0_0_0_all / 7D / 10-24	1	0	3
FR_<10	GN1.7D	6	GNS_DEF_120-219_0_0_all / 7D / <10 & GNS_DEF_all_0_0_all / 7D / <10 & GNS_DEF_80-99_0_0 / 7D / <10 & GNS_DEF_100-119_0_0_all / 7D / <10 & GNS_DEF_>=220_0_0_all / 7D / <10 & GNS_DEF_120-219_0_0 / 7D / <10	4	1	298
FR_<10	GT1.7D	6	GTR_DEF_all_0_0_all / 7D / <10 & GTR_DEF_100-119_0_0_all / 7D / <10 & GTR_DEF_120-219_0_0_all / 7D / <10 & GTR_DEF_90-99_0_0_all / 7D / <10 & GTR_CRU_0_0_0_all / 7D / <10 & GTR_DEF_>=220_0_0_all / 7D / <10	4	1	3038
FR_<10	OTH	25	MIS_MIS_0_0_0 / 7D / <10 & DRB_all_0_0_all / 7D / <10 & DRB_MOL_0_0_0_all / 7D / <10 & OTB_DEF_100-119_0_0 / 7D / <10 & OTB_DEF_>=120_0_0 / 7D / <10 & TBB_DEF_70-99_0_0_all / 7D / <10 & GTR_DEF_90-99_0_0_all / 4 / <10 & GTR_DEF_all_0_0_all / 4 / <10 & GTR_DEF_120-219_0_0_all / 4 / <10 & GTR_DEF_100-119_0_0_all / 4 / <10 & GTR_DEF_>=220_0_0_all / 4 / <10 & OTB_DEF_32-69_0_0 / 7D / <10 & OTB_SPF_32-69_0_0_all / 7D / <10 & MIS_MIS_0_0_0 / 4 / <10 & OTB_DEF_<16_0_0_all / 7D / <10 & OTB_DEF_All_0_0_All / 7D / <10 & OTB_CRU_all_0_0_all / 7D / <10 & OTB_DEF_all_0_0_all / 7D / <10 & OTM_DEF_70-99_0_0_all / 7D / <10 & OTM_DEF_32-69_0_0_all / 7D / <10 & OTM_SPF_32-69_0_0_all / 7D / <10 & OTM_SPF_70-99_0_0_all / 7D / <10 & OTM_SPF_16-31_0_0 / 7D / <10 & FPO_CRU_0_0_0_all / 7D / <10 & FPO_MOL_0_0_0_all / 7D / <10	8	9	2068
FR_<10	TR2.7D	4	OTB_DEF_70-99_0_0 / 7D / <10 & OTB_SPF_70-99_0_0_all / 7D / <10 & OTT_DEF_70-99_0_0 / 7D / <10 & OTB_CRU_70-99_0_0_all / 7D / <10	4	0	1313
FR_Beam	BT2.7D	3	TBB_DEF_70-99_0_0_all / 7D / 10-24 & TBB_DEF_70-99_0_0_all / 7D / 24-40 & TBB_DEF_100-119_0_0_all / 7D / 10-24	3	0	3610
FR_Beam	OTH	4	TBB_DEF_all_0_0_all / 4 / 10-24 & TBB_DEF_all_0_0_all / 7D / 10-24 & TBB_DEF_all_0_0_all / 7D / 24-40 & TBB_DEF_70-99_0_0_all / 4 / 10-24	3	0	644

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
FR_Nets	GT1.4	6	GTR_DEF_100-119_0_0_all / 4 / 10-24 & GTR_DEF_120-219_0_0_all / 4 / 10-24 & GTR_DEF_90-99_0_0_all / 4 / 10-24 & GTR_DEF_all_0_0_all / 4 / 10-24 & GTR_DEF_100-119_0_0_all / 4 / >=40 & GTR_DEF_>=220_0_0_all / 4 / 10-24	4	0	8262
FR_Nets	GT1.7D	7	GTR_DEF_100-119_0_0_all / 7D / 10-24 & GTR_DEF_all_0_0_all / 7D / 10-24 & GTR_DEF_120-219_0_0_all / 7D / 10-24 & GTR_DEF_90-99_0_0_all / 7D / 10-24 & GTR_DEF_all_0_0_all / 7D / 24-40 & GTR_CRU_0_0_0_all / 7D / 10-24 & GTR_DEF_>=220_0_0_all / 7D / 10-24	3	2	18080
FR_Nets	OTH	13	GNS_DEF_120-219_0_0_all / 7D / 10-24 & GNS_DEF_all_0_0_all / 7D / 10-24 & GNS_DEF_80-99_0_0 / 7D / 10-24 & GNS_DEF_100-119_0_0_all / 7D / 10-24 & GNS_DEF_all_0_0_all / 7D / 24-40 & GNS_DEF_>=220_0_0_all / 7D / 10-24 & GNS_DEF_120-219_0_0 / 7D / 10-24 & GNS_DEF_all_0_0_all / 4 / 10-24 & GNS_DEF_120-219_0_0_all / 4 / 10-24 & GNS_DEF_80-99_0_0 / 4 / 10-24 & GNS_DEF_100-119_0_0_all / 4 / 10-24 & GNS_DEF_120-219_0_0 / 4 / 10-24 & GNS_DEF_>=220_0_0_all / 4 / 10-24	5	3	737
FR_OTH	OTH	22	MIS_MIS_0_0_0 / 7D / 10-24 & MIS_MIS_0_0_0 / 7D / 24-40 & DRB_all_0_0_all / 7D / 10-24 & DRB_all_0_0_all / 7D / 24-40 & MIS_MIS_0_0_0 / 7D / >=40 & DRB_MOL_0_0_0_all / 7D / 10-24 & DRB_MOL_0_0_0_all / 7D / 24-40 & DRB_all_0_0_all / 4 / 10-24 & MIS_MIS_0_0_0 / 4 / 24-40 & MIS_MIS_0_0_0 / 4 / 10-24 & MIS_MIS_0_0_0 / 4 / >=40 & DRB_MOL_0_0_0_all / 4 / 10-24 & SSC_DEF_All_0_0_All / 4 / 24-40 & SSC_DEF_All_0_0_All / 4 / 10-24 & SSC_DEF_All_0_0_All / 7D / 24-40 & SSC_DEF_All_0_0_All / 7D / 10-24 & SSC_DEF_70-99_0_0_all / 4 / 24-40 & SSC_DEF_70-99_0_0_all / 4 / 10-24 & MIS_MIS_0_0_0 / 6A / >=40 & MIS_MIS_0_0_0 / 6A / 24-40 & FPO_CRU_0_0_0_all / 7D / 10-24 & FPO_MOL_0_0_0_all / 7D / 10-24	7	6	13900
FR_OTH	TR2.7D	2	SSC_DEF_70-99_0_0_all / 7D / 24-40 & SSC_DEF_70-99_0_0_all / 7D / 10-24	1	0	3268
FR_OTH	pelagic.4	15	OTM_SPF_70-99_0_0_all / 4 / 10-24 & OTM_SPF_70-99_0_0_all / 4 / 24-40 & PS_SPF_0_0_0 / 4 / 24-40 & OTM_SPF_32-69_0_0_all / 4 / 24-40 & OTM_SPF_32-69_0_0_all / 4 / >=40 & OTM_SPF_32-69_0_0_all / 4 / 10-24 & OTM_DEF_70-99_0_0_all / 4 / 10-24 &	4	6	2040

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
			OTM_DEF_32-69_0_0_all / 4 / 10-24 & OTM_DEF_100-119_0_0_all / 4 / 10-24 & OTM_DEF_70-99_0_0_all / 4 / 24-40 & OTM_SPF_16-31_0_0 / 4 / 24-40 & PS_SPF_0_0_0 / 4 / 10-24 & OTM_SPF_16-31_0_0 / 4 / 10-24 & OTM_DEF_32-69_0_0_all / 4 / 24-40 & OTM_DEF_32-69_0_0_all / 4 / >=40			
FR_OTH	pelagic.6A	2	OTM_SPF_32-69_0_0_all / 6A / >=40 & OTM_DEF_32-69_0_0_all / 6A / >=40	1	1	3
FR_OTH	pelagic.7D	16	OTM_DEF_70-99_0_0_all / 7D / 10-24 & OTM_SPF_70-99_0_0_all / 7D / 24-40 & OTM_SPF_70-99_0_0_all / 7D / 10-24 & OTM_DEF_70-99_0_0_all / 7D / 24-40 & OTM_DEF_100-119_0_0_all / 7D / 10-24 & OTM_SPF_32-69_0_0_all / 7D / 10-24 & OTM_SPF_32-69_0_0_all / 7D / 24-40 & OTM_SPF_32-69_0_0_all / 7D / >=40 & OTM_DEF_32-69_0_0_all / 7D / 24-40 & OTM_DEF_32-69_0_0_all / 7D / 10-24 & PS_SPF_0_0_0 / 7D / 24-40 & OTM_SPF_16-31_0_0 / 7D / 24-40 & OTM_SPF_16-31_0_0 / 7D / 10-24 & PS_SPF_0_0_0 / 7D / 10-24 & OTM_DEF_100-119_0_0_all / 7D / 24-40 & OTM_DEF_32-69_0_0_all / 7D / >=40	3	9	1674
FR_Otter10-40	OTH	20	OTB_DEF_32-69_0_0 / 4 / 10-24 & OTB_DEF_32-69_0_0 / 4 / 24-40 & OTB_SPF_32-69_0_0_all / 4 / 10-24 & OTB_DEF_32-69_0_0 / 7D / 10-24 & OTB_DEF_32-69_0_0 / 7D / 24-40 & OTB_SPF_32-69_0_0_all / 7D / 10-24 & OTB_SPF_32-69_0_0_all / 7D / 24-40 & OTB_CRU_32-69_0_0_all / 7D / 24-40 & OTB_DEF_<16_0_0_all / 7D / 10-24 & OTB_DEF_All_0_0_All / 7D / 10-24 & OTB_DEF_All_0_0_All / 7D / 24-40 & OTT_CRU_<16_0_0_all / 7D / 10-24 & OTB_DEF_<16_0_0_all / 7D / 24-40 & OTB_DEF_all_0_0_all / 7D / 10-24 & OTB_DEF_100-119_0_0 / 4 / 24-40 & OTB_DEF_>=120_0_0 / 4 / 10-24 & OTB_DEF_>=120_0_0 / 4 / 24-40 & OTB_DEF_100-119_0_0 / 4 / 10-24 & OTB_DEF_16-31_0_0 / 7D / 10-24 & OTB_DEF_70-99_0_0 / 6A / 24-40	9	6	750
FR_Otter10-40	TR1.6A	7	OTB_DEF_100-119_0_0 / 6A / 24-40 & OTB_DWS_100-119_0_0_all / 6A / 24-40 & OTT_DEF_100-119_0_0 / 6A / 24-40 & OTT_DEF_100-119_0_0 / 6A / 10-24 & OTB_DWS_>=120_0_0_all / 6A / 24-40 & OTB_DEF_>=120_0_0 / 6A / 24-40 & OTT_DEF_>=120_0_0_all / 6A / 24-40	4	0	1438

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
FR_Otter10-40	TR1.7D	7	OTB_DEF_100-119_0_0 / 7D / 24-40 & OTB_DEF_100-119_0_0 / 7D / 10-24 & OTB_DEF_>=120_0_0 / 7D / 10-24 & OTB_DEF_>=120_0_0 / 7D / 24-40 & OTT_DEF_100-119_0_0 / 7D / 10-24 & OTT_CRU_100-119_0_0 / 7D / 10-24 & OTB_DWS_>=120_0_0_all / 7D / 10-24	4	1	305
FR_Otter10-40	TR2.4	6	OTB_DEF_70-99_0_0 / 4 / 10-24 & OTB_DEF_70-99_0_0 / 4 / 24-40 & OTB_CRU_70-99_0_0_all / 4 / 10-24 & OTB_SPF_70-99_0_0_all / 4 / 10-24 & OTB_SPF_70-99_0_0_all / 4 / 24-40 & OTB_CRU_70-99_0_0_all / 4 / 24-40	2	0	19903
FR_Otter10-40	TR2.7D	9	OTB_CRU_70-99_0_0_all / 7D / 10-24 & OTB_DEF_70-99_0_0 / 7D / 10-24 & OTB_DEF_70-99_0_0 / 7D / 24-40 & OTB_SPF_70-99_0_0_all / 7D / 10-24 & OTT_DEF_70-99_0_0 / 7D / 10-24 & OTB_SPF_70-99_0_0_all / 7D / 24-40 & OTB_MOL_70-99_0_0_all / 7D / 10-24 & OTT_CRU_70-99_0_0_all / 7D / 10-24 & OTT_CRU_>=70_0_0 / 7D / 10-24	4	2	56423
FR_Otter>=40	TR1.4	6	OTB_DEF_>=120_0_0 / 4 / >=40 & OTB_DEF_100-119_0_0 / 4 / >=40 & OTB_DWS_100-119_0_0_all / 4 / >=40 & OTB_DWS_>=120_0_0_all / 4 / >=40 & OTT_DEF_100-119_0_0 / 4 / >=40 & OTT_DEF_>=120_0_0_all / 4 / >=40	2	0	131512
FR_Otter>=40	TR1.6A	5	OTB_DEF_>=120_0_0 / 6A / >=40 & OTB_DEF_100-119_0_0 / 6A / >=40 & OTB_DWS_100-119_0_0_all / 6A / >=40 & OTB_DWS_>=120_0_0_all / 6A / >=40 & OTT_DEF_>=120_0_0_all / 6A / >=40	2	0	28104
GE_Beam<24	BT2.4	3	TBB_DEF_70-99_0_0_all / 4 / 10-24 & TBB_DEF_70-99_0_0_all / 4 / <10 & TBB_DEF_100-119_0_0_all / 4 / 10-24	2	1	2054
GE_Beam<24	OTH	1	TBB_CRU_16-31_0_0_all / 3AN / 10-24	0	1	0
GE_Beam<24	beam_oth.4	2	TBB_CRU_16-31_0_0_all / 4 / 10-24 & TBB_CRU_16-31_0_0_all / 4 / <10	2	0	33
GE_Beam>=24	BT2.4	3	TBB_DEF_70-99_0_0_all / 4 / >=40 & TBB_DEF_70-99_0_0_all / 4 / 24-40 & TBB_DEF_100-119_0_0_all / 4 / 24-40	1	1	25641
GE_Beam>=24	OTH	1	TBB_CRU_16-31_0_0_all / 4 / 24-40	1	0	18

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
GE_Otter24-40	OTH	3	OTB_DEF_>=120_0_0_all / 3AN / 24-40 & SSC_DEF_>=120_0_0_all / 3AN / 24-40 & OTB_CRU_70-99_0_0_all / 7D / 24-40	2	1	3382
GE_Otter24-40	TR1.4	3	OTB_DEF_>=120_0_0_all / 4 / 24-40 & SSC_DEF_>=120_0_0_all / 4 / 24-40 & SSC_DEF_100-119_0_0_all / 4 / 24-40	1	2	68560
GE_Otter24-40	TR2.4	3	OTB_CRU_70-99_0_0_all / 4 / 24-40 & OTB_DEF_70-99_0_0_all / 4 / 24-40 & SSC_DEF_70-99_0_0_all / 4 / 24-40	1	2	6137
GE_Otter<24	OTH	6	OTB_DEF_>=120_0_0_all / 3AN / 10-24 & SSC_DEF_>=120_0_0_all / 3AN / 10-24 & OTB_DEF_>=120_0_0_all / 4 / 10-24 & SSC_DEF_>=120_0_0_all / 4 / 10-24 & OTB_CRU_90-119_0_0_all / 3AN / 10-24 & OTB_CRU_70-99_0_0_all / 3AN / 10-24	3	3	12194
GE_Otter<24	TR2.4	2	OTB_CRU_70-99_0_0_all / 4 / 10-24 & OTB_DEF_70-99_0_0_all / 4 / 10-24	1	1	16366
GE_Otter>=40	OTB32-69.4	2	OTB_CRU_32-69_0_0_all / 4 / >=40 & OTB_SPF_32-69_0_0_all / 4 / >=40	1	1	411
GE_Otter>=40	OTB32-69.7D	2	OTB_CRU_32-69_0_0_all / 7D / >=40 & OTB_SPF_32-69_0_0_all / 7D / >=40	0	2	0
GE_Otter>=40	OTH	3	OTB_DEF_>=120_0_0_all / 4 / >=40 & OTB_CRU_32-69_0_0_all / 3AN / >=40 & OTB_SPF_32-69_0_0_all / 3AN / >=40	2	1	48991
GE_Otter>=40	TR3.4	1	OTB_CRU_16-31_0_0_all / 4 / >=40	1	0	757
GE_Static	GN1.3AN	5	GNS_DEF_all_0_0_all / 3AN / 10-24 & GNS_DEF_all_0_0_all / 3AN / 24-40 & GNS_DEF_120-219_0_0_all / 3AN / 10-24 & GNS_DEF_120-219_0_0_all / 3AN / 24-40 & GNS_DEF_100-119_0_0_all / 3AN / 10-24	1	3	441
GE_Static	GN1.4	9	GNS_DEF_all_0_0_all / 4 / 24-40 & GNS_DEF_all_0_0_all / 4 / 10-24 & GNS_DEF_all_0_0_all / 4 / <10 & GNS_DEF_120-219_0_0_all / 4 / 10-24 & GNS_DEF_120-219_0_0_all / 4 / <10 & GNS_DEF_120-219_0_0_all / 4 / 24-40 & GNS_DEF_>=220_0_0_all / 4 / 24-40 & GNS_DEF_100-119_0_0_all / 4 / 10-24 & GNS_DEF_100-119_0_0_all / 4 / 24-40	3	6	3772

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
GE_Static	OTH	5	GNS_DEF_>=220_0_0_all / 6A / 24-40 & GNS_DEF_>=220_0_0_all / 6A / 10-24 & GNS_DEF_all_0_0_all / 6A / 10-24 & FPO_CRU_0_0_0_all / 4 / 10-24 & FPO_CRU_0_0_0_all / 4 / <10	2	3	2
NL_Beam24-40	BT1.3AN	1	TBB_DEF_>=120_0_0_all / 3AN / 24-40	1	0	1161
NL_Beam24-40	BT1.4	1	TBB_DEF_>=120_0_0_all / 4 / 24-40	1	0	3670
NL_Beam24-40	BT2.4	3	TBB_DEF_100-119_0_0_all / 4 / 24-40 & TBB_DEF_70-99_0_0_all / 4 / 24-40 & TBB_CRU_70-99_0_0_all / 4 / 24-40	2	1	71847
NL_Beam24-40	OTH	2	TBB_CRU_16-31_0_0_all / 4 / 24-40 & TBB_DEF_<16_0_0_all / 4 / 24-40	1	1	843
NL_Beam<24	BT1.3AN	2	TBB_DEF_>=120_0_0_all / 3AN / 10-24 & TBB_DEF_>=120_0_0_all / 3AN / <10	1	0	1781
NL_Beam<24	BT1.4	2	TBB_DEF_>=120_0_0_all / 4 / 10-24 & TBB_DEF_>=120_0_0_all / 4 / <10	1	0	2757
NL_Beam<24	BT2.4	5	TBB_DEF_70-99_0_0_all / 4 / 10-24 & TBB_DEF_100-119_0_0_all / 4 / 10-24 & TBB_DEF_70-99_0_0_all / 4 / <10 & TBB_DEF_100-119_0_0_all / 4 / <10 & TBB_CRU_70-99_0_0_all / 4 / 10-24	2	1	22177
NL_Beam<24	beam_oth.4	5	TBB_CRU_16-31_0_0_all / 4 / 10-24 & TBB_CRU_16-31_0_0_all / 4 / <10 & TBB_DEF_16-31_0_0_all / 4 / 10-24 & TBB_DEF_32-69_0_0_all / 4 / <10 & TBB_CRU_16-31_0_0_all / 4 / all	1	3	1758
NL_Beam>=40	BT1.3AN	1	TBB_DEF_>=120_0_0_all / 3AN / >=40	1	0	8354
NL_Beam>=40	BT1.4	1	TBB_DEF_>=120_0_0_all / 4 / >=40	1	0	38721
NL_Beam>=40	BT2.4	3	TBB_DEF_100-119_0_0_all / 4 / >=40 & TBB_DEF_70-99_0_0_all / 4 / >=40 & TBB_CRU_70-99_0_0_all / 4 / >=40	2	1	343675
NL_Otter	OTH	19	OTB_DEF_All_0_0_All / 3AN / >=40 & OTB_DEF_All_0_0_All / 3AN / 10-24 & SSC_DEF_All_0_0_All / 3AN / 24-40 & OTB_MCD_>=55_0_0 / 3AN / 24-40 &	2	12	942

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
			OTB_DEF_>=120_0_0_all / 3AN / 10-24 & OTB_DEF_100-119_0_0_all / 3AN / 10-24 & OTB_DEF_>=120_0_0_all / 3AN / 24-40 & OTB_DEF_100-119_0_0_all / 3AN / >=40 & OTB_DEF_100-119_0_0_all / 3AN / 24-40 & SSC_DEF_100-119_0_0_all / 3AN / 24-40 & OTB_DEF_>=120_0_0_all / 3AN / >=40 & SSC_DEF_>=120_0_0_all / 3AN / 24-40 & SSC_DEF_>=120_0_0_all / 3AN / <10 & SSC_DEF_100-119_0_0_all / 7D / 24-40 & SSC_DEF_100-119_0_0_all / 7D / >=40 & SDN_DEF_>=120_0_0_all / 7D / 24-40 & SSC_DEF_>=120_0_0_all / 7D / 24-40 & SSC_DEF_100-119_0_0_all / 7D / 10-24 & SSC_DEF_100-119_0_0_all / 7D / <10			
NL_Otter	TR1.4	17	OTB_DEF_>=120_0_0_all / 4 / 10-24 & OTB_DEF_>=120_0_0_all / 4 / >=40 & OTB_DEF_>=120_0_0_all / 4 / 24-40 & OTB_DEF_100-119_0_0_all / 4 / 10-24 & OTB_DEF_100-119_0_0_all / 4 / >=40 & OTB_DEF_100-119_0_0_all / 4 / 24-40 & OTB_DEF_>=120_0_0_all / 4 / <10 & OTB_DEF_100-119_0_0_all / 4 / <10 & SSC_DEF_100-119_0_0_all / 4 / 24-40 & SSC_DEF_>=120_0_0_all / 4 / 24-40 & SDN_DEF_>=120_0_0_all / 4 / 24-40 & SSC_DEF_>=120_0_0_all / 4 / 10-24 & SSC_DEF_100-119_0_0_all / 4 / 10-24 & SDN_DEF_>=120_0_0_all_FDF / 4 / 24-40 & OTB_CRU_100-119_0_0_all / 4 / 10-24 & SSC_DEF_>=120_0_0_all / 4 / <10 & SSC_DEF_100-119_0_0_all / 4 / <10	3	8	47045
NL_Otter	TR2.4	16	OTB_DEF_70-99_0_0_all / 4 / 10-24 & OTB_DEF_70-99_0_0_all / 4 / 24-40 & OTB_DEF_70-99_0_0_all / 4 / >=40 & SSC_DEF_70-99_0_0_all / 4 / 24-40 & OTB_DEF_70-99_0_0_all / 4 / <10 & SSC_DEF_70-99_0_0_all / 4 / 10-24 & OTB_MCD_70-99_0_0_all / 4 / 24-40 & OTB_MCD_70-99_0_0_all / 4 / 10-24 & OTB_MCD_70-99_0_0_all / 4 / <10 & SSC_DEF_70-99_0_0_all / 4 / <10 & SDN_DEF_70-99_0_0_all / 4 / 24-40 & SDN_DEF_70-99_0_0_all / 4 / 10-24 & OTB_CRU_70-99_0_0_all / 4 / 24-40 & OTB_CRU_70-99_0_0_all / 4 / >=40 & OTB_CRU_70-99_0_0_all / 4 / 10-24 & SDN_DEF_70-99_0_0 / 4 / 24-40	3	9	35254
NL_Otter	TR2.7D	8	OTB_DEF_70-99_0_0_all / 7D / 24-40 & SSC_DEF_70-99_0_0_all / 7D / 24-40 & OTB_DEF_70-99_0_0_all / 7D / 10-24 & SDN_DEF_70-99_0_0_all / 7D / 24-40 & OTB_CRU_70-99_0_0_all / 7D / >=40 & SSC_DEF_70-99_0_0_all / 7D / 10-24 & SSC_DEF_70-99_0_0_all / 7D / <10 & SDN_DEF_70-99_0_0 / 7D / 24-40	2	5	286

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
NL_Otter	otter_oth.4	9	OTB_DEF_All_0_0_All / 4 / 10-24 & OTB_DEF_All_0_0_All / 4 / 24-40 & OTB_DEF_All_0_0_All / 4 / >=40 & SSC_DEF_All_0_0_All / 4 / 24-40 & OTB_MCD_>=55_0_0 / 4 / 24-40 & OTB_MCD_>=55_0_0 / 4 / 10-24 & SDN_all_0_0_all / 4 / 24-40 & SSC_DEF_All_0_0_All / 4 / <10 & OTB_MCD_>=55_0_0 / 4 / >=40	2	5	2784
NL_Pelagic	pelagic.4	7	OTM_SPF_32-69_0_0_all / 4 / 24-40 & OTM_SPF_32-69_0_0_all / 4 / 10-24 & OTM_SPF_32-69_0_0_all / 4 / >=40 & OTM_SPF_32-69_0_0_all / 4 / <10 & OTM_SPF_100-119_0_0 / 4 / >=40 & OTM_SPF_16-31_0_0 / 4 / >=40 & OTM_SPF_16-31_0_0 / 4 / 10-24	4	3	944
NL_Pelagic	pelagic.6A	2	OTM_SPF_32-69_0_0_all / 6A / >=40 & OTM_SPF_32-69_0_0_all / 6A / 24-40	1	1	386
NL_Pelagic	pelagic.7D	2	OTM_SPF_32-69_0_0_all / 7D / >=40 & OTM_SPF_16-31_0_0 / 7D / >=40	1	1	10
NO_DSeine24-40	OTH	5	SSC_DEF_<16_0_0 / 4 / 24-40 & SSC_DEF_90-99_0_0 / 4 / 24-40 & SSC_DEF_16-31_0_0 / 4 / 24-40 & SSC_DEF_<16_0_0 / 3AN / 24-40 & SSC_DEF_32-69_0_0 / 4 / 24-40	3	2	318
NO_DSeine24-40	TR1.4	2	SDN_DEF_>=120_0_0_all / 4 / 24-40 & SSC_DEF_>=120_0_0_all / 4 / 24-40	0	2	0
NO_Otter	otter_oth.4	3	OTB_DEF_>0_0_0 / 4 / all & OTB_DEF_<16_0_0 / 4 / all & OTB_CRU_>0_0_0 / 4 / all	0	3	0
NO_Otter24-40	OTB32-69.4	2	OTB_CRU_32-69_0_0_all / 4 / 24-40 & OTB_SPF_32-69_0_0_all / 4 / 24-40	0	2	0
NO_Otter24-40	OTH	7	OTB_CRU_32-69_0_0_all / 3AN / 24-40 & OTB_SPF_32-69_0_0_all / 3AN / 24-40 & OTB_DEF_<16_0_0 / 3AN / 24-40 & OTB_CRU_<16_0_0 / 3AN / 24-40 & OTB_SPF_<16_0_0 / 3AN / 24-40 & OTB_DEF_>=120_0_0_all / 3AN / 24-40 & OTB_CRU_16-31_0_0_all / 3AN / 24-40	2	4	13
NO_Otter24-40	TR1.4	3	OTB_DEF_>=120_0_0_all / 4 / 24-40 & PTB_SPF_>=120_0_0 / 4 / 24-40 & OTB_DEF_100-119_0_0 / 4 / 24-40	2	1	296

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
NO_Otter24-40	TR3.4	4	OTB_CRU_16-31_0_0 / 4 / 24-40 & OTB_DEF_16-31_0_0 / 4 / 24-40 & OTB_SPF_16-31_0_0 / 4 / 24-40 & OTB_CRU_16-31_0_0_all / 4 / 24-40	1	1	47262
NO_Otter24-40	otter_oth.4	5	OTB_DEF_<16_0_0 / 4 / 24-40 & OTB_SPF_<16_0_0 / 4 / 24-40 & OTB_DEF_70-89_0_0 / 4 / 24-40 & OTB_SPF_>0_0_0 / 4 / 24-40 & OTB_CRU_<16_0_0 / 4 / 24-40	4	0	1743
NO_Otter>=40	OTB32-69.4	2	OTB_CRU_32-69_0_0_all / 4 / >=40 & OTB_SPF_32-69_0_0_all / 4 / >=40	0	2	0
NO_Otter>=40	OTH	5	OTB_CRU_32-69_0_0_all / 3AN / >=40 & OTB_SPF_32-69_0_0_all / 3AN / >=40 & OTB_CRU_16-31_0_0_all / 3AN / >=40 & OTB_CRU_16-31_0_0 / 3AN / >=40 & OTB_DEF_16-31_0_0 / 3AN / >=40	1	3	80
NO_Otter>=40	TR1.4	1	OTB_DEF_>=120_0_0_all / 4 / >=40	0	1	0
NO_Otter>=40	TR3.4	4	OTB_CRU_16-31_0_0 / 4 / >=40 & OTB_DEF_16-31_0_0 / 4 / >=40 & OTB_SPF_16-31_0_0 / 4 / >=40 & OTB_CRU_16-31_0_0_all / 4 / >=40	1	1	150397
NO_Otter>=40	otter_oth.4	5	OTB_CRU_<16_0_0 / 4 / >=40 & OTB_DEF_<16_0_0 / 4 / >=40 & OTB_SPF_<16_0_0 / 4 / >=40 & OTB_CRU_>0_0_0 / 4 / >=40 & OTB_DEF_>0_0_0 / 4 / >=40	5	0	10533
NO_Pelagic	OTH	5	OTM_DEF_16-31_0_0 / 3AN / >=40 & PTM_DEF_16-31_0_0 / 3AN / >=40 & OTM_DEF_<16_0_0 / 3AN / >=40 & OTM_DEF_16-31_0_0 / 3AN / 10-24 & OTM_DEF_<16_0_0 / 3AN / 10-24	2	0	38
NO_Pelagic	pelagic.4	24	OTM_DEF_16-31_0_0 / 4 / >=40 & OTM_DEF_<16_0_0 / 4 / >=40 & PS_SPF_>0_0_0 / 4 / >=40 & PS_SPF_>0_0_0 / 4 / 10-24 & PS_SPF_>0_0_0 / 4 / 24-40 & PS_SPF_16-31_0_0 / 4 / >=40 & PS_SPF_32-69_0_0 / 4 / >=40 & PTM_DEF_16-31_0_0 / 4 / >=40 & PTM_DEF_<16_0_0 / 4 / >=40 & OTM_SPF_16-31_0_0 / 4 / >=40 & PS_SPF_16-31_0_0 / 4 / 24-40 & PS_SPF_32-69_0_0 / 4 / 24-40 & OTM_DEF_16-31_0_0 / 4 / 10-24 & OTM_SPF_16-31_0_0 / 4 / 10-24 & PTM_DEF_<16_0_0 / 4 / 24-40 & PTM_SPF_16-31_0_0 / 4 / >=40 & PS_SPF_32-69_0_0 / 4 / 10-24 & OTM_DEF_>0_0_0 / 4 / >=40 & OTM_SPF_<16_0_0 / 4 / >=40 & OTM_DEF_70-89_0_0 / 4 / >=40 & OTM_SPF_<16_0_0 / 4 / 24-40 &	6	6	7899

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
			OTM_DEF_<16_0_0 / 4 / 24-40 & OTM_DEF_<16_0_0 / 4 / 10-24 & PS_SPF_>=120_0_0 / 4 / >=40			
NO_Static	GN1.4	9	GNS_CRU_120-219_0_0 / 4 / 10-24 & GNS_DEF_all_0_0_all / 4 / 24-40 & GNS_DEF_all_0_0_all / 4 / 10-24 & GNS_DEF_all_0_0_all / 4 / >=40 & GNS_DEF_120-219_0_0_all / 4 / 24-40 & GNS_DEF_120-219_0_0_all / 4 / 10-24 & GNS_DEF_120-219_0_0_all / 4 / >=40 & GNS_DEF_>=220_0_0_all / 4 / 24-40 & GNS_DEF_>=220_0_0_all / 4 / 10-24	1	8	374
NO_Static	LL1.4	3	LLS_FIF_0_0_0_all / 4 / >=40 & LLS_FIF_0_0_0_all / 4 / 24-40 & LLS_FIF_0_0_0_all / 4 / 10-24	0	3	0
NO_Static	OTH	11	GNS_DEF_all_0_0_all / 3AN / 10-24 & GNS_DEF_all_0_0_all / 3AN / 24-40 & LLS_FIF_0_0_0_all / 3AN / 10-24 & FPO_CRU_0_0_0_all / 3AN / 10-24 & FPO_CRU_>0_0_0 / 3AN / 10-24 & FPO_DEF_>0_0_0 / 3AN / 10-24 & FPO_DEF_>0_0_0 / 3AN / 24-40 & FPO_DEF_>0_0_0 / 4 / 10-24 & FPO_CRU_0_0_0_all / 4 / 10-24 & FPO_CRU_>0_0_0 / 4 / 10-24 & FPO_DEF_>0_0_0 / 4 / 24-40	4	6	69
OTH_OTH	OTH	77	SSC_DEF_32-69_0_0_all / 4 / 24-40 & SSC_DEF_32-69_0_0_all / 7D / 24-40 & SSC_DEF_100-119_0_0_all / 4 / 24-40 & SSC_DEF_100-119_0_0_all / 4 / 10-24 & SSC_DEF_>=120_0_0_all / 4 / 24-40 & SSC_DEF_70-99_0_0_all / 4 / 24-40 & SSC_DEF_70-99_0_0_all / 4 / 10-24 & SSC_DEF_70-99_0_0_all / 7D / 24-40 & SSC_DEF_70-99_0_0_all / 7D / 10-24 & MIS_MIS_0_0_0_HC / 4 / 24-40 & MIS_MIS_0_0_0_HC / 4 / 10-24 & MIS_MIS_0_0_0_HC / 7D / 24-40 & MIS_MIS_0_0_0_HC / 7D / 10-24 & GTR_DEF_all_0_0_all / 4 / 10-24 & GTR_DEF_all_0_0_all / 7D / 10-24 & TBB_DEF_>=120_0_0_all / 3AN / >=40 & TBB_DEF_>=120_0_0_all / 3AN / 10-24 & TBB_DEF_>=120_0_0_all / 4 / >=40 & TBB_DEF_>=120_0_0_all / 4 / 10-24 & TBB_DEF_>=120_0_0_all / 4 / 24-40 & MIS_MIS_0_0_0_HC / 3AN / <10 & MIS_MIS_0_0_0_HC / 3AN / 24-40 & MIS_MIS_0_0_0_IBC / 3AN / 10-24 & MIS_MIS_0_0_0_IBC / 3AN / 24-40 & MIS_MIS_0_0_0_IBC / 3AN / >=40 & MIS_MIS_0_0_0_HC / 3AN / >=40 & MIS_MIS_0_0_0_IBC / 3AN / <10 & MIS_MIS_0_0_0_HC / 4 / <10 & MIS_MIS_0_0_0_IBC / 4 / 10-24 & MIS_MIS_0_0_0_HC / 4 / >=40 & MIS_MIS_0_0_0_IBC / 4 / >=40 & MIS_MIS_0_0_0_IBC / 4 / 24-40 & MIS_MIS_0_0_0_IBC / 4 / <10 & MIS_MIS_0_0_0_IBC / 6A / >=40 & MIS_MIS_0_0_0_IBC / 7D / >=40 &	0	77	0

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
			MIS_MIS_0_0_0_HC / 7D / >=40 & MIS_MIS_0_0_0_HC / 6A / >=40 & MIS_MIS_0_0_0_HC / 6A / 10-24 & MIS_MIS_0_0_0_HC / 6A / 24-40 & OTM_SPF_32-69_0_0_all / 4 / >=40 & MIS_MIS_0_0_0_HC / 4 / all & MIS_MIS_0_0_0_HC / 7D / <10 & GNS_DEF_all_0_0_all / 4 / <10 & GNS_DEF_10-30_0_0_all / 4 / <10 & GNS_DEF_all_0_0_all / 4 / 10-24 & GNS_DEF_100-119_0_0_all / 4 / 10-24 & FPO_CRU_0_0_0 / 4 / 10-24 & FPO_CRU_0_0_0 / 4 / 24-40 & SDN_DEF_>=120_0_0_all / 3AN / 10-24 & SSC_DEF_>=120_0_0_all / 3AN / 10-24 & SDN_DEF_>=120_0_0_all / 4 / 10-24 & SSC_DEF_>=120_0_0_all / 4 / 10-24 & DRB_CRU_>0_0_0 / 4 / all & SPR_DEF_>0_0_0 / 4 / 24-40 & OTB_CRU_32-69_0_0_all / 3AN / 10-24 & OTB_SPF_32-69_0_0_all / 3AN / 10-24 & OTB_CRU_32-69_0_0_all / 4 / 10-24 & OTB_SPF_32-69_0_0_all / 4 / 10-24 & OTB_DEF_70-89_0_0 / 3AN / 10-24 & OTB_DEF_90-99_0_0 / 3AN / 10-24 & OTB_SPF_70-89_0_0 / 3AN / 10-24 & OTB_SPF_90-99_0_0 / 3AN / 10-24 & OTB_CRU_70-89_0_0 / 3AN / 10-24 & OTB_DEF_<16_0_0 / 3AN / 10-24 & OTB_SPF_<16_0_0 / 3AN / 10-24 & OTB_CRU_<16_0_0 / 3AN / 10-24 & OTB_DEF_>=120_0_0_all / 3AN / 10-24 & OTB_DEF_>=120_0_0_all / 4 / 10-24 & OTB_CRU_90-119_0_0_all / 3AN / 10-24 & OTB_DEF_16-31_0_0 / 3AN / 10-24 & OTB_CRU_16-31_0_0 / 3AN / 10-24 & OTB_CRU_16-31_0_0_all / 3AN / 10-24 & OTB_DEF_16-31_0_0 / 4 / 10-24 & OTB_SPF_16-31_0_0 / 4 / 10-24 & OTB_CRU_16-31_0_0_all / 4 / 10-24 & MIS_MIS_0_0_0_HC / 6A / <10			
SC_Beam	BT2.6A	2	TBB_DEF_70-99_0_0_all / 6A / 10-24 & TBB_DEF_70-99_0_0_all / 6A / <10	1	0	58
SC_Beam	OTH	8	TBB_DEF_>=120_0_0_all / 4 / >=40 & TBB_DEF_>=120_0_0_all / 4 / <10 & TBB_DEF_>=120_0_0_all / 4 / 10-24 & TBB_DEF_>=120_0_0_all / 6A / <10 & TBB_DEF_>=120_0_0_all / 6A / 10-24 & TBB_DEF_70-99_0_0_all / 4 / >=40 & TBB_DEF_70-99_0_0_all / 4 / 10-24 & TBB_DEF_70-99_0_0_all / 4 / <10	5	1	9369
SC_Otter<10	OTH	2	OTB_DEF_>=120_0_0_all / 4 / <10 & OTB_DEF_>=120_0_0_all / 6A / <10	1	0	461
SC_Otter<10	TR2.4	1	OTB_CRU_70-99_0_0_all / 4 / <10	1	0	7636
SC_Otter<10	TR2.6A	1	OTB_CRU_70-99_0_0_all / 6A / <10	1	0	8872

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
SC_Otter<24	TR1.4	2	OTB_DEF_>=120_0_0_all / 4 / 10-24 & OTB_DEF_>=120_0_0_all / 4 / 10-24	1	0	252675
SC_Otter<24	TR1.6A	2	OTB_DEF_>=120_0_0_all / 6A / 10-24 & OTB_DEF_>=120_0_0_all / 6A / 10-24	2	0	19920
SC_Otter<24	TR2.4	2	OTB_CRU_70-99_0_0_all / 4 / 10-24 & OTB_CRU_70-99_0_0_all / 4 / 10-24	2	0	98627
SC_Otter<24	TR2.6A	1	OTB_CRU_70-99_0_0_all / 6A / 10-24	1	0	103818
SC_Otter>=24	OTH	4	OTB_DEF_>=120_0_0_all / 7D / 24-40 & OTB_DEF_>=120_0_0_all / 7D / >=40 & OTB_CRU_70-99_0_0_all / 4 / 24-40 & OTB_CRU_70-99_0_0_all / 4 / >=40	4	0	9774
SC_Otter>=24	TR1.4	4	OTB_DEF_>=120_0_0_all / 4 / 24-40 & OTB_DEF_>=120_0_0_all / 4 / 24-40 & OTB_DEF_>=120_0_0_all / 4 / >=40 & OTB_DEF_>=120_0_0_all / 4 / >=40	3	0	552632
SC_Otter>=24	TR1.6A	4	OTB_DEF_>=120_0_0_all / 6A / >=40 & OTB_DEF_>=120_0_0_all / 6A / >=40 & OTB_DEF_>=120_0_0_all / 6A / 24-40 & OTB_DEF_>=120_0_0_all / 6A / 24-40	2	0	73018
SC_Otter>=24	TR2.7D	2	OTB_CRU_70-99_0_0_all / 7D / 24-40 & OTB_CRU_70-99_0_0_all / 7D / >=40	1	0	2191
SC_Static	GN1.4	2	GNS_DEF_>=220_0_0_all / 4 / 24-40 & GNS_DEF_>=220_0_0_all / 4 / 10-24	0	2	0
SC_Static	LL1.4	4	LLS_DEF_0_0_0_all / 4 / 10-24 & LLS_DEF_0_0_0_all / 4 / 24-40 & LLS_FIF_0_0_0_all / 4 / 24-40 & LLS_FIF_0_0_0_all / 4 / 10-24	2	2	283
SC_Static	LL1.6A	3	LLS_DEF_0_0_0_all / 6A / 24-40 & LLS_FIF_0_0_0_all / 6A / 24-40 & LLS_DEF_0_0_0_all / 6A / 10-24	1	2	19
SC_Static	OTH	2	GNS_DEF_>=220_0_0_all / 6A / 24-40 & GNS_DEF_>=220_0_0_all / 6A / 10-24	0	2	0
SC_Static	pots.4	2	FPO_CRU_0_0_0_all / 4 / 24-40 & FPO_CRU_0_0_0_all / 4 / 10-24	2	0	34

Study to assess the robustness of mixed fisheries scenario assumptions

Fleet	Métier	n strata	Strata (corresponding to the country of the fleet)	n clusters	NA cluster	Landed weight (t;2019-21)
SC_Static	pots.6A	2	FPO_CRU_0_0_0_all / 6A / 10-24 & FPO_CRU_0_0_0_all / 6A / 24-40	1	1	6893
SC_Static<10	LL1.4	2	LLS_DEF_0_0_0_all / 4 / <10 & LLS_FIF_0_0_0_all / 4 / <10	1	1	1493
SC_Static<10	OTH	6	GNS_DEF_>=220_0_0_all / 4 / <10 & FPO_CRU_0_0_0_all / 4 / <10 & FPO_CRU_0_0_0_all / 7D / <10 & GNS_DEF_>=220_0_0_all / 6A / <10 & LLS_DEF_0_0_0_all / 6A / <10 & LLS_FIF_0_0_0_all / 6A / <10	1	4	942
SC_Static<10	pots.6A	1	FPO_CRU_0_0_0_all / 6A / <10	1	0	12842
SW_Otter	OTH	9	OTB_CRU_32-69_0_0_all / 3AN / 24-40 & OTB_CRU_32-69_0_0_all / 3AN / 10-24 & OTB_CRU_32-69_2_22_all / 3AN / 24-40 & OTB_CRU_32-69_2_22_all / 3AN / 10-24 & OTB_CRU_32-69_2_22_all / 3AN / <10 & OTB_CRU_32-69_0_0_all / 3AN / <10 & OTB_CRU_32-69_0_0_all / 4 / 24-40 & OTB_CRU_32-69_0_0_all / 4 / 10-24 & OTB_CRU_32-69_0_0_all / 4 / <10	3	0	5381
SW_Otter	TR1.4	3	OTB_DEF_>=120_0_0_all / 4 / 10-24 & OTB_DEF_>=120_0_0_all / 4 / 24-40 & OTB_DEF_>=120_0_0_all / 4 / <10	3	0	16306
SW_Otter	TR2.3AN	3	OTB_CRU_90-119_0_0_all / 3AN / 24-40 & OTB_CRU_90-119_0_0_all / 3AN / 10-24 & OTB_CRU_90-119_0_0_all / 3AN / <10	2	0	14584
SW_Otter	TR2_grid.3AN	3	OTB_CRU_70-89_2_35_all / 3AN / 10-24 & OTB_CRU_70-89_2_35_all / 3AN / <10 & OTB_CRU_70-89_2_35_all / 3AN / 24-40	1	0	5842
SW_Static	OTH	6	GNS_DEF_all_0_0_all / 3AN / 10-24 & GNS_DEF_all_0_0_all / 3AN / <10 & GTR_DEF_all_0_0_all / 3AN / 10-24 & GTR_DEF_all_0_0_all / 3AN / <10 & LLS_FIF_0_0_0_all / 3AN / 10-24 & LLS_FIF_0_0_0_all / 3AN / <10	3	0	1738
SW_Static	pots.3AN	2	FPO_CRU_0_0_0_all / 3AN / 10-24 & FPO_CRU_0_0_0_all / 3AN / <10	1	0	3629

ANNEX 2: OVERVIEW OF NORTH SEA FLEET DISTINCTIONS USED IN THE ICES WGMIXFISH ADVICE NORTH SEA MODEL

In the current implementation of the North Sea mixed-fisheries model used by ICES, accounts for known national fishing patterns which give the resulting decisions associated with fleets:

- Belgium: distinction between < 24 m and ≥ 24 m beam trawlers; shrimp fisheries with 16–31 mm excluded;
- Denmark: distinction of the < 10 m vessels (trawlers only); separation of the trawlers at < 24 m, 24–40 m and ≥ 40 m; fully documented fishery (FDF) vessels in a separate fleet;
- England: distinction of the < 10 m vessels; otter trawlers and seiners pooled together, with separation at < 24 m, 24–40 m and ≥ 40 m; FDF vessels in a separate fleet;
- France: distinction of the < 10 m vessels; separation of the trawlers at < 40 m and ≥ 40 m, specific gill- and trammel-net fleet;
- Germany: distinction between < 24 m and ≥ 24 m beam trawlers; shrimp fisheries with 16–31 mm excluded; otter trawlers and seiners pooled together with separation at < 24 m, 24–40 m and ≥ 40 m;
- Netherlands: distinction between < 24 m, 24–40 m and ≥ 40 m beam trawlers; otter trawlers and seiners pooled together;
- Norway: otter trawlers and seiners pooled together, with separation at < 40 m and ≥ 40 m; no mesh size used for métiers definition;
- Scotland: distinction of the < 10 m vessels (trawlers only); separation of the trawlers at < 24 m and ≥ 24 m; FDF vessels in a separate fleet; otter trawlers and seiners pooled together;
- Sweden: no distinction of vessel size.

ANNEX 3: FRAMEWORK FOR DEFINING MÉTIER AND FLEET UNITS IN THE NORTH SEA

Data submitted to ICES WGMIXFISH (see Table 1 of the main report for details on this dataset) was used to conduct a principal component and cluster analysis following the methodology as described in Moore et al. (2019). This multivariate analysis allows to group input data according to similarities across multiple input variables. In this case, the input variables represent the landings proportion of a selection of important demersal fish species (and *Nephrops*) in the North Sea for the years 2019-2021

1 DATA

For the North Sea case study, the mixed-fisheries data were first filtered using a selection of species that are considered as the main target species describing the demersal fisheries in the region. These include the species assessed in WGNSSK: brill, cod, dab, flounder, grey gurnard, haddock, lemon sole, red mullet, *Nephrops*, Norway pout, plaice, saithe, pollock, sole, turbot, whiting and witch flounder. Furthermore, the analysis was restricted to the years 2019–2021 inclusive. As a result, not all fleet–métier definitions of the North Sea WGMIXFISH model can be matched to a cluster: because of the mismatch in the time frame (2009–2021 vs 2019–2021), some strata used to define those métiers did not appear in the data used for clustering.

2 METHODOLOGY

To identify the effect of data aggregation according to different strata describing potential fleets and métiers in the North Sea, the method described in Moore et al. (2019) was applied to the WGMIXFISH data. In this method, the variance in catch profiles after grouping the data according to some predefined strata is analysed using a principal component analysis (PCA). In a second step, clusters are identified according to the results of the PCA, which can give guidance for the definitions of fleets and/or métiers in a fishery.

3 RESULTS

At the start of the analysis, data were grouped according to a selection of fishing activity descriptors – including gear, ICES subdivision, target species assemblage, mesh size and vessel length. The country was always retained in the grouping as it is an important variable underlying the management of fleets (e.g. TACs are distributed in quota at the national level). Next, the PCA analysis was performed on the catch proportions (of the 17 selected species). The results of this analysis are summarised in Table 2.

All PCAs presented perform similarly in terms of explained (60 %–68 %) variance by the first four components and none of them showed a clear inflection point in the scree plot (Figure 1). However, the PCAs cannot be compared directly because they use different input data. This indicates that the aggregation level of the data up to the country and gear level has little effect on the variability in the data. This is also reflected by the number of clusters required to explain 90 % of the variability in catch composition, as well as the description of the clusters in terms of gears and catch composition (for example, see PCA 4 ⁽⁸⁾).

The PCA analysis provides useful insights into the input data and shows which different strata can potentially be grouped together. However, the PCA cannot be used directly to define fleets and métiers; this requires additional information on how quotas are distributed according to fishing vessels, as well as (technical) characteristics of fishing vessels that provide information on the different fishing strategies the vessels have (for example, switching between mesh size, or gear, or spatial differentiation). Ideally, the PCA should also be run on data for a single year (or even a single quarter if strong seasonal fluctuations in stock biomass are present) or a metric of catchability, this would

avoid effects of biomass changes over time reflected in the landings compositions of the strata present in the data.

PCA 4, which best reflects the aggregation level of the fleet-métier definitions used to define fleets and métiers by WGMIXFISH-ADVICE, is used to test the fleet-métier definitions of this model. In ANNEX 1, the fleet and métier definitions of the current WGMIXFISH North Sea model used for advice are presented, including the number of strata on which the fleet-métier combinations are based.

In total, 56 % (88 out of 159) of all fleet-métier combinations (representing 51 % of the landed weight) are based on a relatively small number of strata (≤ 3) (Table 3). For the other fleet-métier combinations presented in the model, the number of strata used ranges from 4 to 77. However, the fleet-métiers with a high number of strata are mainly found in the OTH métier groups, which represent métiers that do not reach the landing threshold of any of the species included in the model. The OTH_OTH fleet, that includes all fleets, across countries, comprising a single OTH métier, is defined based on 77 strata. The non-OTH métiers composed of a high number of strata (≥ 10) comprise mainly pelagic fleets including the FR_OTH fleet (pelagic 4 métier, with 15 strata, and the pelagic 7d métier with 16 strata), the NO_Pelagic fleet with the pelagic 4 métier composed of 24 strata, and the NL_Otter fleet (TR1.4 métier, with 17 strata, and the TR2.4 métier with 16 strata). The NL_Otter fleet comprises both the OTB (bottom otter trawl), and SDN/SSC (Danish/Scottish seine) gears, of which the latter comprised a relatively small fishery (targeting mainly non-quota species) at the time of development of the North Sea mixed-fisheries model; however, the Dutch flyshoot fisheries expanded over the last decade.

Table 4 shows the number of clusters by fleet-métier for both the specific métiers, and the métiers classified as OTH. Overall, 31 % of the métiers belong to a single cluster, while another 29 % of the métiers comprises strata that belong to different clusters in terms of catch composition. In addition, 5 % of the fleet-métiers (of which one non-OTH métier) has strata that belong to ≥ 6 different clusters. For the non-OTH métiers, 37 of the fleet-métiers belong to a single cluster, while 33 % of the fleet-métier combinations have strata that are grouped in two different clusters according the PCA and subsequent cluster analysis.

The fleet-métier disaggregation in the North Sea WGMIXFISH advice model is sensible. Nevertheless, the PCA analysis indicated that some fleet-métier combinations would benefit from a further disaggregation in terms of variability in catch composition. In addition, the model comprises a large number of OTH métier categories, which have a poorer performance in terms of fleet-métier aggregation. Nevertheless, all these métiers comprise < 5 % of the total landed volume of demersal species.

If new input data (e.g. spatially disaggregated) is used for the short-term mixed-fisheries projections (1 year in the North Sea) in the future, it is recommended that the data be explored using a PCA analysis, as presented here, before assigning the fleet and métier definition

Table 2: Summary of the eight PCA runs showing the aggregation level of the data and the resulting number of observations after grouping, the variance explained by the first four PCA axes, and the number of clusters that explain 90 % of the variance in catch composition of the data.

PCA run	Aggregation level	n	Var. by first four axes	n_clust (90 % var)
PCA 1	Country + year + ICES div * + gear + dom. spp. * + mesh size + vessel length	1 585	63	22
PCA 2	Country + year + ICES div + gear + dom. spp. + mesh size	855	60	2 2
PCA 3	Country + ICES div + gear + dom. spp. + mesh size	369	62	23
PCA 4	Country + ICES div + gear + dom. spp. + mesh size + vessel length	729	65	23
PCA 5	Country + year + ICES div + gear + dom. spp.	540	64	22
PCA 6	Country + ICES div + gear + dom. spp.	208	65	21
PCA 7	Country + gear	74	68	19
PCA 8	Country + gear + target spp.	104	68	19

* ICES div = ICES division; Dom. spp. = target assemblage

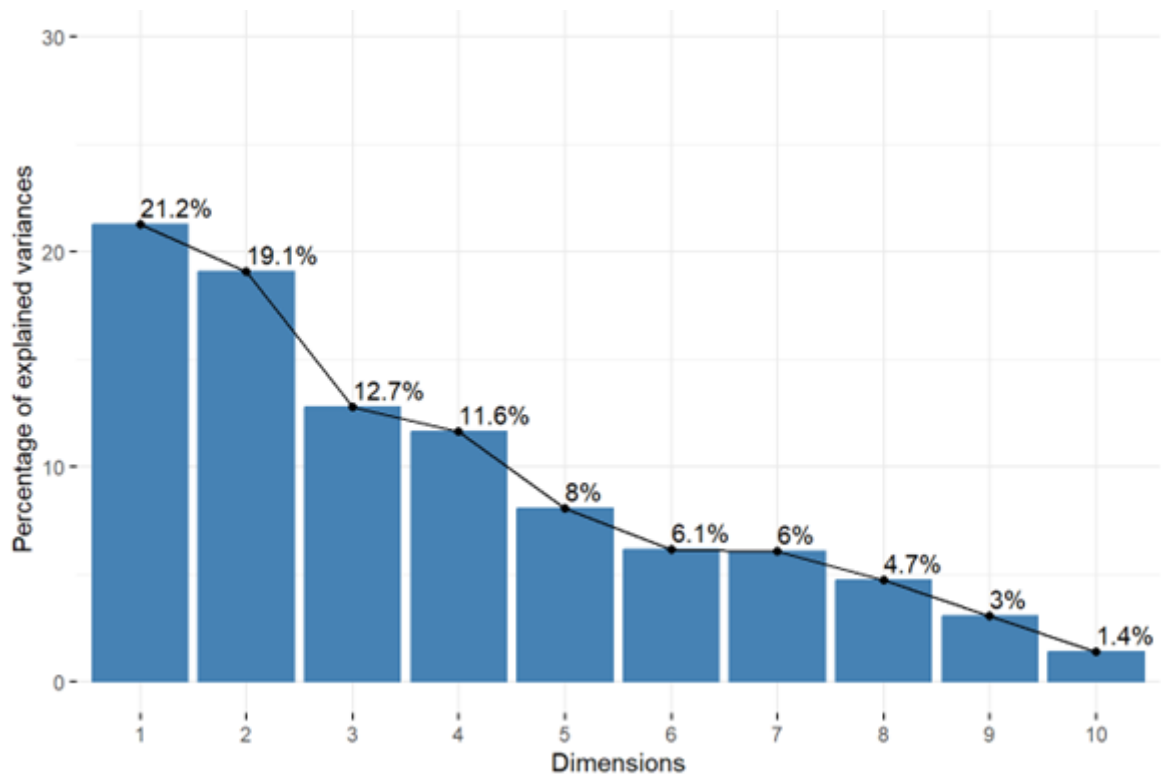


Figure 1: Scree plot of principal component analysis components (labelled dimensions) in order of the proportion of the data variance they explain.

Table 3: Overview of the number of strata used to condition métiers. Only values for strata for which a fleet-métier combination exists are presented in the table.

Number of strata	Specific métiers	OTH métiers
1	27	2
2	36	4
3	17	2
4	13	5
5	7	5
6	5	5
7	6	3
8	1	1
9	5	2
11	0	1
13	0	1
15	1	0
16	2	0
17	1	0
19	0	2
20	0	1
22	0	1
24	1	0
25	0	1
77	0	1

Table 4: Overview of the number of clusters to which the métiers are assigned with respect to PCA 4 and the number of clusters that explain 90 % of the variance.

Number of clusters	1	2	3	4	5	6	7	8	9	10
Non-OTH métiers	45	40	17	11	8	0	1	0	0	0
OTH métiers	5	6	12	6	1	2	2	1	1	1

ANNEX 4: MATHEMATICAL REPRESENTATION OF CONSTRAINTS USED IN TESTING NORTH SEA CASE STUDY LINKS TO SENSITIVITY UNCERTAINTY OF FORECAST CONDITIONING

For the North Sea case study a linear programming model was implemented with different constraints that represent three different scenarios in terms of fleet-effort proportions across métiers:

$$Max \left(\prod_{m \in \text{métiers}} \sum E_m \right)$$

Subjected to the following constraints:

1. $E_m \geq 0$, for each $m \in \text{métiers}$
2. $\sum_{m \in \text{métiers}} E_m \leq Capacity_{fleet}$
3. $\sum_{m \in \text{métiers}} q_{m_s} E_m B_s \leq Quota_s$, for each $s \in \text{species}$
4. $E_m - effortshare_m \sum_{m \in \text{métiers}} E_m = 0$
5. $E_m - \min(effortshare)_m \sum_{m \in \text{métiers}} E_m \geq 0$
6. $E_m - \max(effortshare)_m \sum_{m \in \text{métiers}} E_m \leq 0$

ANNEX 5: CELTIC SEA CASE STUDY INVESTIGATION INTO DEFINING MÉTIER AND FLEET UNITS

This analysis is an update of the work previously completed by the Celtic Sea subgroup at WGMIXFISH (Davie & Lordan, 2011; Moore et al., 2019; ICES, 2018). A multivariate analysis (principal component analysis and hierarchical clustering) has been applied to identify homogenous groupings of métiers. This framework is currently only applicable to métier definitions.

1 DATA

The outputs presented here are solely based on the mixed fisheries data as submitted to the ICES WGMIXFISH-advice. This decision was made based on the exploration of available data within section 2, which highlighted the discrepancies between the different data products available to this study. Although this limits the scope with respect to fleet/métier definitions, using a single data source (validated by WGMIXFISH) facilitates the interpretation of the results as there are no (potential) effect of using different data sets on the results.

The data submitted to ICES WGMIXFISH-advice uses a similar stratification level as the data submitted to ICES for single species stock assessments. Effort and catch/landings (by species) are submitted by country, quarter, métier DCF level 6, vessel length (following the STECF AER definitions), and ICES subdivision resulting in an extensive dataset. To reduce the number of strata (and potential fleet/métiers), the data is grouped into categories as such that the variability of the data, describing the heterogeneity of the fishery, is as much as possible maintained.

In order to reduce the number of categories, an aggregation threshold was used to identify 'small' métiers. A métier failing to catch 1.0% of at least one of the stocks considered was classified as small, and not considered as a separate métier but aggregated by fleet in one 'Other' métier (OTH). Further, fleets that contain only the 'OTH' métier are aggregated into one single 'OTH' fleet.

2 METHODOLOGY

To identify the effect of data aggregation according to different strata describing potential fleets and métiers in the North Sea, the method described in Moore et al. (2019) was applied to the WGMIXFISH data. In this method, the variance in catch profiles after grouping the WGMIXFISH data according to some predefined strata is analysed using a PCA. Clusters were identified according to the results of the PCA which can give guidance for the definitions of métiers in a fishery.

The mixed fisheries data were first filtered using a selection of species that are considered as the main target species describing the demersal fisheries in the region. These include the species assessed in WGCSE and WGBIE: for cod (cod.27.7e-k), haddock (had.27.7b-k), whiting (whg.27.7b-ce-k), Norway lobster (FUs 16, 17, 19, 20–21, 22, and 27.7 outside FUs), sole (sol.27.7e and sol.27.7fg), white and black-bellied anglerfish (mon.27.78abd and ank.27.78abd), megrim (meg.27.7b-k8abd), and hake (hke.27.3a46-8abd) in the Celtic Sea. The analysis was restricted to the years 2019-2021 inclusive.

The landings data was grouped according to a selection of fishing activity descriptors with country (flag of vessel provenance), area (ICES Division), vessel length class, and year of retained catch. Therefore, providing a description of fishing activity which is aggregated to the level of year and ICES Division. Country was always retained in the grouping as it is an important variable underlying the management of fleets (e.g. TACs are distributed in quota at the national level). The PCA analysis was then performed on the landings proportions of the 15 selected stocks.

The results of the analysis are summarised in Table 1. PCA 7 and 8 were excluded from the final comparison, the cluster catch profiles these PCAs created were inconsistent with the expert understanding of the fisheries. These landings profiles can be reviewed here as part of study code ⁽¹⁾. These inconsistencies are likely driven by the overly simplistic nature of the model set up, only incorporating gear and target assemblage as fishing activity descriptors.

Table 1: Summary of the 8 PCA runs showing the aggregation level of the data and the resulting number of observations after grouping, the variance explained by the first four PCA axes, and the number of cluster that explain 90% of the variance in catch composition of the data

PCA run	Aggregation level	n	Var. by first 4 axes	n_clust (90% var)	Included
PCA 1	Country + Year + ICES Div + Gear + Dom spp. + Mesh Size + Vessel Length	1204	58%	21	Yes
PCA 2	Country + Year + ICES Div + Gear + Dom spp. + Mesh Size	768	61%	19	Yes
PCA 3	Country + ICES Div + Gear + Dom spp. + Mesh Size	520	62%	17	Yes
PCA 4	Country + ICES Div + Gear + Dom spp. + Mesh Size + Vessel Length	829	60%	19	Yes
PCA 5	Country + Year + ICES Div + Gear + Dom spp	1118	63%	18	Yes
PCA 6	Country + ICES Div + Gear + Dom spp	345	69%	18	Yes
PCA 7	Country + Gear	61	79%	17	No
PCA 8	Country + Gear + Target spp	75	81%	20	No

3 DISCUSSION

All PCAs presented perform very similar in terms of explained (58 %-69 %) variance by the first 4 components and none of them showed a clear inflection point in the scree plot. Although the PCAs cannot be compared directly, each PCA is run on varying levels of aggregation of fishing activity. The results of the PCA, combined with expert knowledge to review the resulting landings profile for each principle component, provides information. This is also reflected by the number of clusters required to explain 90 % of the variability in catch composition, as well as the description of the clusters in terms of gears and catch

⁽¹⁾ https://github.com/IrishMarineInstitute/STARMixFish/blob/main/lot_2/TASK_2/07a_PCA_7.html and https://github.com/IrishMarineInstitute/STARMixFish/blob/main/lot_2/TASK_2/08a_PCA_8.html

composition. PCA 6 provides best the aggregation level at which to define métiers within the mixed fishery assessment model for the Celtic Sea ⁽²⁾.

4 CONCLUSION

This analysis indicates that current métier typology and grouping used in the Celtic Sea WGMIXFISH advice model is sensible, and consistent with the previous findings (Moore et al., 2019, ICES, 2018). This indicates that at the resolution of year and ICES divisions, there is stability in the definitions used for métiers, and they maintain relevance to the current fishing patterns in the Celtic Sea. However, if new input data (e.g. spatially disaggregated) are used for mixed fisheries projections in the future, it is recommended to explore the data using a PCA analysis, as presented here, before defining the fleet and métiers definitions.

5 REFERENCES

Davie, S. & Lordan, C. (2011). Definition, dynamics and stability of métiers in the Irish otter trawl fleet. *Fisheries Research*, 111: 145–158.

ICES. (2018). Ad hoc Report on the Special Request on further development of ICES mixed fisheries considerations and biological interactions, Nov-Dec 2018. ICES CM 2018/ACOM: 65. 82pp.

Moore, C., Davie, S., Robert, M., Pawlowski, L., Dolder, P. & Lordan, C. (2019). Defining métier for the Celtic Sea mixed fisheries: A multiannual international study of typology. *Fisheries Research*, 219, 105310. DOI: 10.1016/j.fishres.2019.105310

⁽²⁾ see for example PCA 6: https://github.com/IrishMarineInstitute/STARMixFish/blob/main/lot_2/TASK2/04a_PCA_4.html

ANNEX 6: EXAMPLE OF IMPACT OF SPATIAL DISAGGREGATION FOR THE IRISH *NEPHROPS* FLEET

This case study explores the impact of spatial disaggregation on the choking patterns of cod in the Irish *Nephrops* fleet.

To complete this work, landings data reported by fishers to the operations table (daily activity recorded by fishers) of the electronic logbooks system was used to describe the landing species composition of trips (Figure 1). This format of data would be similar to that reported to ICES RDBES. These data were visualised using the tools developed to identify species interactions (section 5.2 of the main report).

The objective was to identify the number and frequency of fishing trips operating within *Nephrops* Functional Units (FUs) that could be completely decoupled from any technical interactions with cod, the primary choking species within the Celtic Seas mixed-fisheries model.

Despite the increased spatial resolution provided by this new data, from ICES division (currently used by WGMIXFISH) down to ICES statistical rectangle, it was not possible to completely decouple landings of cod and *Nephrops* on individual trips. Based on *Nephrops* biology and their fisheries, the occurrence of technical interactions between these two species is likely to be highly influenced by the FU being presented.

For this case study FU 16, the Porcupine Bank, was selected as an example. FU 16 is considered to be a highly targeted *Nephrops* fishery, executed predominantly by bottom otter trawl (OTB) gears from the Irish fleet. However, even in FU 16, it can be seen that there are still some technical interactions with cod, with a number of trips (< 10) still catching cod in this area, see Figure 6. As it was not possible to completely decouple *Nephrops* trips from trips where cod was caught at the level of statistical rectangle, there was no clear way to refine fleets in this case. Therefore, there was no need to rerun Fcube.

To create fleets that are not artificially choked by false technical interactions would require more spatially disaggregated data. Therefore, the WGMIXFISH Celtic Seas subgroup is developing a framework (see section 3.2.1 of the main report) that will allow for the identification of technical interactions at a more spatially disaggregated level (VMS pings).

Study to assess the robustness of mixed-fisheries scenario assumptions

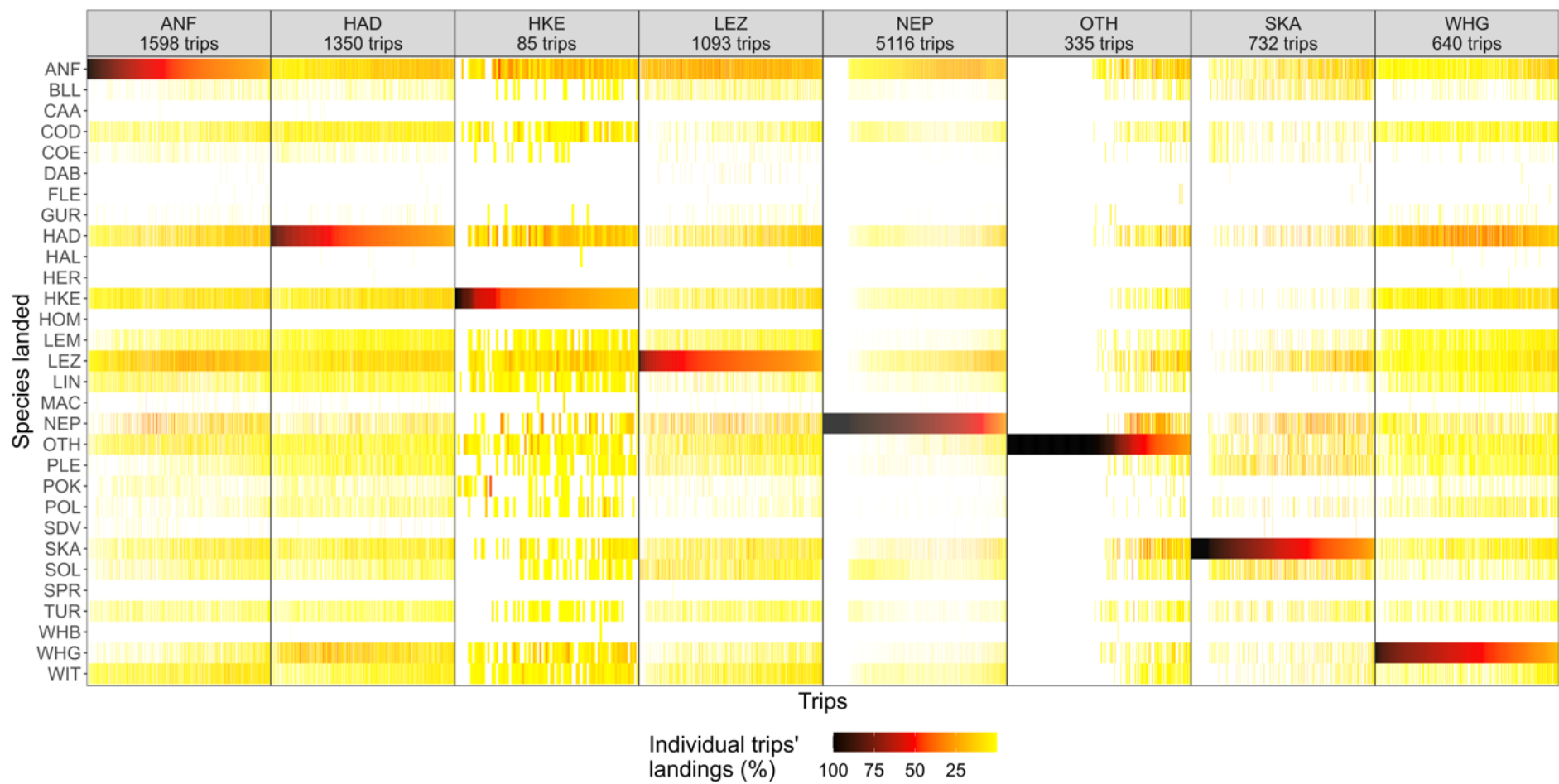


Figure 1: Targeting behaviour and landings composition by trip ordered by targeting. The panels show the trips of Irish fleets operating with bottom otter trawl (OTB) gear in the Celtic Sea. Species abbreviations: ANF = anglerfish; BLL = brill; CAA = wolffish; COD = cod; COE = conger eel; DAB = dab; FLE = flounder; GUR = gurnard; HAD = haddock; HAL = halibut; HER = herring; HKE = hake; HOM = horse mackerel; LEM = lemon sole; LEZ = megrim;; LIN = ling; MAC = mackerel; NEP = *Nephrops*; OTH = 'other'; PLE = plaice; POK = saithe; POL = pollack; SDV = smooth-hounds; SKA = skates and rays; SOL = common sole; SPR = sprat; TUR = turbot; WHB = blue whiting; WHG = whiting; WIT = witch flounder.

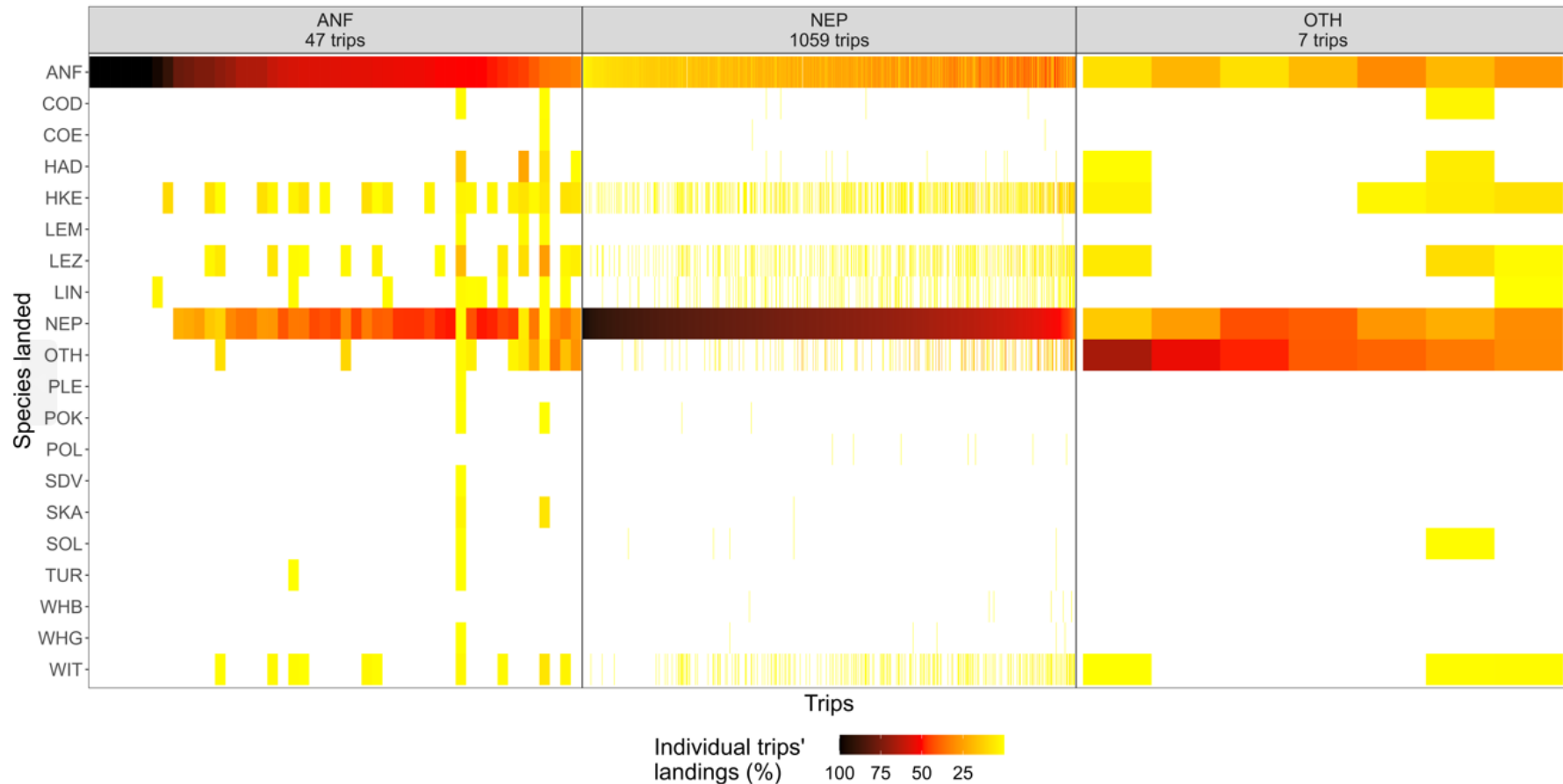


Figure 2: Targeting behaviour and landings composition by trip ordered by targeting. The panels show the trips of Irish fleets operating with the OTB gear for trips that fished the Porcupine Bank (encompassing statistical rectangles: 31D5, 32D5, 33D5, 31D6, 32D6, 33D6, 32D7, 33D7, 34D8, 35D8, 34D5, 35D5, 34D6, 35D6, 34D7, 35D7, 32D8, 33D8). Species abbreviations: ANF = anglerfish; BLL = brill; CAA = wolffish; COD = cod; COE = conger eel; DAB = dab; FLE = flounder; GUR = gurnard; HAD = haddock; HAL = halibut; HER = herring; HKE = hake; HOM = horse mackerel; LEM = lemon sole; LEZ = megrim;; LIN = ling; MAC = mackerel; NEP = *Nephrops*; OTH = 'other'; PLE = plaice; POK = saithe; POL = pollack; SDV = smooth-hounds; SKA = skates and rays; SOL = common sole; SPR = sprat; TUR = turbot; WHB = blue whiting; WHG = whiting; WIT = witch flounder.

ANNEX 7: TECHNICAL EXPLANATION PREVENTING USE OF FLBEIA IN THE CELTIC SEA

The WGMIXFISH inter-benchmark in 2021 (IBPMIXFISH; ICES, 2021b) concluded that it was not possible to use FLBEIA for Celtic Seas advice purposes. When the FLBEIA model was applied in the Celtic Sea, several problems were encountered in reproducing the advice and forecast of mixed-fisheries scenarios.

These problems were mainly attributed to the use of the Cobb–Douglas model at high levels of fishing mortality and the impact of discards weight-at-age in the forecast of discards. IBPMIXFISH recommended continuing working on the Celtic Sea model conditioning, the implementation of Baranov catch production function in FLBEIA and identifying the most appropriate way to project over-quota discards and discard weights to be implemented later in FLBEIA. This work has continued intersessionally, the Centre for Environment, Fisheries and Aquaculture Science (Cefas) presented an update of this work at WGMIXFISH-METHODS 2023 (ICES, 2023b). This work has focused on improving the implementation of Pope’s approximation as a method to improve the outcomes of using FLBEIA in the Celtic Sea (ICES, 2023b). Using a simplistic test data set the behaviour of the equations was explored, rather than the complex reality of mixed fisheries, therefore drivers in changes in the forecast could be attributed to the equation behaviour rather than masked by other factors (i.e. fishery dynamics). Arbitrary values for stock numbers, catchability and natural mortality are used to generate simple simulation scenarios to understand how and where the Baranov and Pope’s approximation catch-production functions differ.

The intersessional analysis has demonstrated how the decoupling of dependencies among fleet harvesting under Pope’s approximation leads to differences with Baranov in realised fleet catches for a given level of fleet effort. Consequently, the identified effort-limiting stock may differ between the two catch-production functions. The simulations do not aim to emulate reality, there are clear mismatches in quota share given the differences in fleet catchabilities, so it remains unclear how these findings map onto real-world management strategies. Nevertheless, simulations showed that discrepancies increased at high stock-exploitation levels, and this has implications for catch-advice-based mixed-fisheries models using Pope’s approximation, especially when considering stocks with poor status.

ANNEX 8: LINKS TO SENSITIVITY UNCERTAINTY OF FORECAST CONDITIONING IN THE CELTIC SEA

Investigations into the effect of uncertainty of fleet and métier definitions on model behaviour is currently being undertaken within WGMIXFISH-METHODS, where Cefas has applied Monte Carlo simulations to stochastically sample input parameter values from a suitable probability distribution fitted to historical data. At WGMIXFISH-METHODS 2023 (ICES, 2023b) several methodological advances were presented, many of which derive from this, the outcomes of the Second Scoping Workshop on Next Generation of Mixed Fisheries Advice (WKMIXFISH2; ICES, 2023d), or have been identified as a priority by WGMIXFISH. These analyses explored sensitivity to model assumptions, incorporating uncertainty in model parameters and novel methods for using spatial data to define métiers. Additionally, the application of mixed-fisheries methods in externally developed models of the Bay of Biscay and Western Mediterranean were presented. The work reported here has also been reported in its complete format in the WGMIXFISH-METHODS report (ICES, 2023b), where the Celtic Sea Case study was developed.

Mixed-fisheries considerations are based on model forecasts that explicitly account for technical interactions among fleets and characterise the quota underutilisation or overshoot that may occur for given assumptions around fleet activity. Following WKMIXFISH2 (ICES, 2023d) there is growing stakeholder appetite for more robust incorporation of fishery uncertainties into mixed-fisheries forecasts. Here, we present work on the propagation of fleet parameter uncertainty in mixed-fisheries forecasts using the Celtic Seas Fcube model as a case study. Analyses are based on data from the 2022 ICES WGMIXFISH-ADVANCE meeting (ICES, 2022c), which contains information to 2021.

Three major sources of fishing fleet parameter uncertainty are dealt with as three main sub-headings: catchability; métier effort proportion and fleet quota share; realised quota share. The objectives are two-fold. First, to develop a generic set of methods to condition parameter uncertainty that will perform well in most cases and are robust to moderate levels of missing and noisy data. Second, to evaluate the effect of forecasted parameter ranges on model outputs compared with current deterministic condition approaches.

For each parameter type, we use historical variation to estimate future parameter uncertainty. For métier-stock catchability and métier-effort proportion, observation data are derived from landings and effort accessions data. However, there are few good data sources for quota allocation to fleets. Currently, the historic shares of stock landings are used as a proxy for quota share, assuming that quota allocations and fishing patterns are stable from year to year. However, stakeholders have highlighted that recorded landings are not necessarily an accurate reflection of quota share for several quota-limited stocks (ICES, 2023c; WKMIXFISH2), and historical under-utilisation of quota could therefore lead to unrealistically conservative estimates of future quota share and potentially erroneous identification of choke stock(s). WGMIXFISH-METHODS (ICES, 2022b) highlighted the potential value of the Fisheries Data Exchange System (FIDES), the official register of quota and quota exchanges in the EU at the national level, to inform the forecast of quota share for quota-limited stocks. We therefore explore the effects of using FIDES in conjunction with landings data, compared to current historical landings-share methods.

The use of time-series observations means that the analysis must account for temporal correlations and observation uncertainty. Improving on methods presented at ICES WGMIXFISH-METHODS 2022 (ICES, 2022b), a simple state-space modelling approach was adopted, consisting of a random walk on the latent temporal process and an observation noise model. Models were developed using TMB (Template Model Builder; Kristensen et al., 2016), which facilitates automatic differentiation using C++ programming templates, and fitted using maximum likelihood techniques. For details on

the specific methodology refer to the 2023 WGMIXFISH-METHODS report (ICES, 2023b).

SIMULATION RESULTS

Mixed-fisheries simulations were carried out under four effort scenarios:

1. Min: fleet activity stops when the quota for any stock is consumed;
1. Status quo: fleet activity is the average of the most recent three data years;
2. Haddock: fleet activity is the effort required to consume haddock quota (or status quo if haddock is not exploited);
3. Whiting: fleet activity is the effort required to consume whiting quota (or status quo if whiting is not exploited).

The impact of fleet parameter uncertainty on model outputs varied depending on the stock and the effort scenarios considered (see Figure 1 for illustrative example). For instance, cod is the chief limiting stock in the Celtic Sea and very little variation is observed under the 'min' scenario. However, technical interactions with haddock and whiting in many métiers means that uncertainty in catchability translates to large variation in the forecasted landings under the haddock and whiting scenarios.

For Celtic Sea cod, simulations using deterministic conditioning fall within the 90 % uncertainty envelope, although overall output uncertainties are large. However, there are large deviations between outputs from deterministic and stochastic conditioning for sole, suggesting that existing conditioning approaches are not adequately capturing the historical quota-share dynamics for this stock.

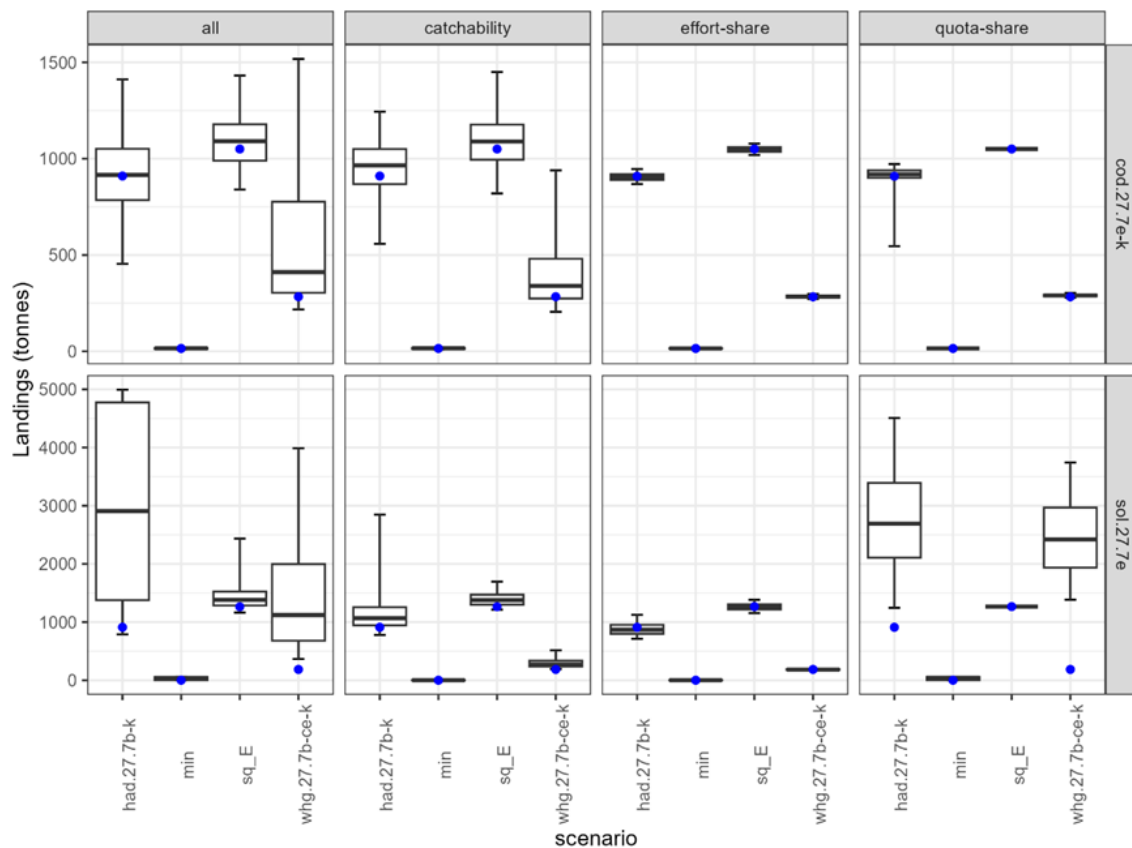


Figure 1: Variation in landings of cod (cod.27.7e-k) and sole (sol.27.7e) given uncertainty in métier-stock catchability, métier effort-share and fleet-stock landings-share under different effort scenarios. Boxes and whiskers span the 50 % and 90 % confidence intervals, respectively. Blue points are outputs under current deterministic methods.

These outputs may be easily integrated into the existing headline message in the mixed-fisheries considerations to provide context around predicted choking patterns under each effort scenario. Confidence intervals help to bracket predictions and highlight the key system uncertainties to stakeholders. Disaggregated sources of uncertainty are complementary to a more comprehensive sensitivity analysis and help highlight where more precise data are needed.

CINEA Task 3, catchability

Vanessa Trijoulet

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1 Task 3.1 Review the catchability assumption made when conditioning the North Sea mixed fisheries model, and characterise the resulting uncertainty in the input parameters

The current assumption for catchability per métier in the North Sea mixed fisheries advice is that catchability in the projection years is the same as the last observed catchability (last data year). However, catchability can be quite variable over time as it often reflects changes in fishing behavior or opportunities (see Appendix A).

The most recent North Sea mixed fisheries advice model includes observed catchability by métier for the years 2014-2021 (ICES 2022b, 2022a). We back calculated the catchability in 2015-2021 following the current status-quo catchability assumption and compared this to the true observed catchability for the same years. Standardized residuals were estimated for each year (y), fleet, (f), métier (m), stock (s), and stock age (a) as follows:

$$res_{y,f,m,s,a} = \frac{\hat{q}_{y,f,m,s,a} - q_{y,f,m,s,a}}{sd(\hat{q}_{f,m,s,a})}, \text{ with } \hat{q} \text{ being the predicted catchability and } q \text{ the observed catchability.}$$

Given that the catchability are very small numbers used as scaler on the total catch per stock, the performance metrics could be considered on the log scale. However, given that some of the observed or predicted catchability values are 0 in some years, a lot of the diagnostics are lost by making the computation not possible on log scale. As a result, standardized residuals are calculated on the natural scale.

For each fleet, métier and stock, the histogram of the residuals distribution is given in Appendix B. Overall, the residuals vary per fleet, métier and stocks. Some are satisfactory residuals (normally distributed around

0) but others are unsatisfactory (e.g., skewed, with large variance).

Correlation in the residuals was estimated using the autocorrelation function (ACF) in the three dimensions (years, ages and cohort), with lag being set at the maximum the number of ages caught for a stock (Appendix C). Most métiers show a correlation across years, which was expected given that the predicted catchability is the observed catchability in the previous year. However, many métiers also show a high correlation across ages and to a lesser extent within cohort but it varies across métiers and stocks. Most métiers show a strong lag 1 correlation in their residuals, predicting catchability with correlation across years, ages or cohort could therefore be considered as possible alternative model assumption.

2 Task 3.2 Formulate a limited number of simple alternative scenarios for model conditioning of catchability.

Here, four simple assumptions for modelling catchability are considered and evaluated through a simple retrospective analysis with different performance metrics. The retrospective exercise was performed on the catchability per métier using the latest advice model conditioning (ICES 2022b, 2022a). Catchability in the last 5 years (2017-2021) was predicted following four assumptions:

- sQ: catchability for a métier is set equal to the previous year catchability (status-quo, current assumption for the mixed fisheries North Sea case study)
- Ave: catchability for a métier is set equal to the previous 3-year catchability average (assumption currently used for some mixed fisheries case studies other than the North Sea case study)
- lm: catchability for a métier is estimated following a linear regression on the previous years (starting in 2014). The catchability is set to 0 if predicted to be negative.
- AR1: catchability for a métier is estimated following an autoregressive process (AR1) using an integrated moving average (ARIMA) on the previous years (starting in 2014). The catchability is set to 0 if predicted to be negative. *This might/will be changed to Klaas' AR1 model instead, or we can also use Klaas' option as an additional one*

Different types of performance metrics are considered to compare the four models and each of them are presented below for different levels of aggregation:

- Proportion of a model being the best model based on the model having the smallest residuals (i.e., $abs(res)$) as estimated in Part 1. Larger is the proportion, better is the model.
- Relative errors on the log scale, i.e., $RE = \frac{\log(\hat{q}) - \log(q)}{\log(q)}$. This performance metric is the only one considered on log scale but inherently ignores catchability of 0. The best model is the one with the RE the closest to 0.
- Rank of each model, based on sorting in ascending order the absolute value of res . If residuals are the same, the rank will be shared between the model at the same level (e.g, rank of 1.5 if two models have best residuals, mainly happens when $q = \hat{q} = 0$). The best model is the one with the lowest rank.

2.1 Results at the maximum level of aggregation

If the results are fully aggregated (no distinction between fleet, métier, year or stock), the status-quo catchability, which is the option currently used for the North Sea case study is the best option for the three performance metrics (Table 1). The performance of the other models depends on the performance metric considered but it seems that the linear regression model could be the best assumption after the status-quo one.

Table 1: Performance metrics aggregated at the level of the entire North Sea model.

	Proportion of being best	Median relative error (%)	Mean rank
sQ	0.523	-0.462	1.869
Ave	0.135	-1.331	2.860
lm	0.252	-1.392	2.432
AR1	0.189	-1.811	2.839

2.2 Results at the stock level

When the results are aggregated at the stock level, for 12 out of 20 stocks, the status-quo catchability is the best predictor no matter the performance metric considered (Figure 1 and Table 2).

Table 2: Number of stocks for which a model does the best according to each performance metric. There are 20 stocks in total (10 fish stocks and 10 Norway lobster stocks), it is possible that the number of stocks for the proportion of being the best model metric sum to more than 20 if some models have the same standard residuals (usually when catchability is 0).

	Proportion of being best	Median relative error (%)	Mean rank
sQ	20	12	20
Ave	0	5	0
lm	0	2	0
AR1	1	1	0

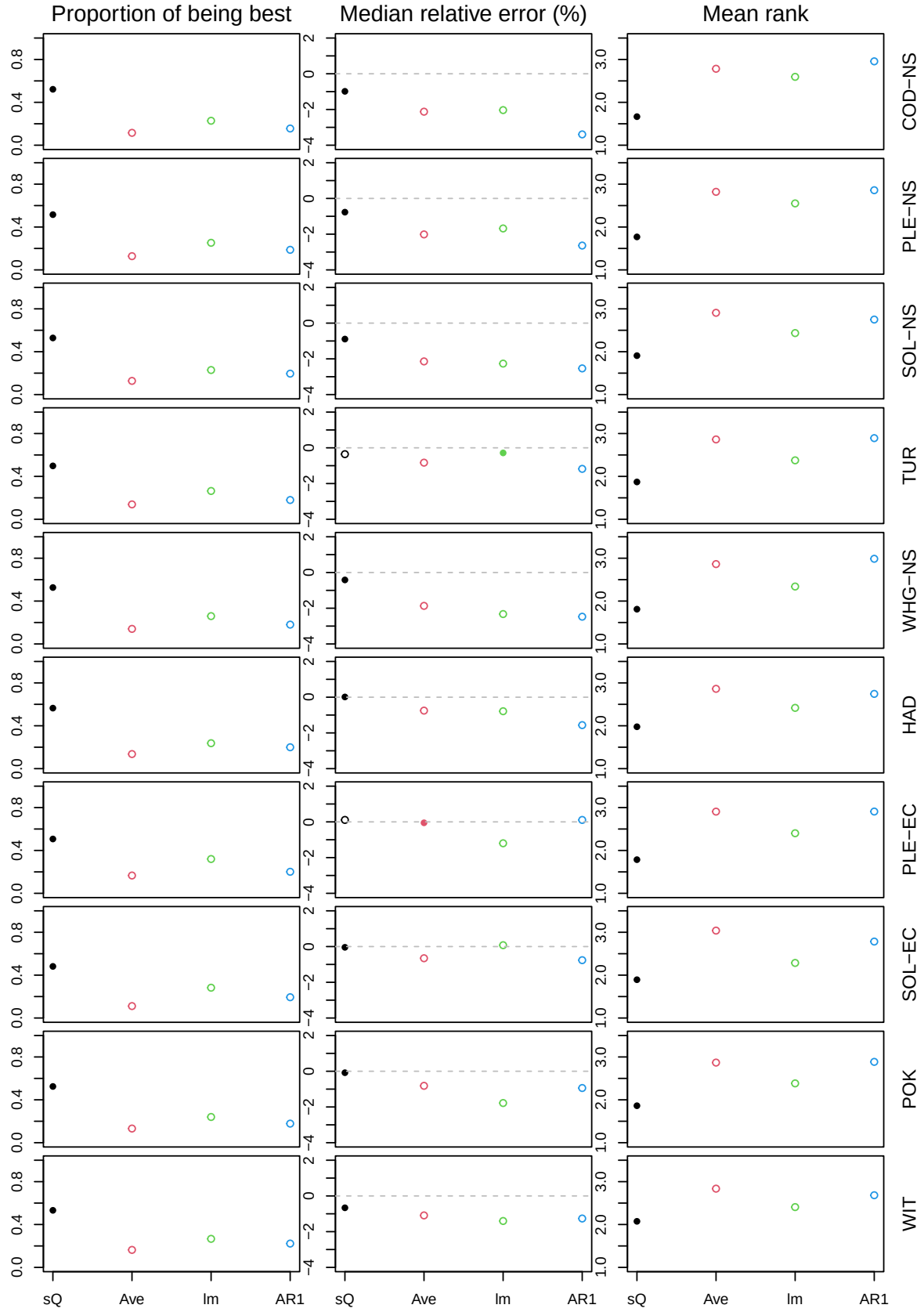


Figure 1: Performance metrics presented at the stock level. The best value for each performance metric is highlighted by a solid circle.

2.3 Results at the fleet level

When the results are aggregated at the fleet level, the status-quo assumption is the best model overall for all performance metrics considered (Figure 2). Other models can be favored when looking at the mean relative error in the log catchability but the status-quo model is still the most often chosen as best model (Table 3).

Table 3: Number of fleets for which a model does the best according to each performance metric. The total number of fleets is 46.

	Proportion of being best	Median relative error (%)	Mean rank
sQ	46	29	46
Ave	0	5	0
lm	0	9	0
AR1	0	3	0

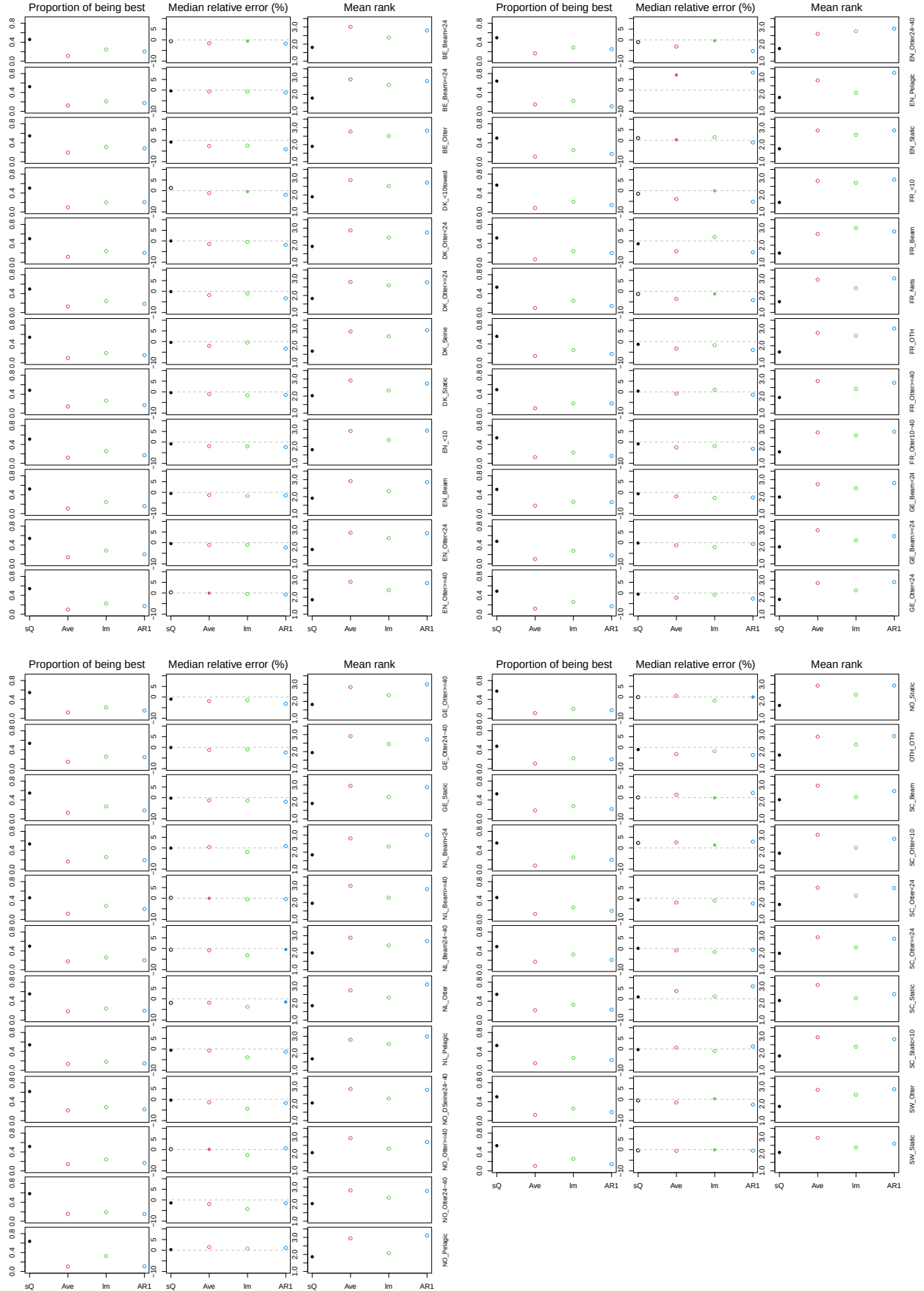


Figure 2: Performance metrics presented at the fleet level. The best value for each performance metric is highlighted by a solid circle.

2.4 Results at the fleet level and per predicted year

The best model can vary at the fleet level, over time, and depending on the performance metric considered but the status-quo option is still the best overall (Figure 3). Results are more variable when looking at the relative error in log catchability where for a specific fleet, the best model might differ depending on the predicted year. This makes it difficult to choose one assumption that is best for all fleets at any time since catchability will also depend on fleet opportunities.

2.5 Results at the métier level

Given that the North Sea case study includes 152 métiers, the results are only presented as the number of métiers for which the different models are best (Table 4). The status-quo assumption is the one that is the best for most of the métiers no matter the performance metric considered.

Table 4: Number of métiers for which a model does the best according to each performance metric.

	Proportion of being best	Median relative error (%)	Mean rank
sQ	149	87	141
Ave	0	21	0
lm	3	28	7
AR1	0	16	4

3 References

ICES. 2022a. “Working Group on Mixed Fisheries Advice (WGMIXFISH-ADVICE; Outputs from 2021 Meeting).” <https://doi.org/10.17895/ices.pub.9379>.

———. 2022b. “Greater North Sea - Mixed Fisheries Considerations.”

A Appendix A: Change in observed catchability over time

Figure 4 shows the observed catchability at age per fleet, métier and stock for the years 2014-2021. For some métiers and stocks, catchability can vary over time, making the current assumption of status-quo catchability in the projections questionable.

B Appendix B: Error in the current status-quo catchability assumption

Figure 5 shows the distribution of the error (standardized residuals) in the current catchability predictions (status-quo) for the years 2015-2021.

C Appendix C: Correlation in the current status-quo catchability residuals

Figure 6 shows the ACF plot for correlation in the status-quo catchability residuals. It is possible that some correlations are missing for certain lags, notably if residuals could not be computed because the catchability was null.

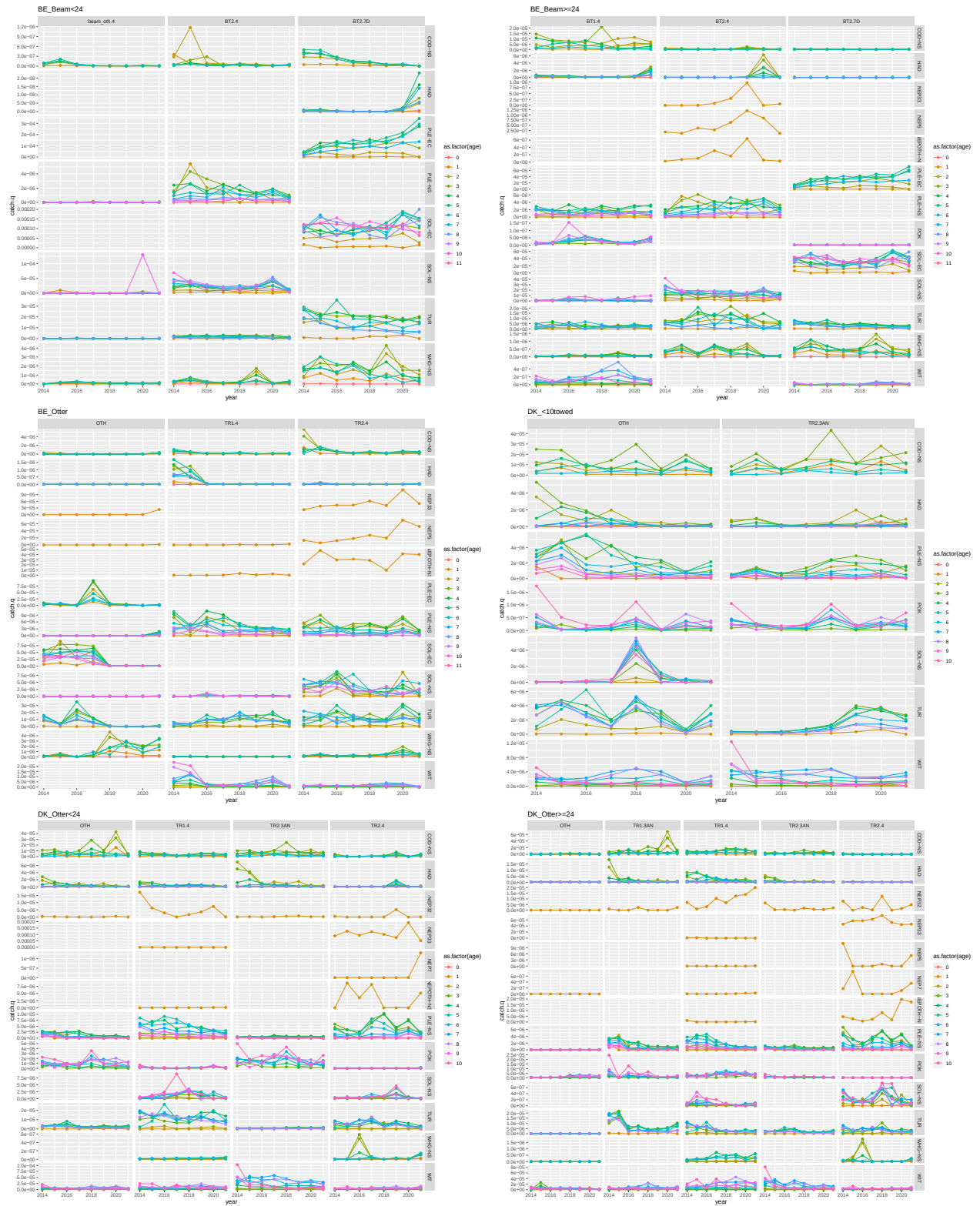


Figure 4: Observed catchability at age per fleet, métier and stocks.

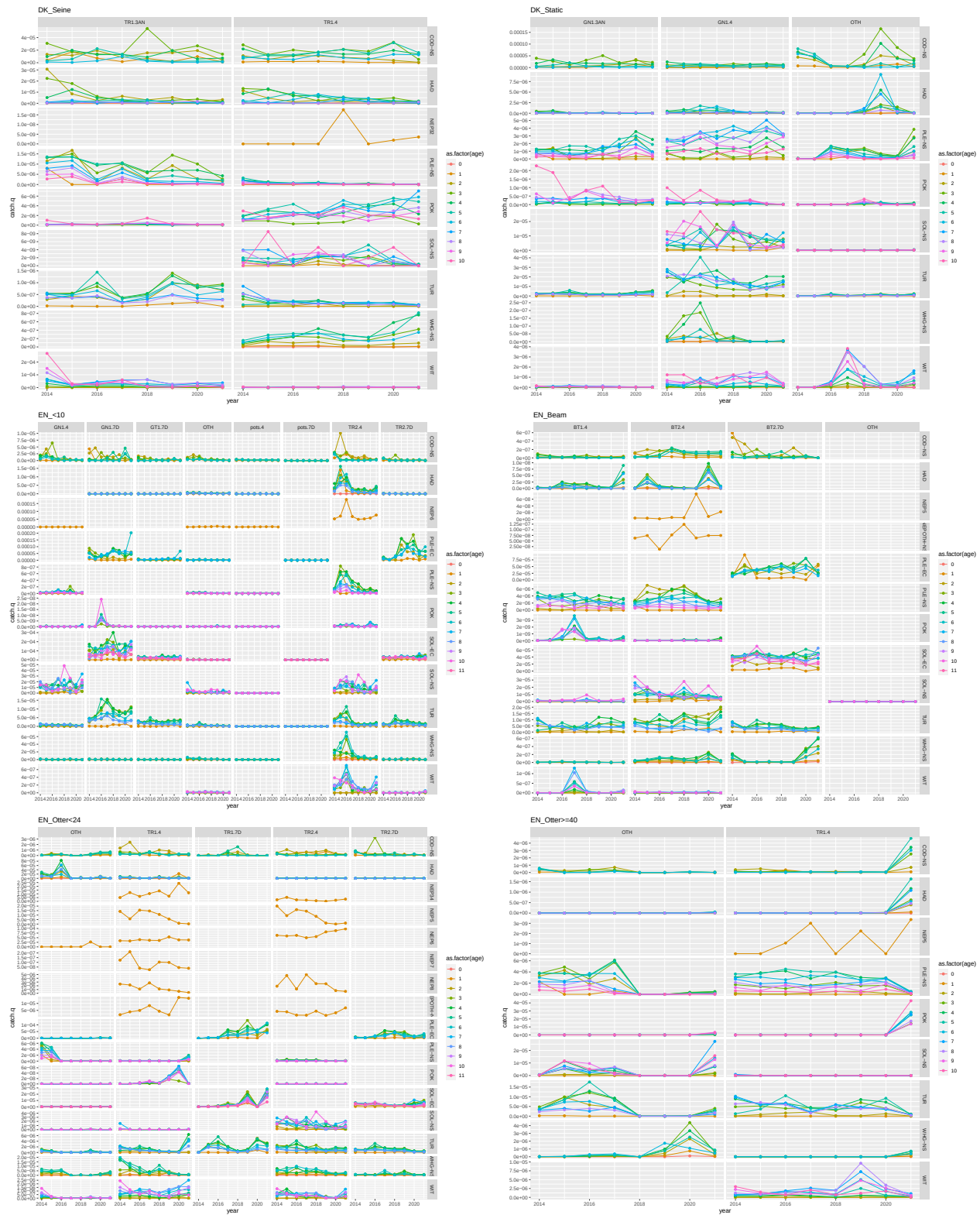
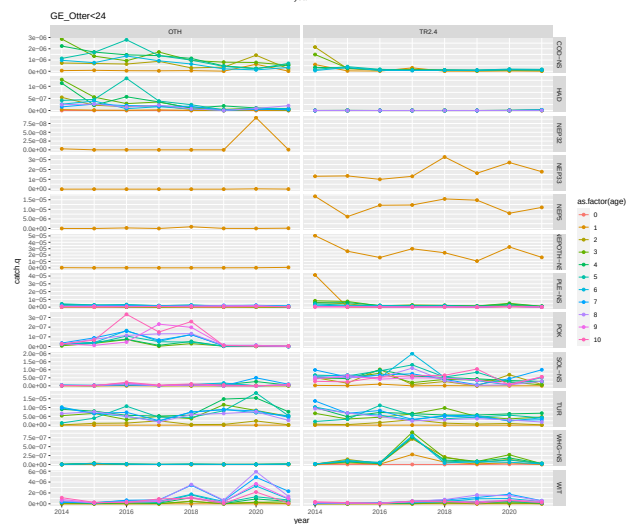
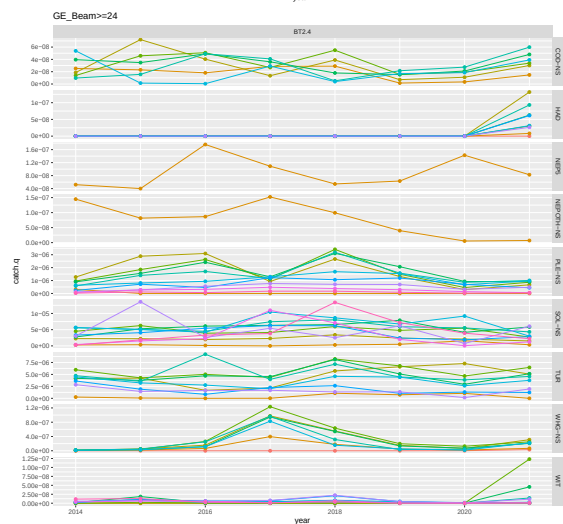


Figure 4 (continued): Observed catchability at age per fleet, métier and stocks.



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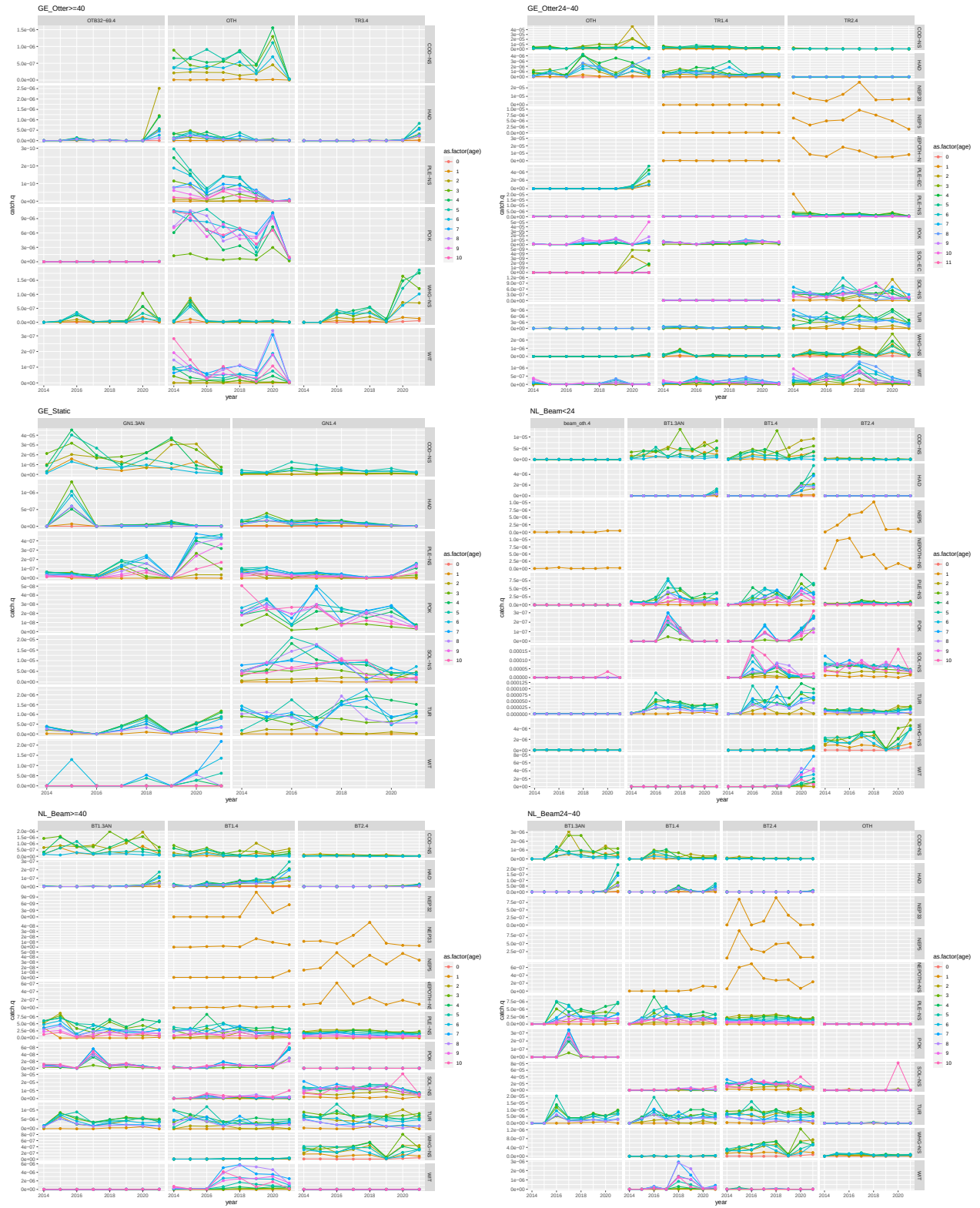


Figure 4 (continued): Observed catchability at age per fleet, métier and stocks.

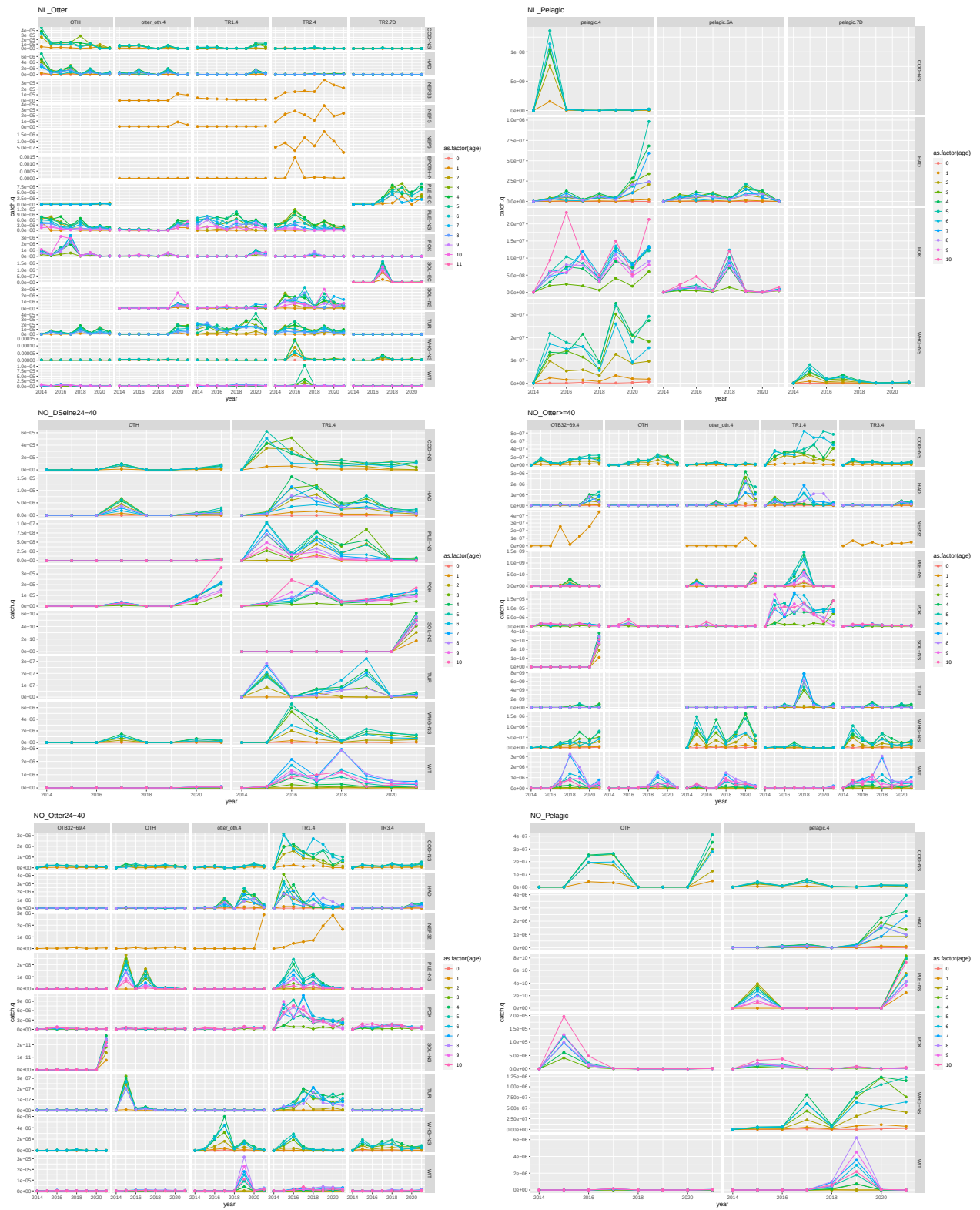


Figure 4 (continued): Observed catchability at age per fleet, métier and stocks.

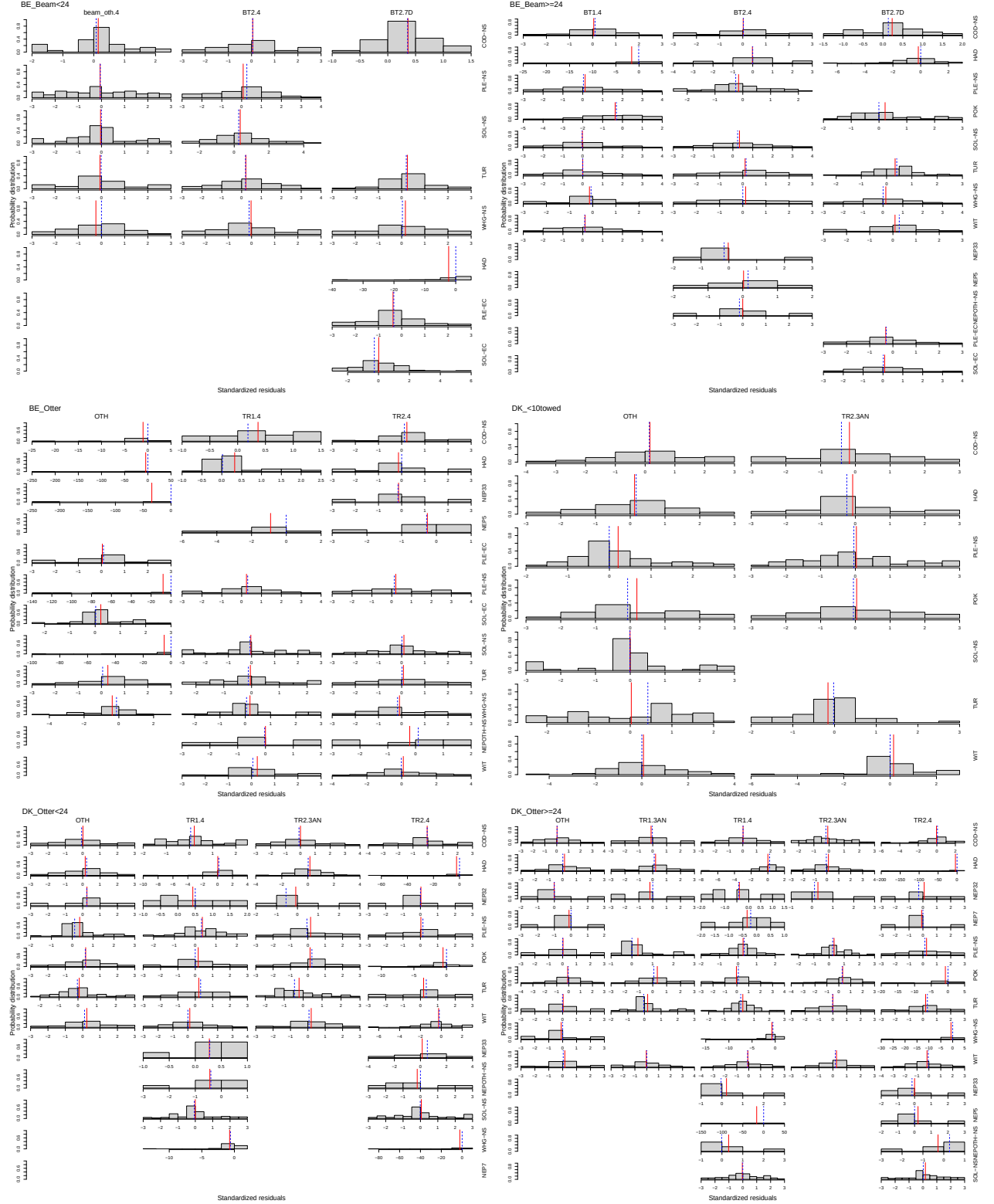


Figure 5: Distribution of the standardized residuals when catchability follows the status-quo assumption. Mean and median of the distribution are showed as red and dashed blue lines, respectively.

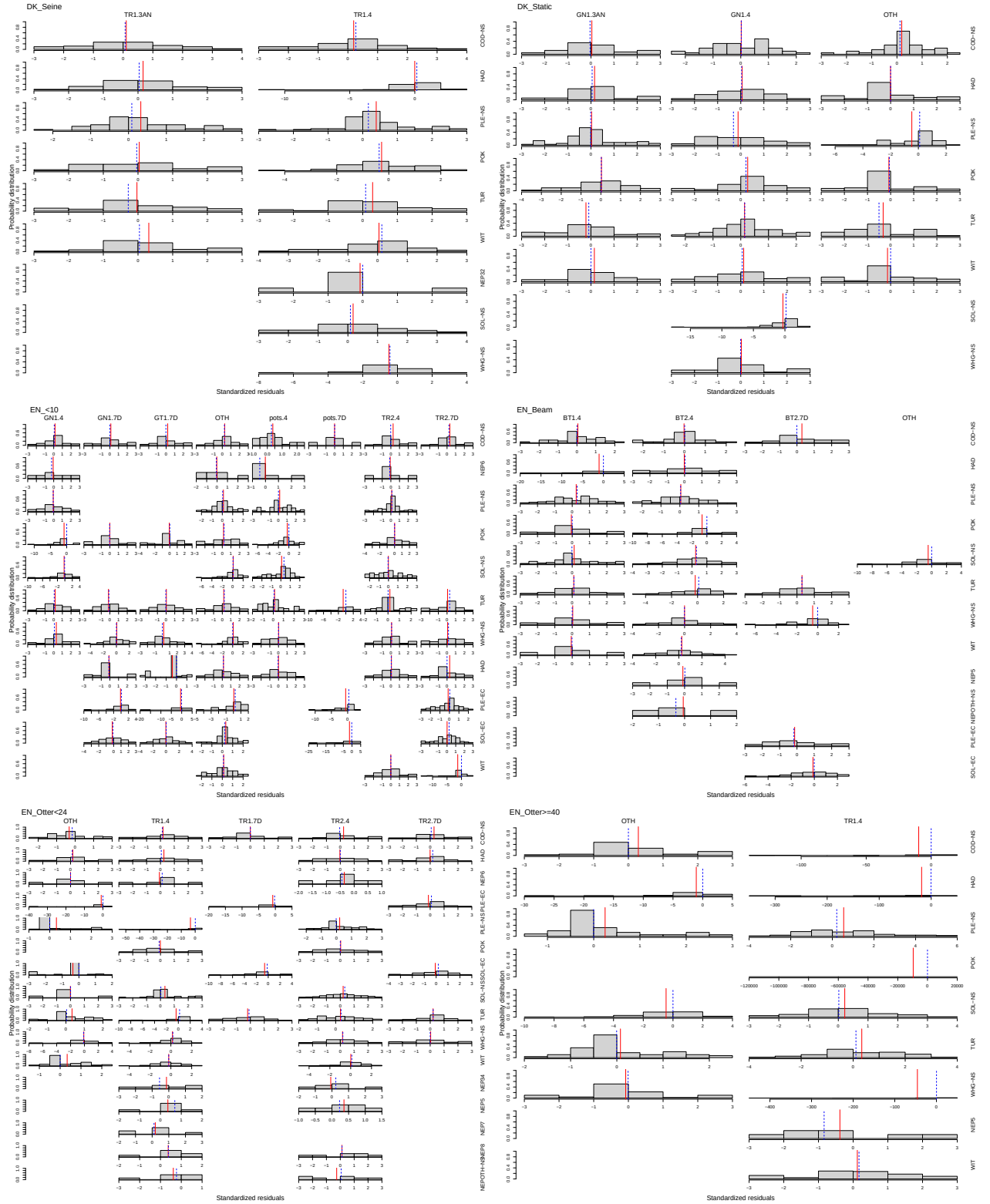


Figure 5 (continued): Distribution of the standardized residuals when catchability follows the status-quo assumption. Mean and median of the distribution are showed as red and dashed blue lines, respectively.

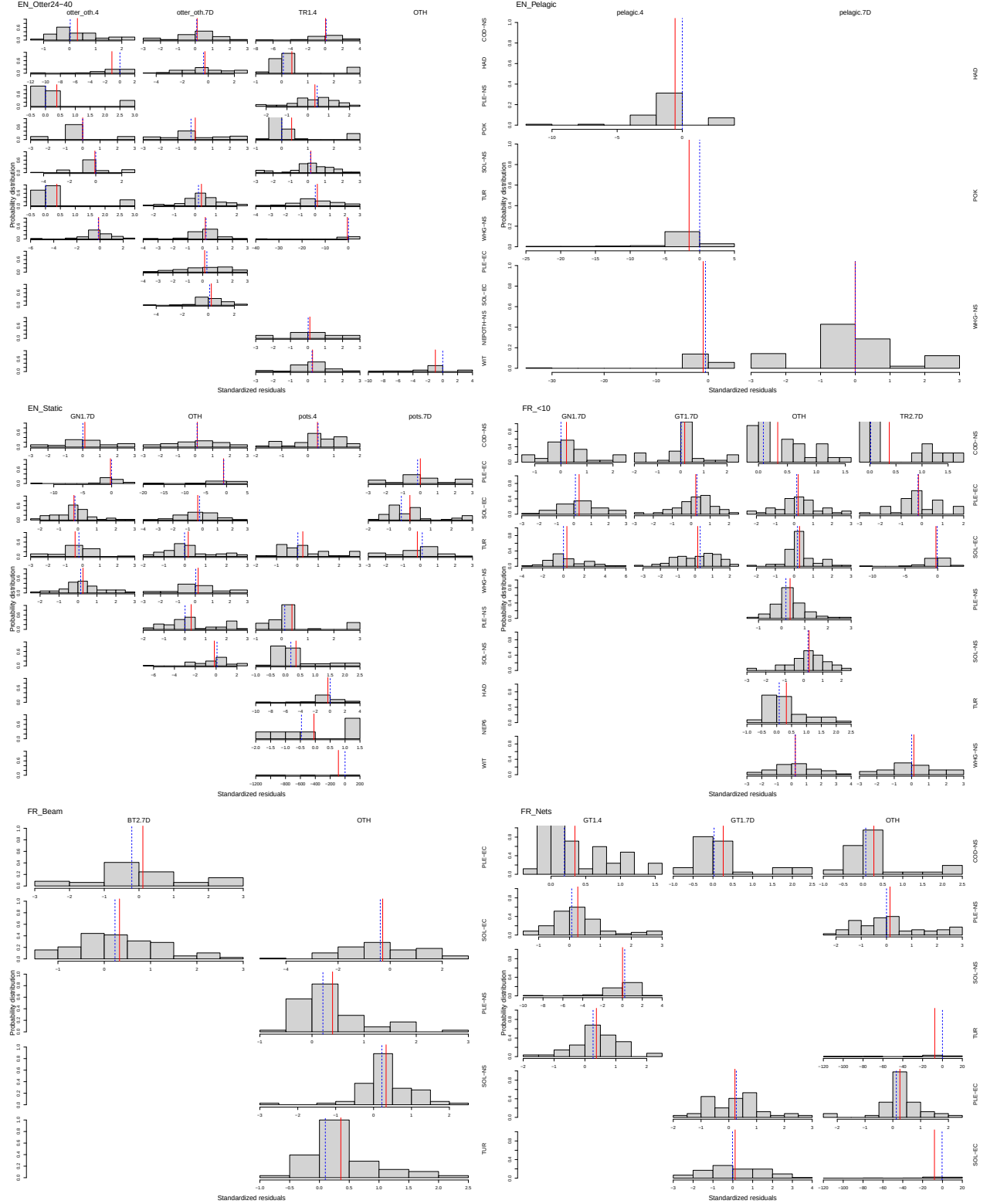


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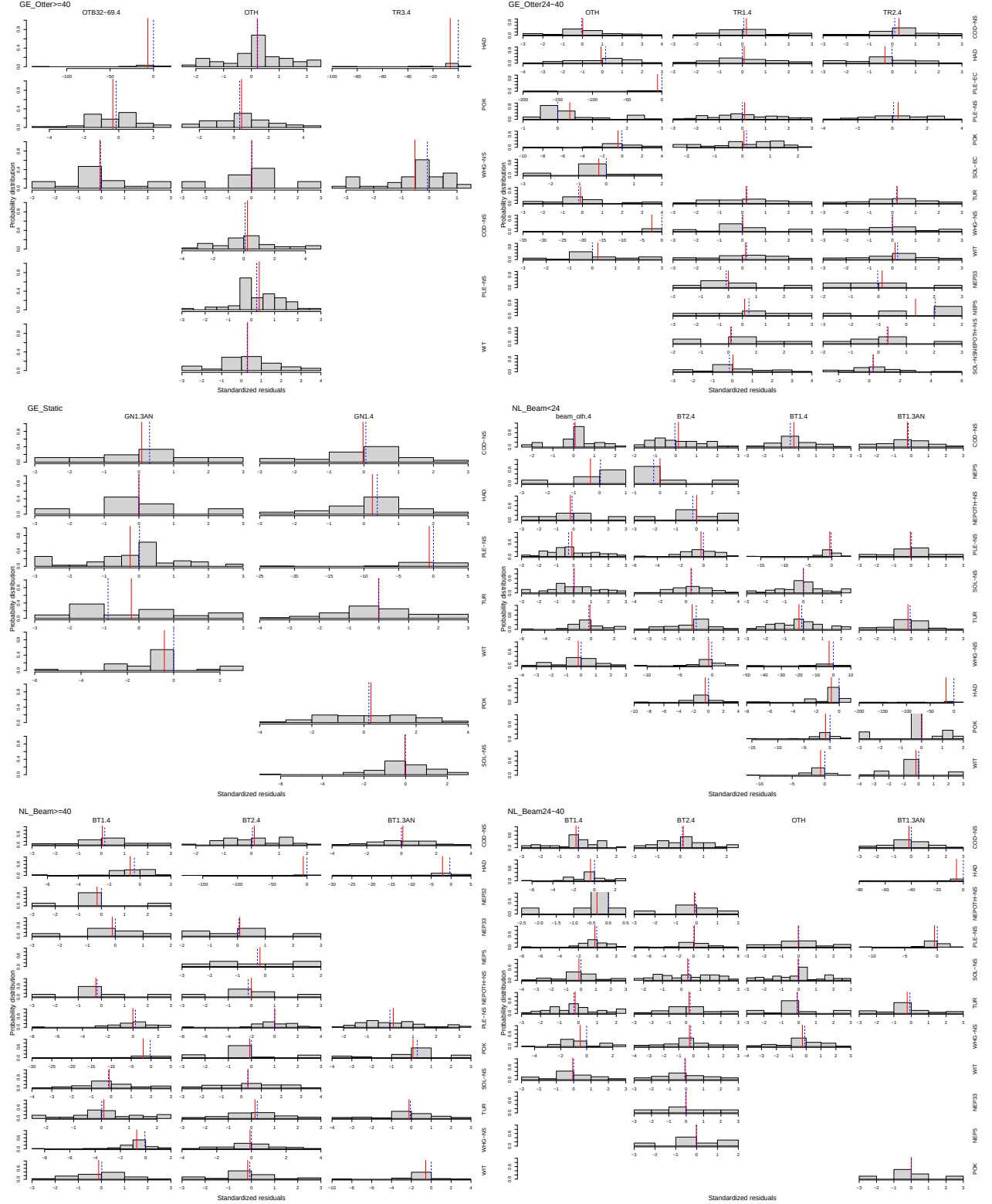


Figure 5 (continued): Distribution of the standardized residuals when catchability follows the status-quo assumption. Mean and median of the distribution are showed as red and dashed blue lines, respectively.

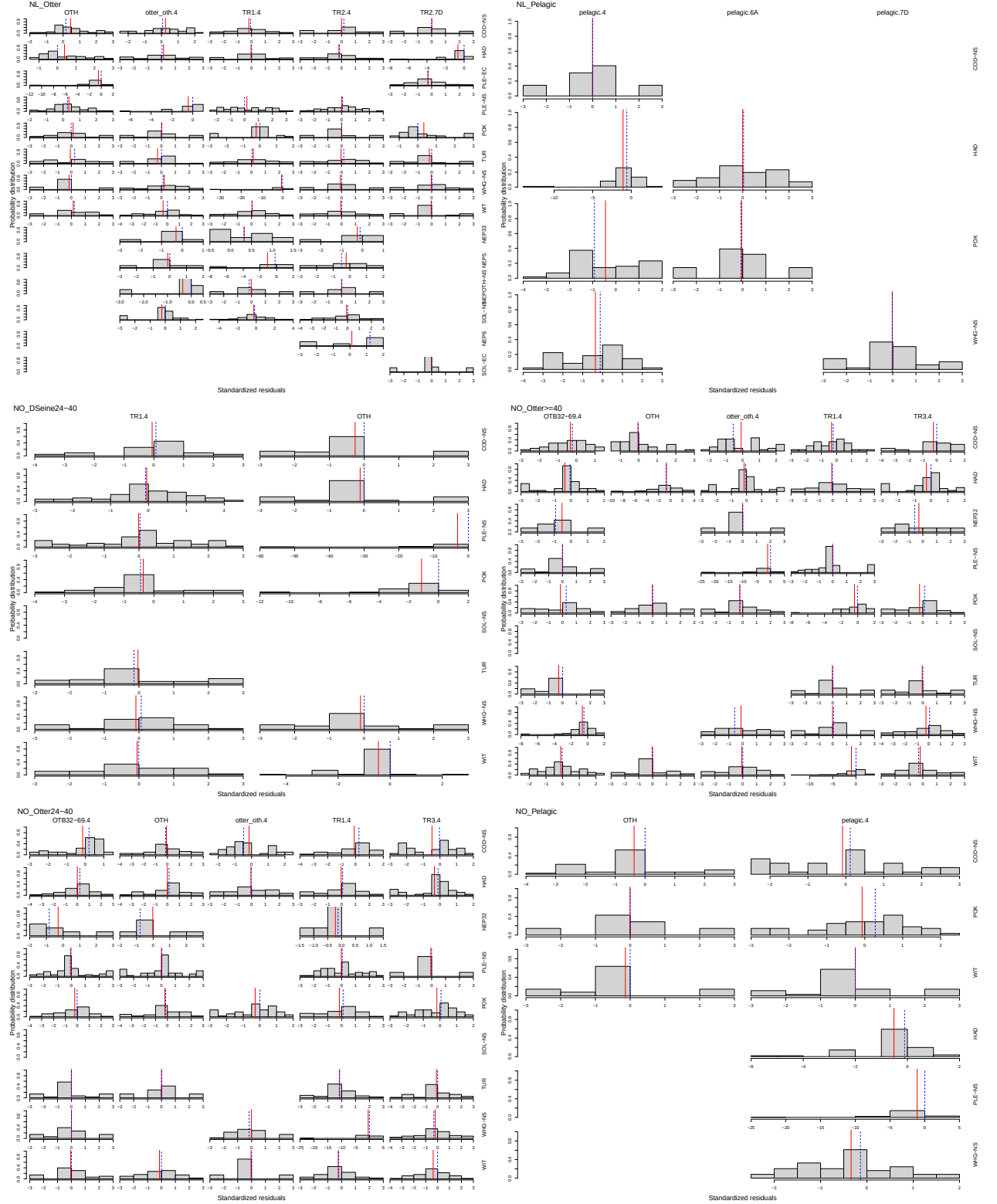


Figure 5 (continued): Distribution of the standardized residuals when catchability follows the status-quo assumption. Mean and median of the distribution are shown as red and dashed blue lines, respectively.

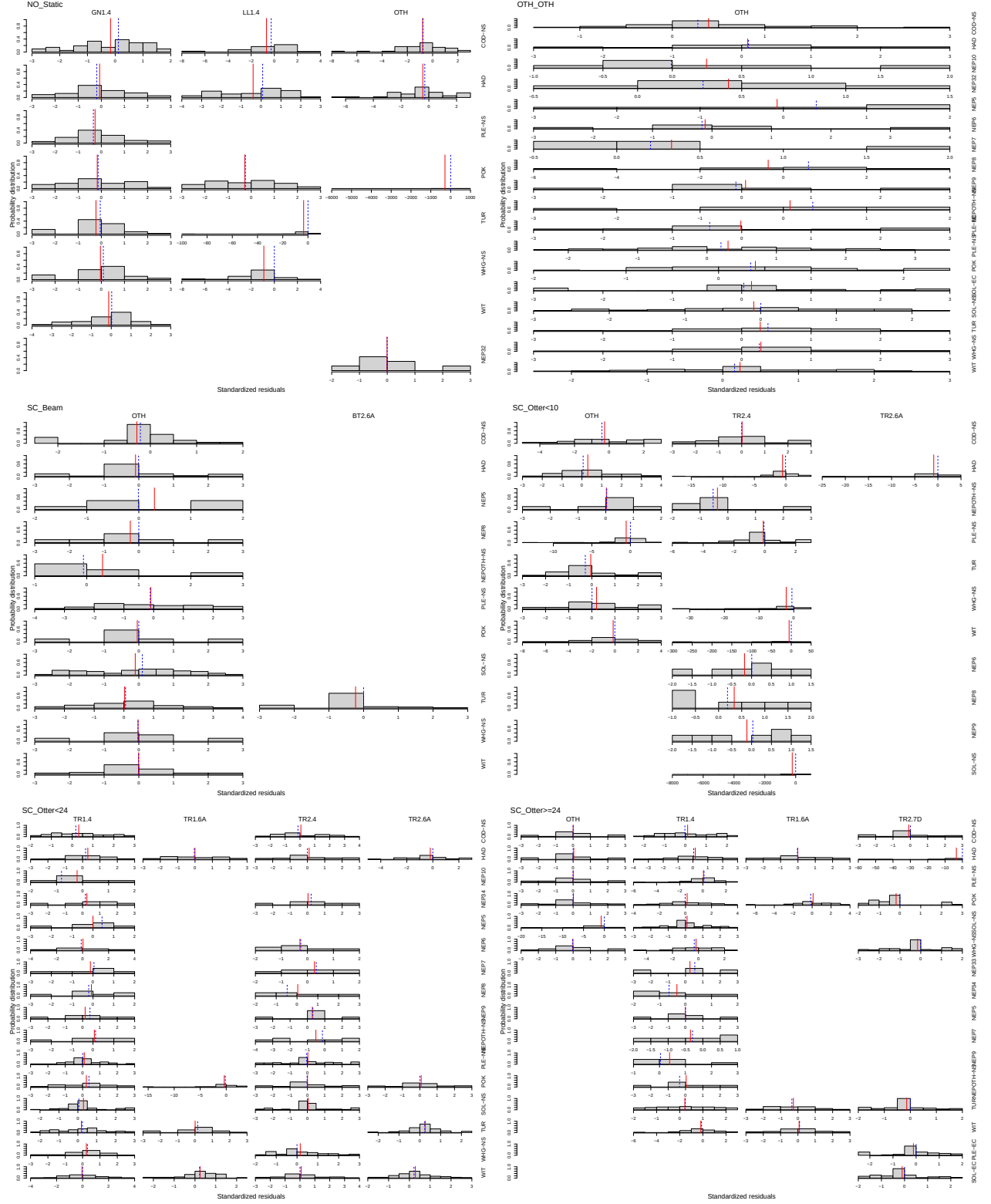


Figure 5 (continued): Distribution of the standardized residuals when catchability follows the status-quo assumption. Mean and median of the distribution are showed as red and dashed blue lines, respectively.

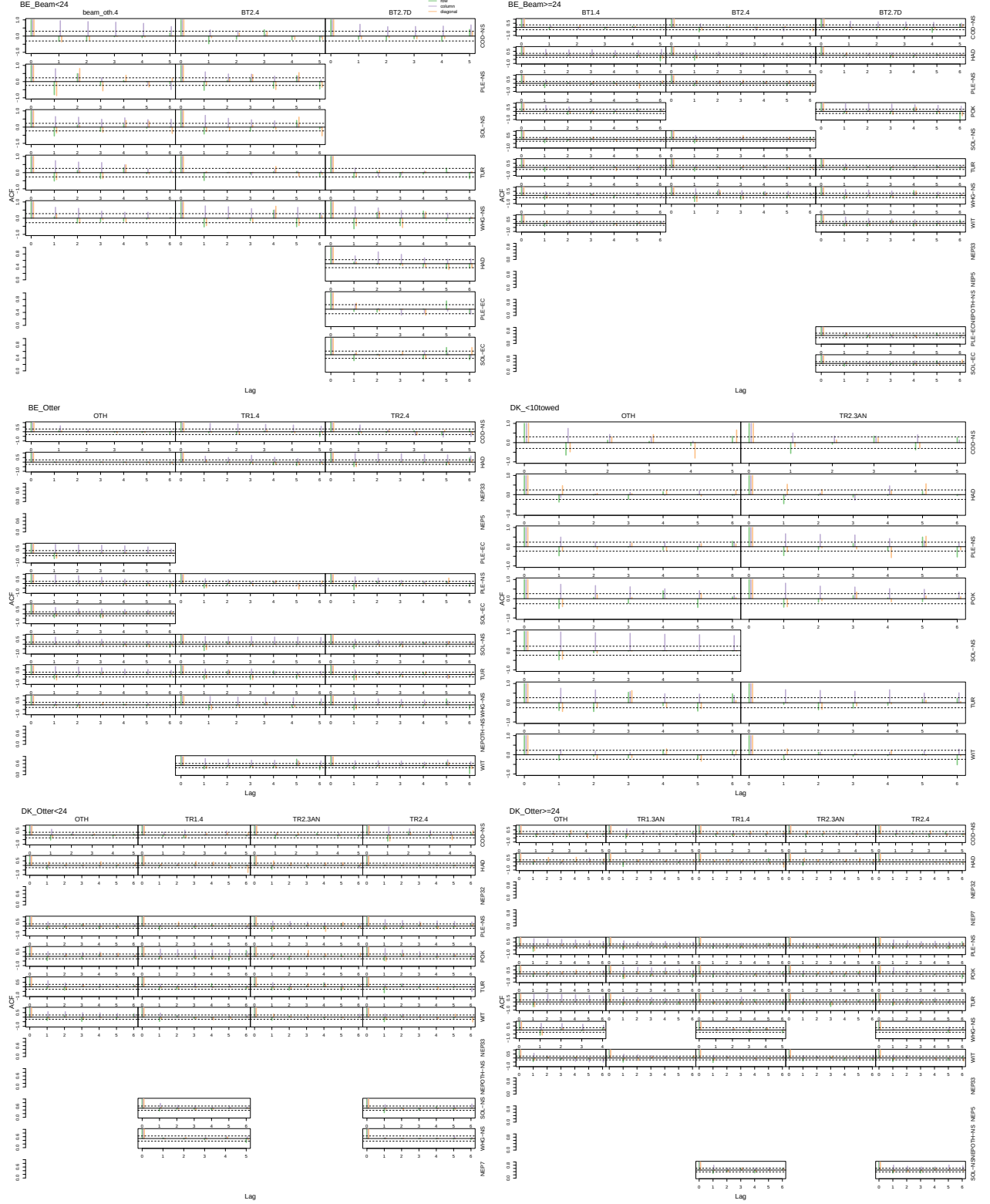


Figure 6: Autocorrelation in the the current status-quo catchability standardized residuals. The dimensions "row" (green), "column" (purple) and "diagonal" (orange) correspond to the correlation across years, ages, and within cohort, respectively. The maximum lag is set to be the maximum number of ages caught by the métier for each stock. The dashed horizontal lines represent the 95% confidence interval. Correlations beyond these lines are therefore considered non-zero.

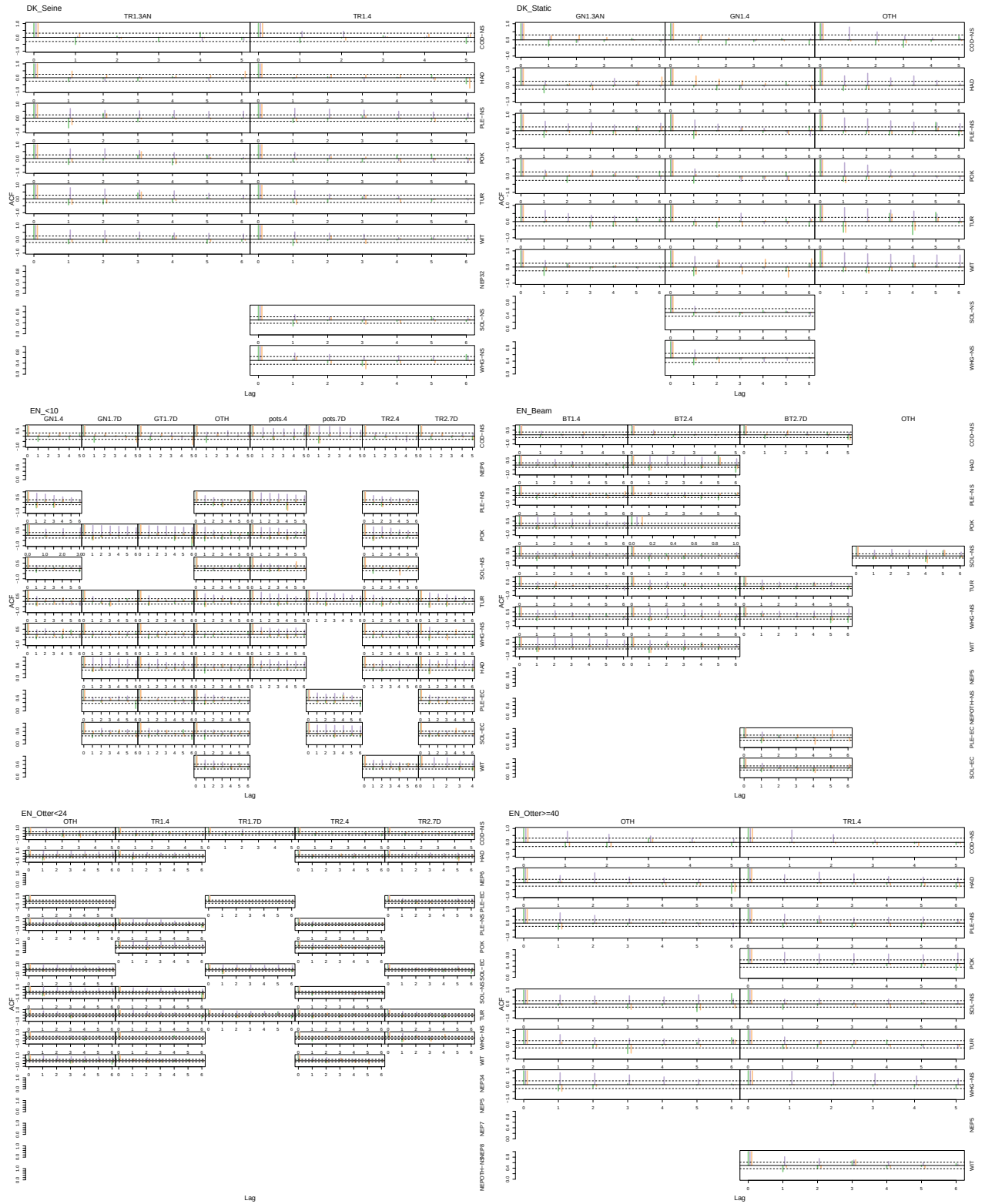


Figure 6 (continued): Autocorrelation in the the current status-quo catchability standardized residuals. The dimensions "row" (green), "column" (purple) and "diagonal" (orange) correspond to the correlation across years, ages, and within cohort, respectively. The maximum lag is set to be the maximum number of ages caught by the métier for each stock. The dashed horizontal lines represent the 95% confidence interval. Correlations beyond these lines are therefore considered non-zero.

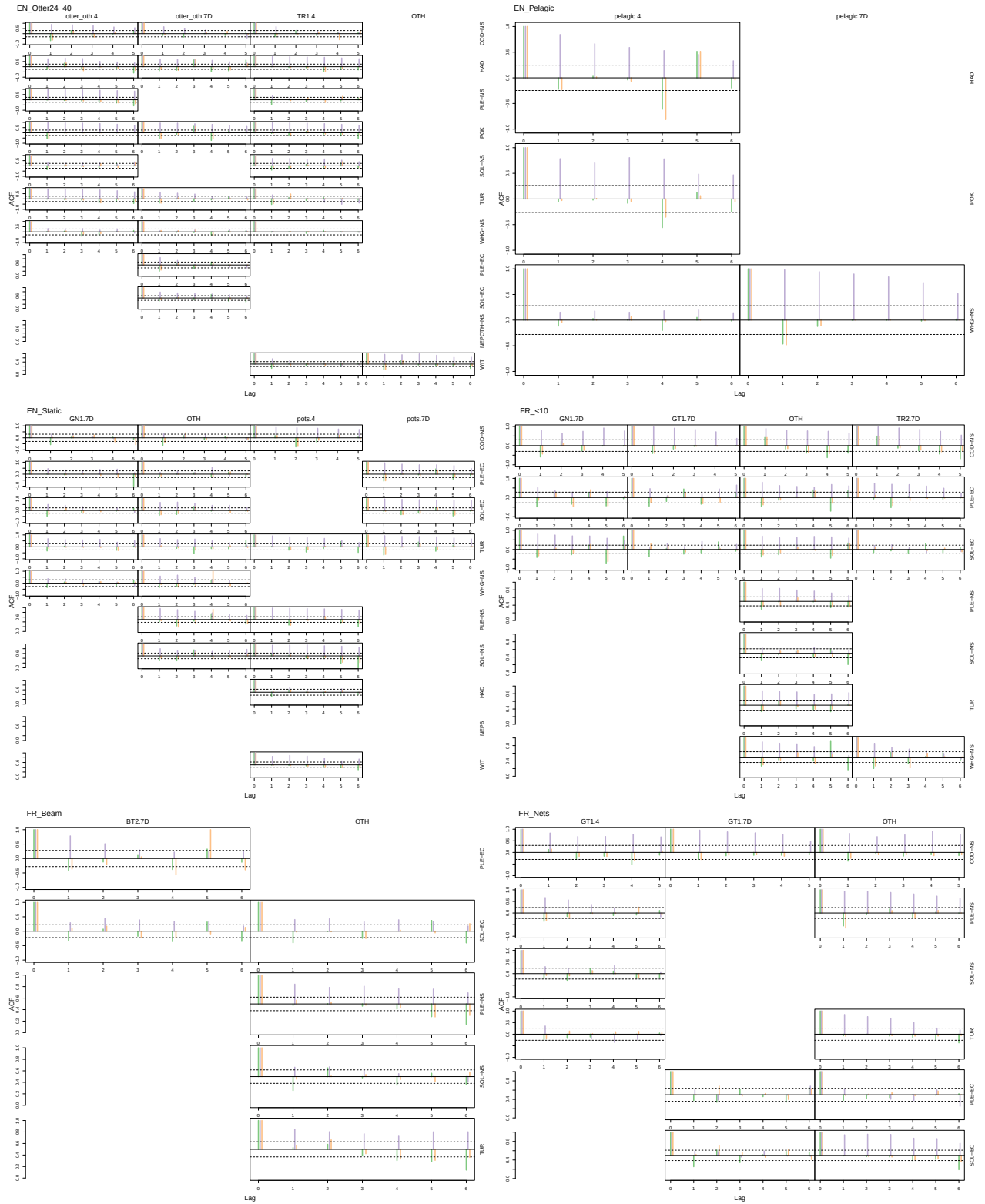


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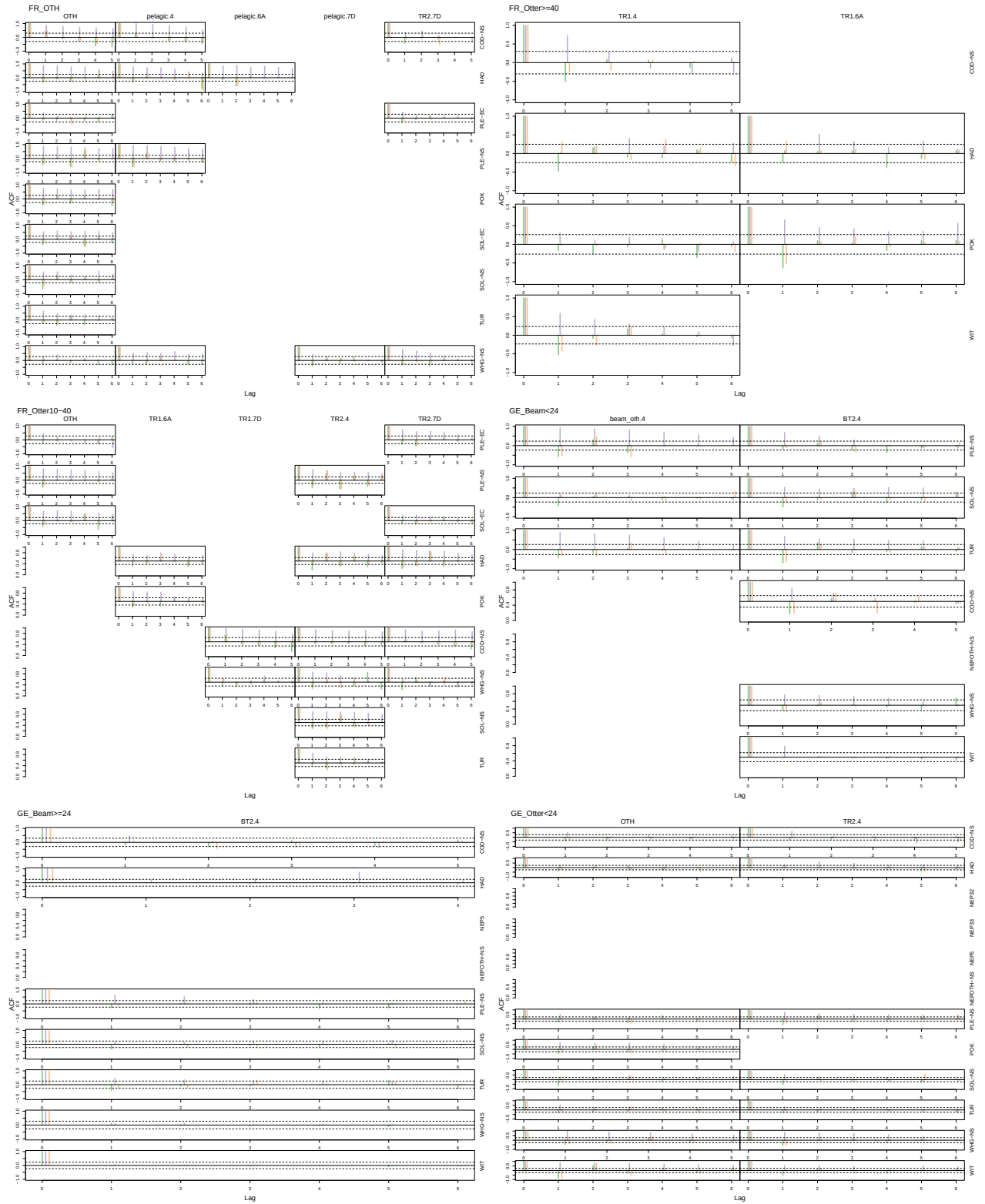


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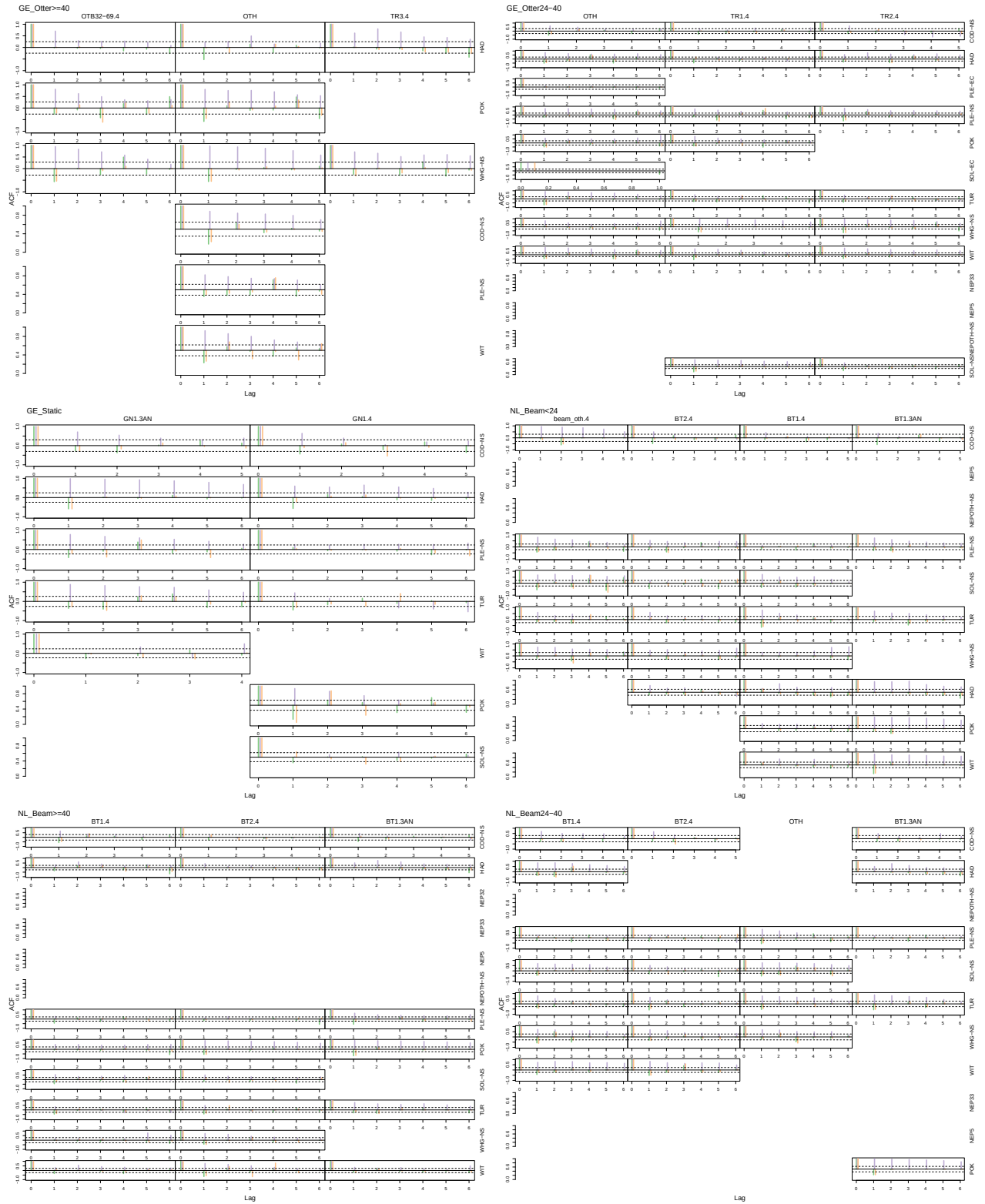


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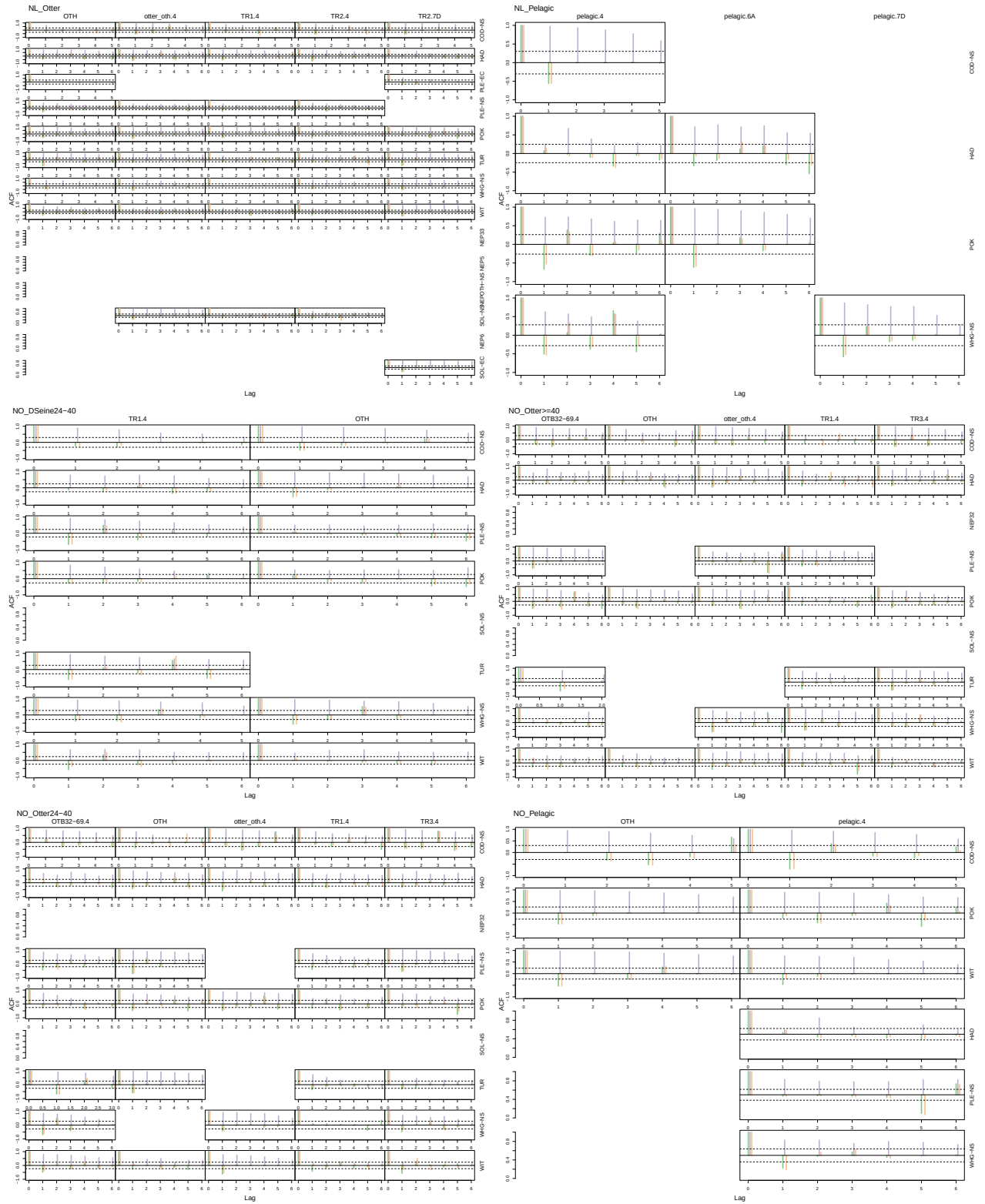


Figure 6 (continued): Autocorrelation in the the current status-quo catchability standardized residuals. The dimensions "row" (green), "column" (purple) and "diagonal" (orange) correspond to the correlation across years, ages, and within cohort, respectively. The maximum lag is set to be the maximum number of ages caught by the métier for each stock. The dashed horizontal lines represent the 95% confidence interval. Correlations beyond these lines are therefore considered non-zero.

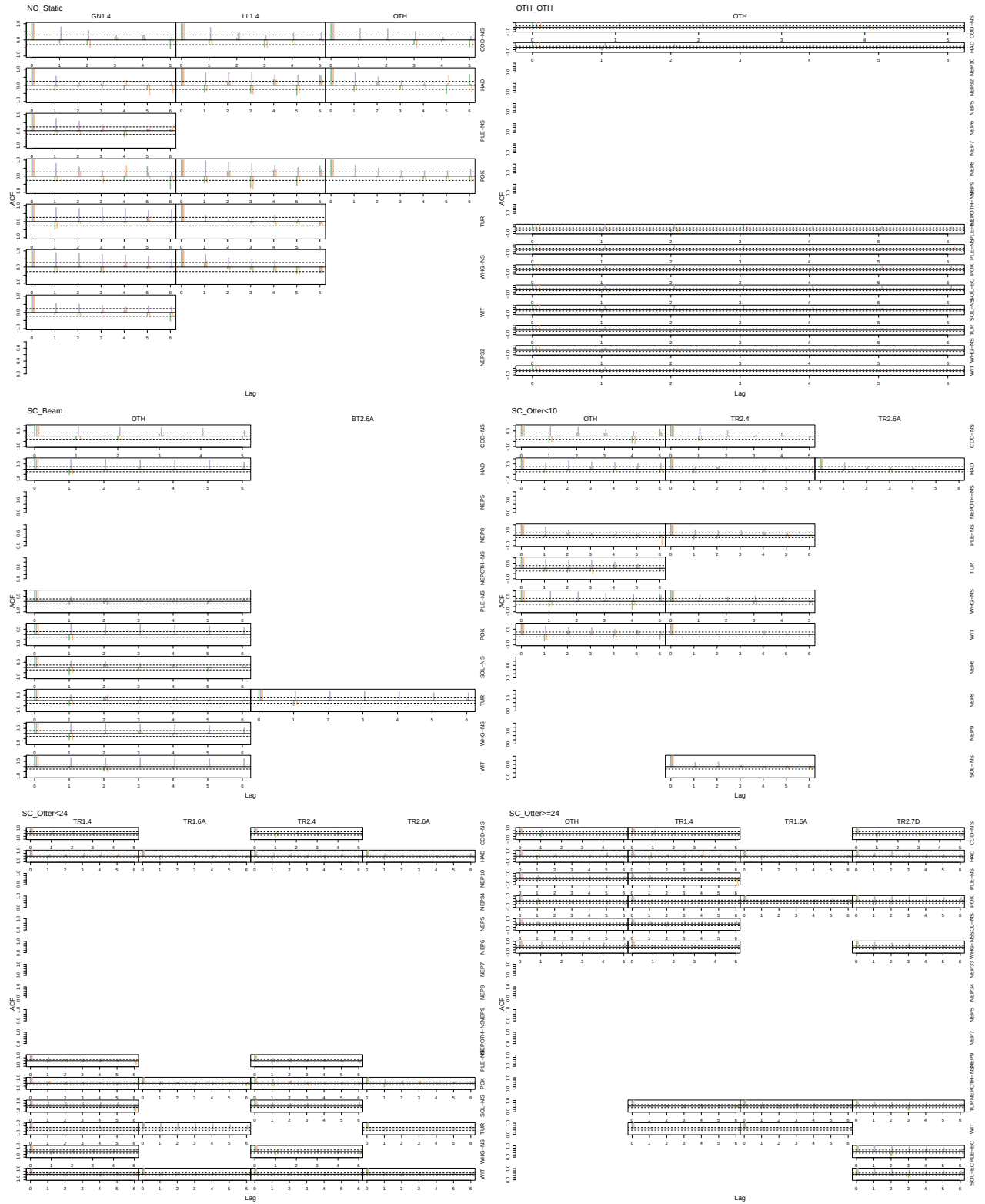


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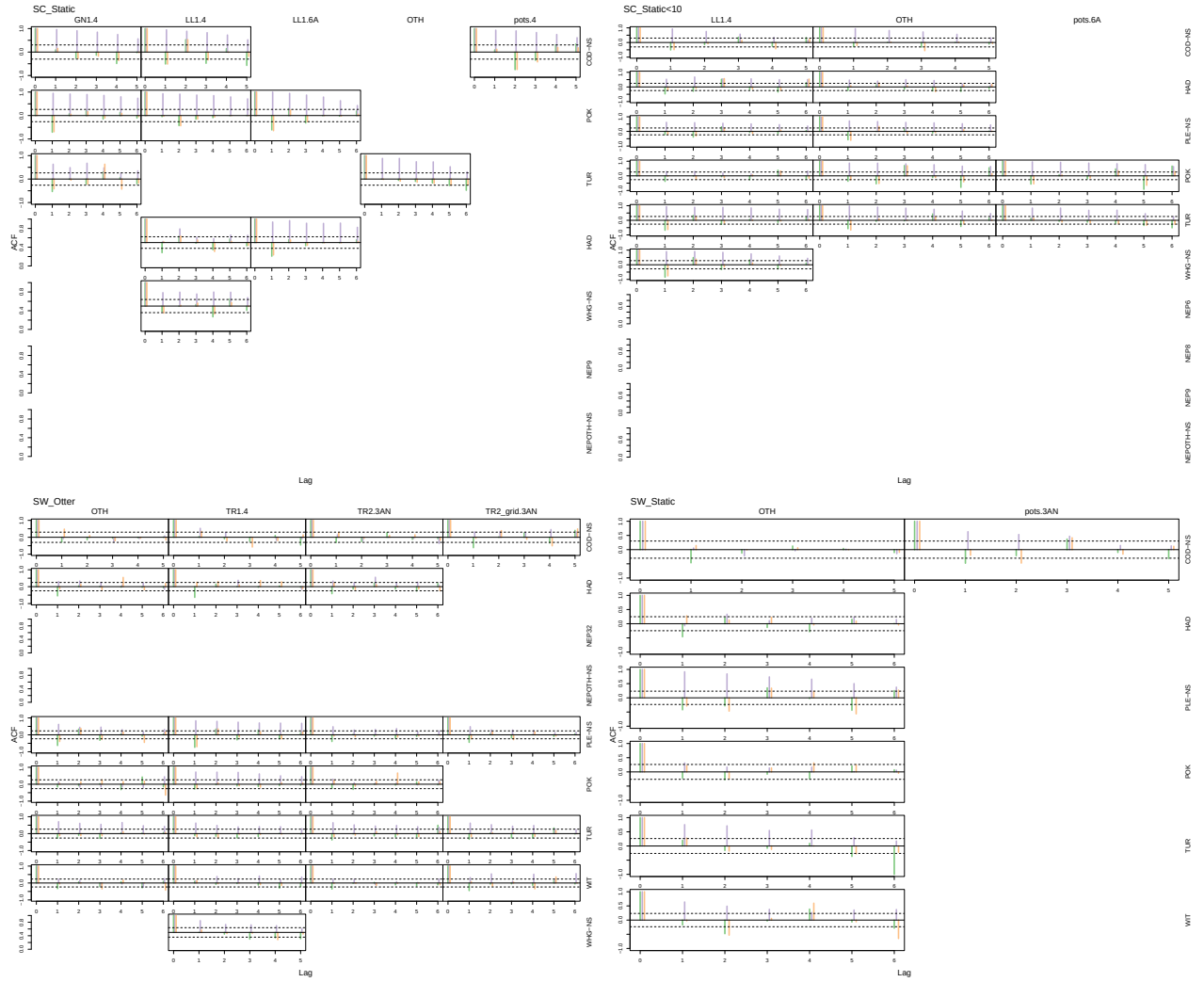


Figure 6 (continued): Autocorrelation in the the current status-quo catchability standardized residuals. The dimensions "row" (green), "column" (purple) and "diagonal" (orange) correspond to the correlation across years, ages, and within cohort, respectively. The maximum lag is set to be the maximum number of ages caught by the métier for each stock. The dashed horizontal lines represent the 95% confidence interval. Correlations beyond these lines are therefore considered non-zero.

CINEA Task 3, effort proportions

Jasper Bleijenberg

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1 Task 3.1 Review the effort proportions assumption made when conditioning the North Sea mixed fisheries model, and characterise the resulting uncertainty in the input parameters

The most recent North Sea mixed fisheries advice model includes observed effort share by métier for the years 2012-2021 (ICES 2022b, 2022a). We back calculated the effort shares in 2013-2021 following the current status-quo effort proportions assumption and compared this to the true observed effort proportions for the same years. Standardized residuals were estimated for each year (y), fleet, (f) and métier (m) as follows:

$$res_{y,f,m} = \frac{\hat{eff}_{y,f,m} - eff_{y,f,m}}{sd(eff_{f,m,s})}, \text{ with } \hat{eff} \text{ being the predicted effort shares and } eff \text{ the observed effort shares.}$$

For each fleet and métier, the histogram of the residuals distribution is given in Appendix B. Overall, the residuals vary per fleet and métier. Some are satisfactory residuals (normally distributed around 0) but others are unsatisfactory (e.g., skewed, with large variance).

Correlation in the residuals was estimated using the autocorrelation function (ACF) in the three dimensions (years, ages and cohort), with lag being set at the maximum the number of ages caught for a stock (Appendix

C). Most métiers show a high correlation across years, which was expected given that the predicted effort proportions is the observed effort proportions in the previous year. Some métiers also show correlation across ages and cohort but it varies across métiers and stocks. Most métiers show a strong lag 1 correlation in their residuals, predicting effort proportions with correlation across years, ages or cohort could therefore be considered as possible alternative model assumption.

2 Task 3.2 Formulate a limited number of simple alternative scenarios for model conditioning of catchability.

Here, four simple assumptions for modelling effort proportions are considered and evaluated through a simple retrospective analysis with different performance metrics. The retrospective exercise was performed on the effort proportions per métier using the latest advice model conditioning (ICES 2022b, 2022a). Effort proportions in the last 5 years (2017-2021) was predicted following four assumptions:

- sQ: effort proportions for a métier is set equal to the previous year's effort (status-quo, current assumption for the mixed fisheries North Sea case study)
- Ave: effort proportions for a métier is set equal to the previous 3-year effort proportions average (assumption currently used for some mixed fisheries case studies other than the North Sea case study)
- lm: effort proportions for a métier is estimated following a linear regression on the previous years (starting in 2012). The effort proportions is set to 0 if predicted to be negative.
- AR1: effort proportions for a métier is estimated following an autoregressive process (AR1) using an integrated moving average (ARIMA) on the previous years (starting in 2012). The effort proportions is set to 0 if predicted to be negative. *This might/will be changed to Klaas' AR1 model instead, or we can also use Klaas' option as an additional one*

Different types of performance metrics are considered to compare the four models and each of them are presented below for different levels of aggregation:

- Proportion of a model being the best model based on the model having the smallest residuals (i.e., $abs(res)$) as estimated in Part 1. Larger is the proportion, better is the model.
- Relative errors on the log scale, i.e., $RE = \frac{\log(\hat{q}) - \log(q)}{\log(q)}$. This performance metric is the only one considered on log scale but inherently ignores effort proportions of 0. The best model is the one with the RE the closest to 0.
- Rank of each model, based on sorting in ascending order the absolute value of res . If residuals are the same, the rank will be shared between the model at the same level (e.g, rank of 1.5 if two models have best residuals, mainly happens when $q = \hat{q} = 0$). The best model is the one with the lowest rank.

2.1 Results at the maximum level of aggregation

If the results are fully aggregated (no distinction between fleet and métier), the status-quo effort proportions, which is the option currently used for the North Sea case study is the best option for the three performance metrics (Table 1). The performance of the other models depends on the performance metric considered.

Table 1: Performance metrics aggregated at the level of the entire North Sea model.

	Proportion of being best	Median relative error (%)	Mean rank
sQ	0.615	0.064	1.762
Ave	0.176	-0.167	2.753
lm	0.217	-0.747	2.505
AR1	0.164	-0.379	2.981

2.2 Results at the fleet level

When the results are aggregated at the fleet level, the status-quo assumption is the best model overall for 2 out of 3 of the performance metrics considered (Figure 1 (continued)). Other models can be favored when looking at the mean relative error in the log effort proportions but the status-quo model is still the most often chosen as best model (Table 2).

Table 2: Number of fleets for which a model does the best according to each performance metric.

	Proportion of being best	Median relative error (%)	Mean rank
sQ	41	16	42
Ave	2	17	1
lm	5	8	3
AR1	2	4	2

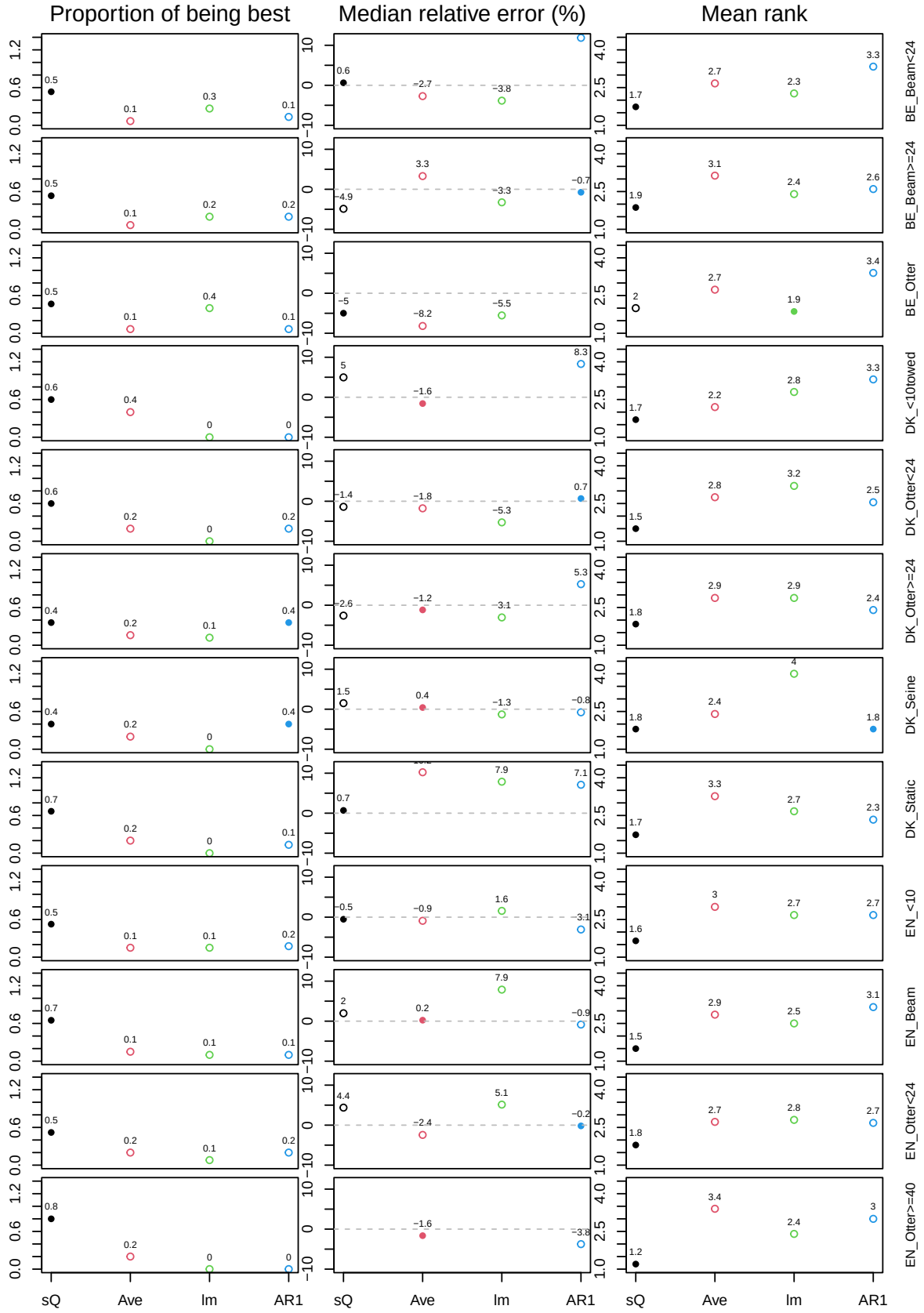


Figure 1: Performance metrics presented at the fleet level. The best value for each performance metric is highlighted by a solid circle.

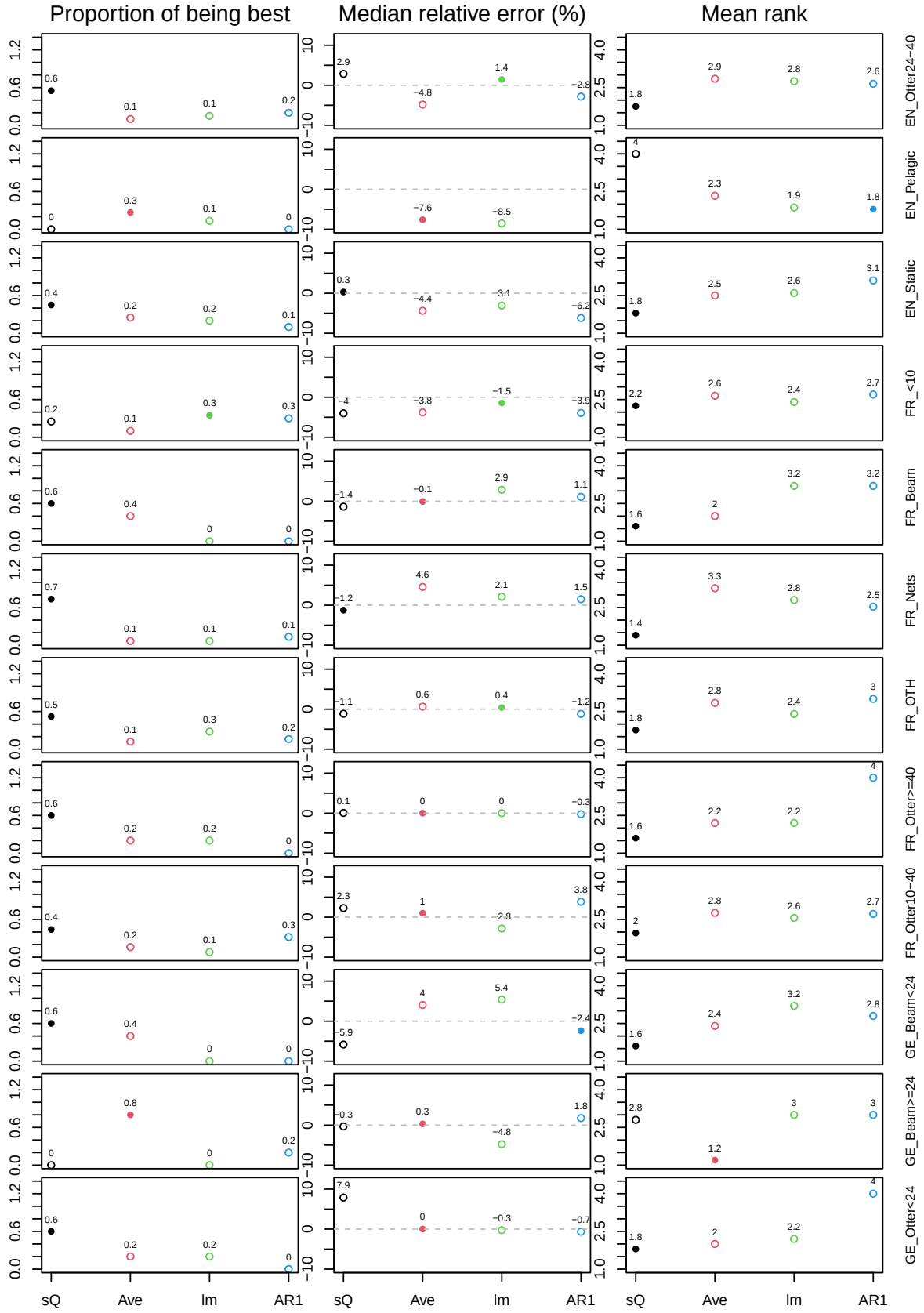


Figure 1 (continued): Performance metrics presented at the fleet level. The best value for each performance metric is highlighted by a solid circle.

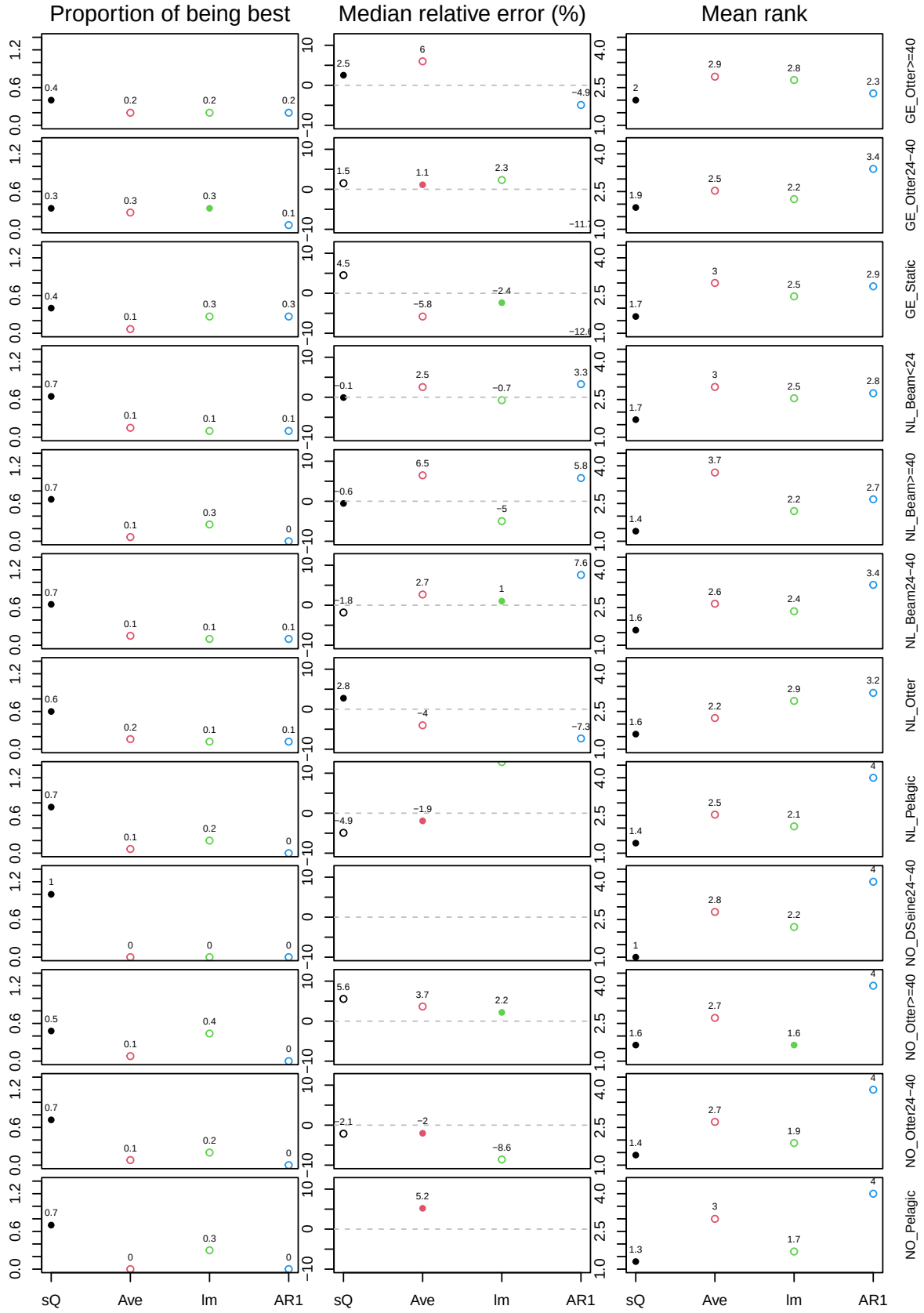


Figure 1 (continued): Performance metrics presented at the fleet level. The best value for each performance metric is highlighted by a solid circle.

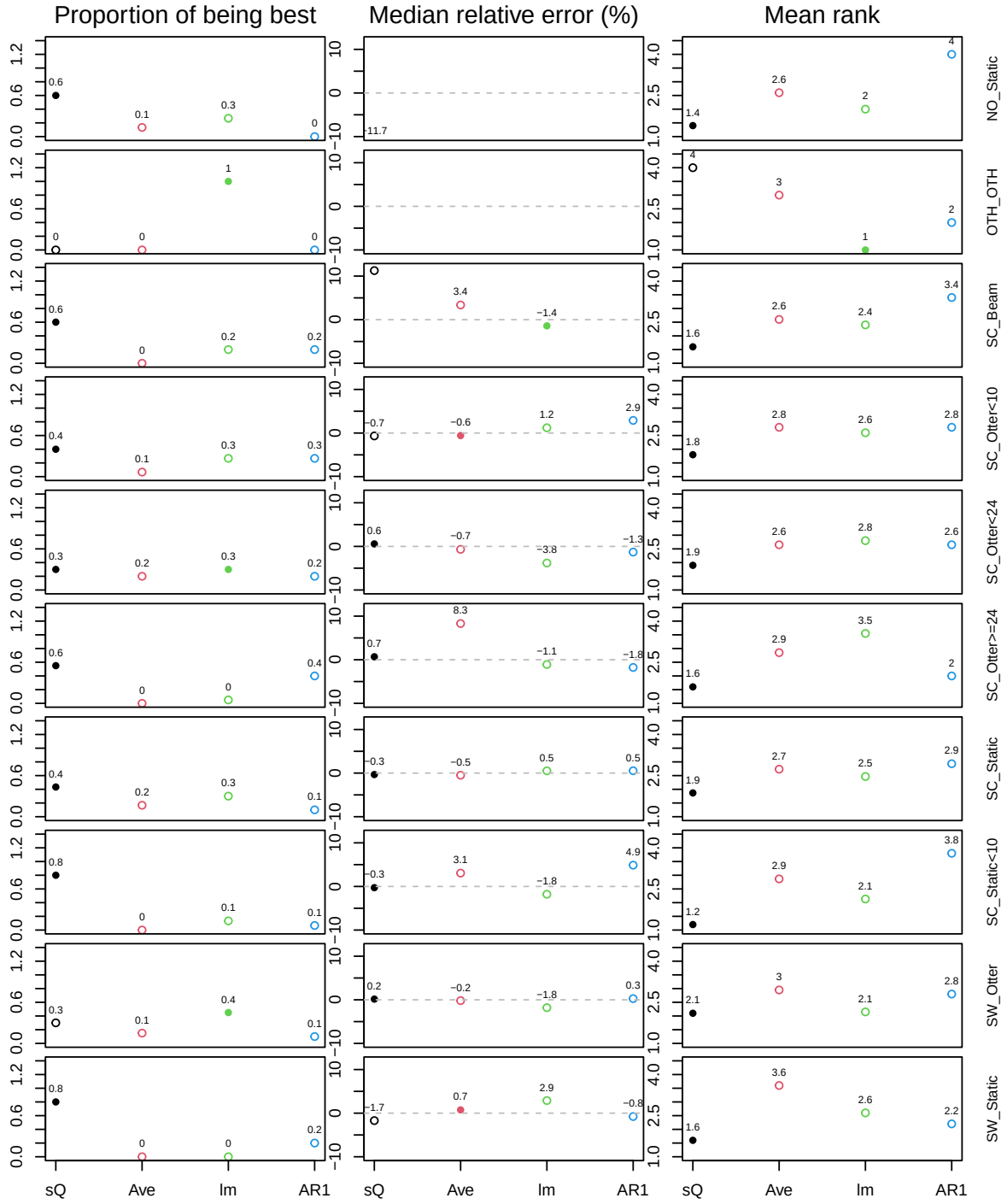


Figure 1 (continued): Performance metrics presented at the fleet level. The best value for each performance metric is highlighted by a solid circle.

2.3 Results at the fleet level and per predicted year

The best model can vary at the fleet level, over time, and depending on the performance metric considered but the status-quo option is still the best overall (Figure 2 (continued)). Results are more variable when looking at the relative error in log effort proportions where for a specific fleet, the best model might differ depending on the predicted year. This makes it difficult to choose one assumption that is best for all fleets at any time since effort share will also depend on fleet opportunities.

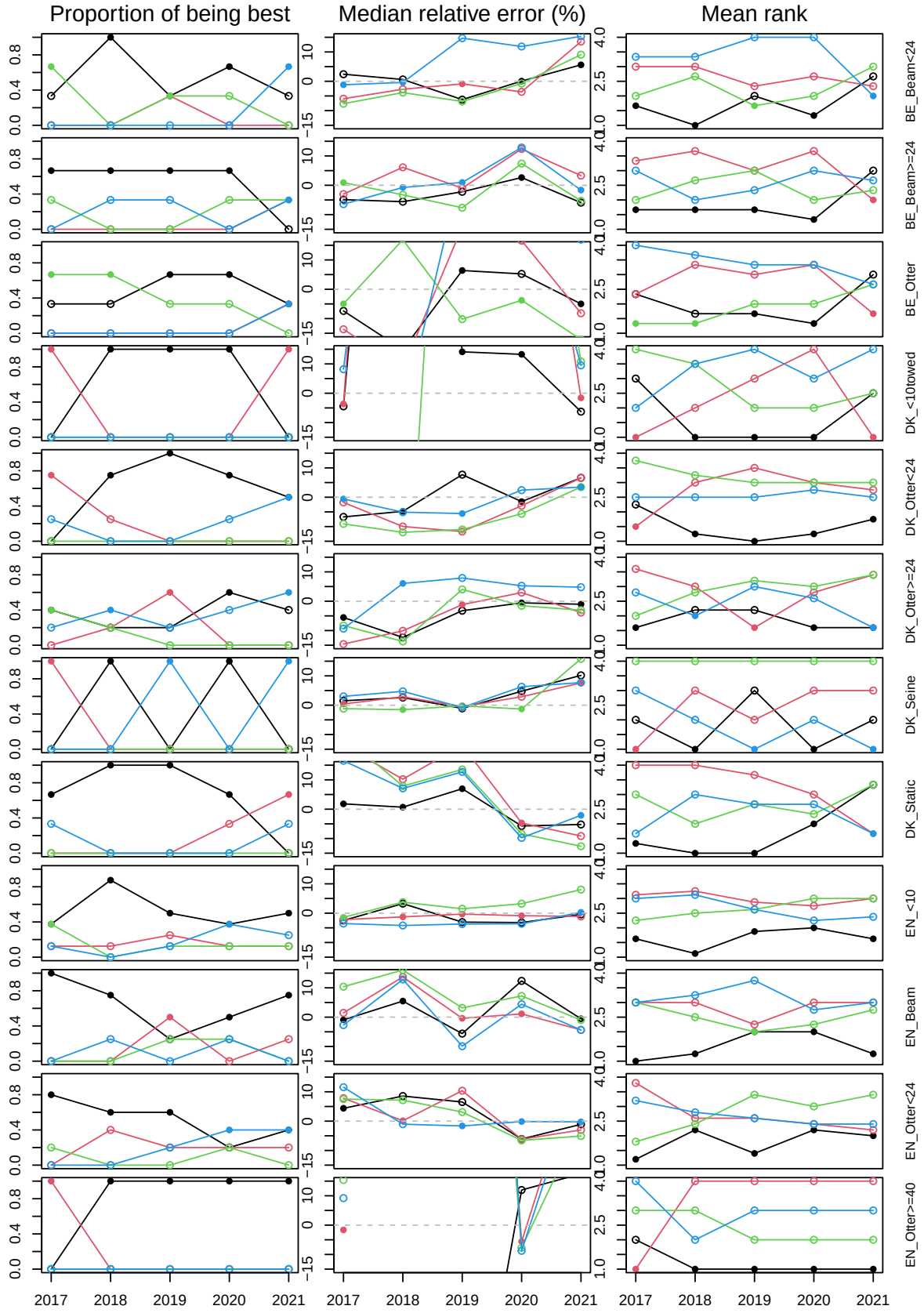


Figure 2 (continued): Performance metrics presented at the fleet level and over time. The best value for each performance metric is highlighted by a solid circle.

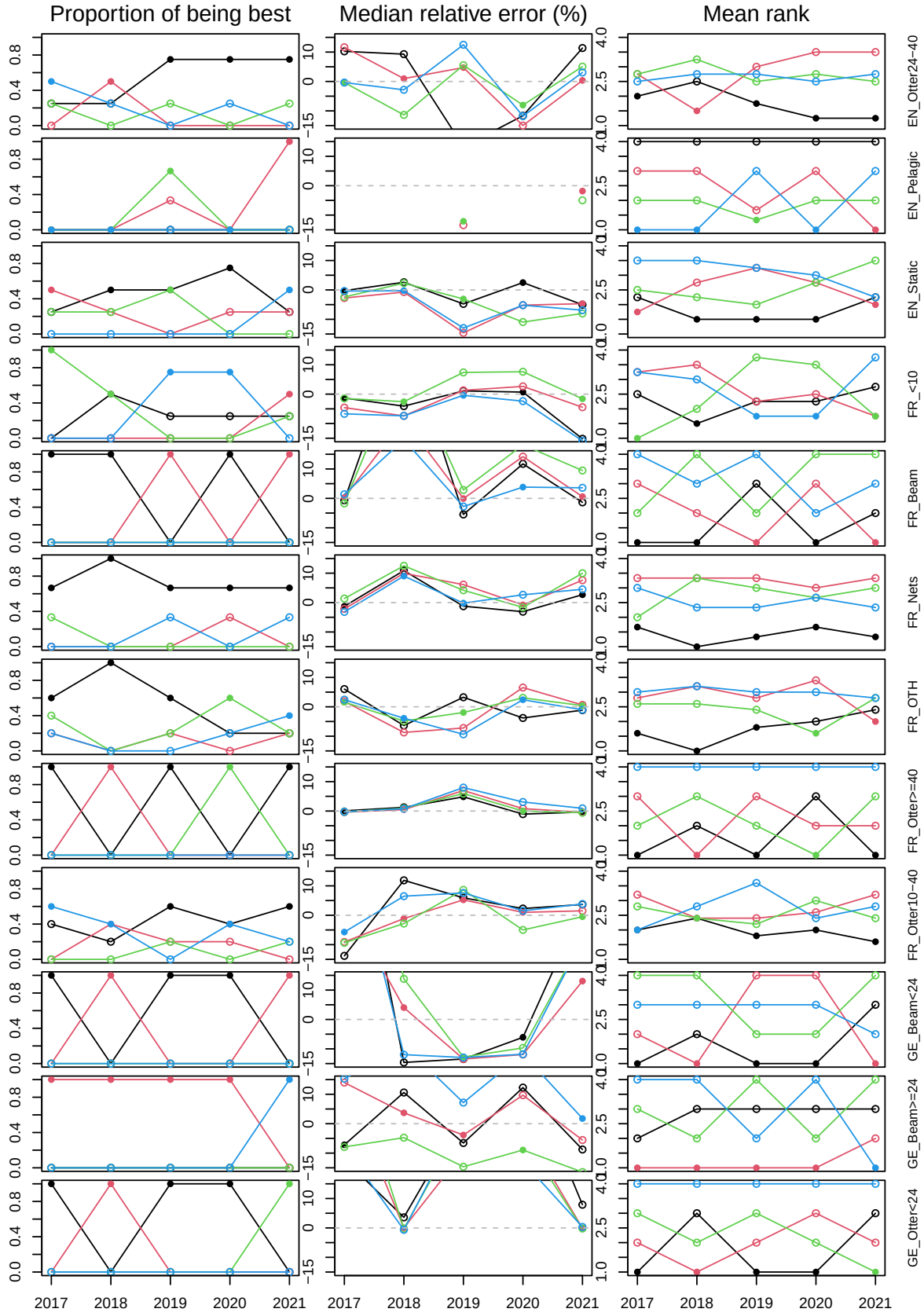


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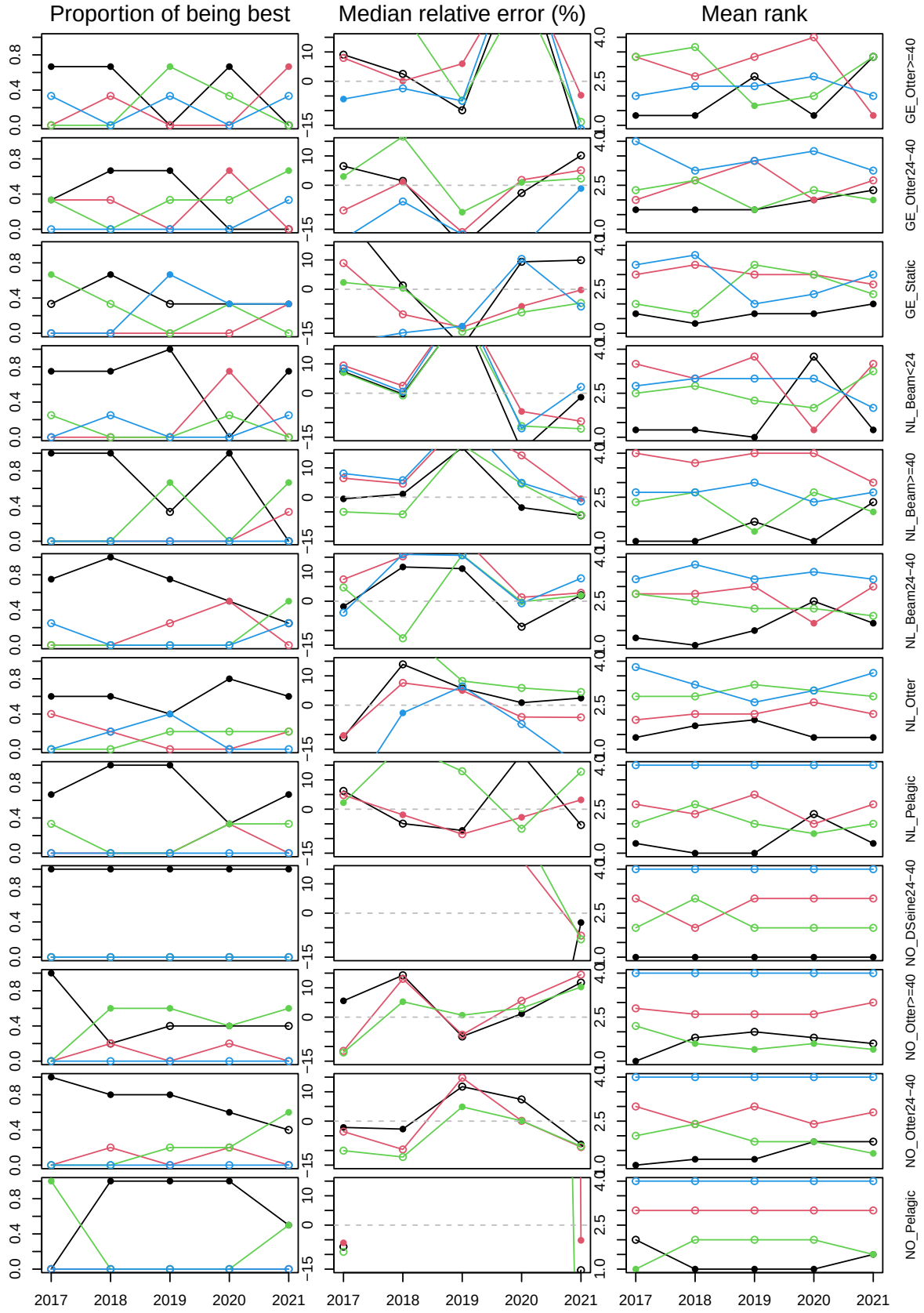


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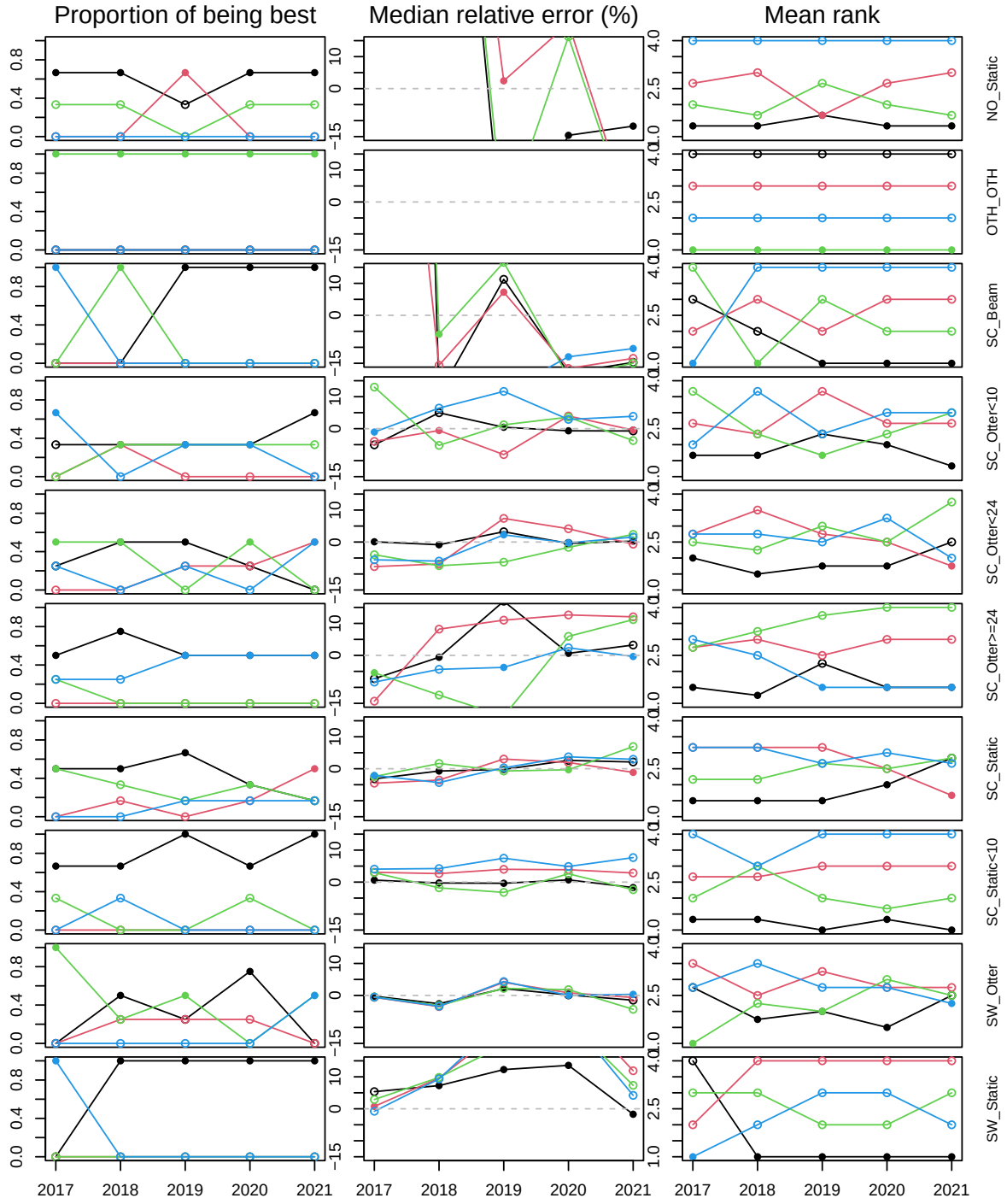


Figure 2 (continued): Performance metrics presented at the fleet level and over time. The best value for each performance metric is highlighted by a solid circle.

2.4 Results at the métier level

Given that the North Sea case study includes 156 métiers, the results are only presented as the number of métiers for which the different models are best (Table 3). The status-quo assumption is the one that is the best for most of the métiers no matter the performance metric considered.

Table 3: Number of métiers for which a model does the best according to each performance metric.

	Proportion of being best	Median relative error (%)	Mean rank
sQ	120	67	127
Ave	18	35	11
lm	28	36	26
AR1	26	17	17

3 References

ICES. 2022a. “Working Group on Mixed Fisheries Advice (WGMIXFISH-ADVICE; Outputs from 2021 Meeting).” <https://doi.org/10.17895/ices.pub.9379>.
———. 2022b. “Greater North Sea - Mixed Fisheries Considerations.”

A Appendix A: Change in observed effort proportions over time

Figure 3 (continued) shows the observed effort proportions per fleet, for the years 2012-2021. Effort proportions can vary over time, making the current assumption of status-quo effortshare in the projections questionable.

B Appendix B: Error in the current status-quo effortshare assumption

Figure 4 shows the distribution of the error (standardized residuals) in the current effortshare predictions (status-quo) for the years 2013-2021.

C Appendix C: Correlation in the current status-quo effortshare residuals

Figure 5 shows the ACF plot for correlation in the status-quo effortshare residuals. It is possible that some correlations are missing for certain lags, notably if residuals could not be computed because the effortshare was null.



Figure 3 (continued): Observed effortshare at age per fleet, métier and stocks.

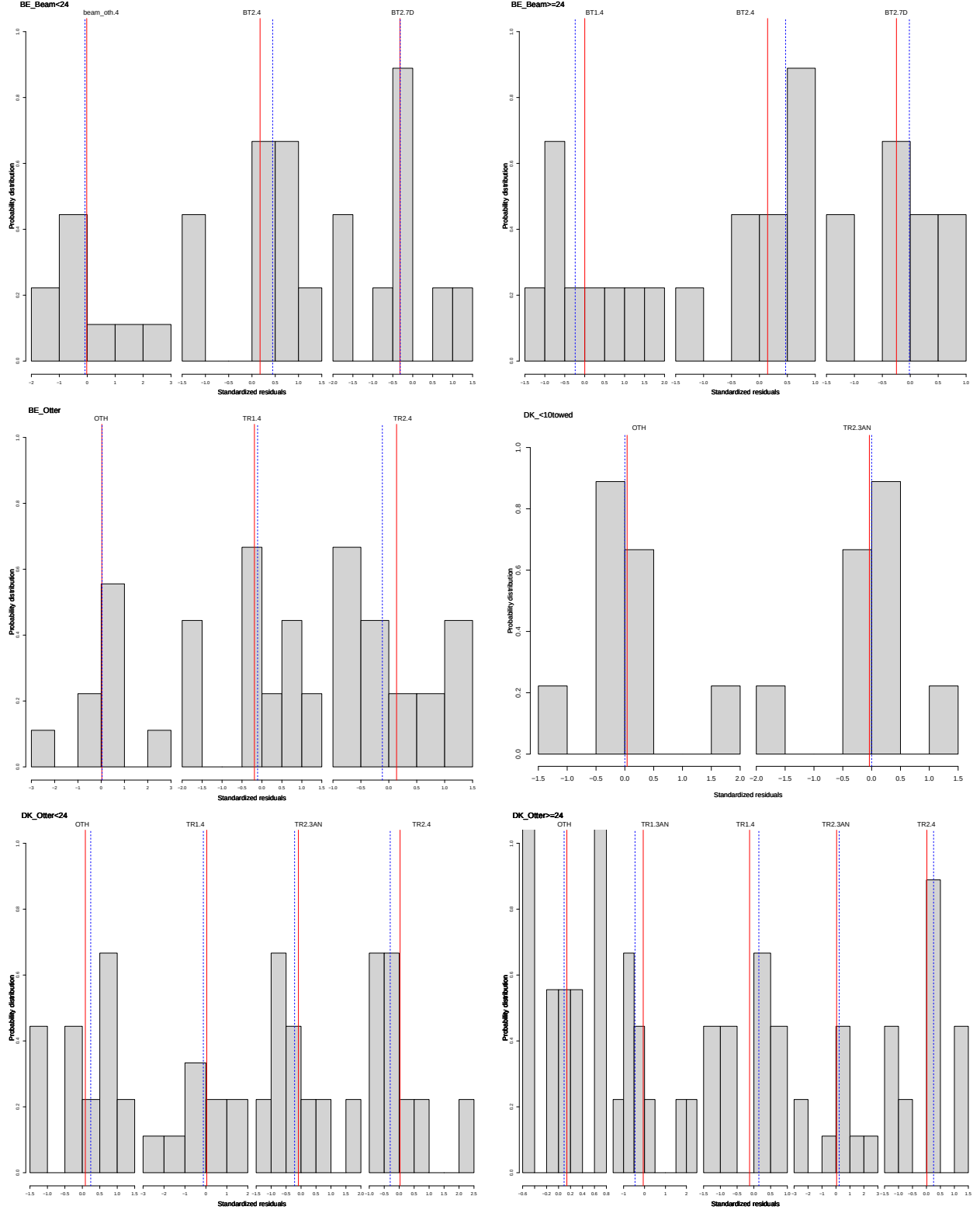


Figure 4: Distribution of the standardized residuals when effortshare is follows the status-quo assumption. Mean and median of the distribution are showed as red and dashed blue lines, respectively.

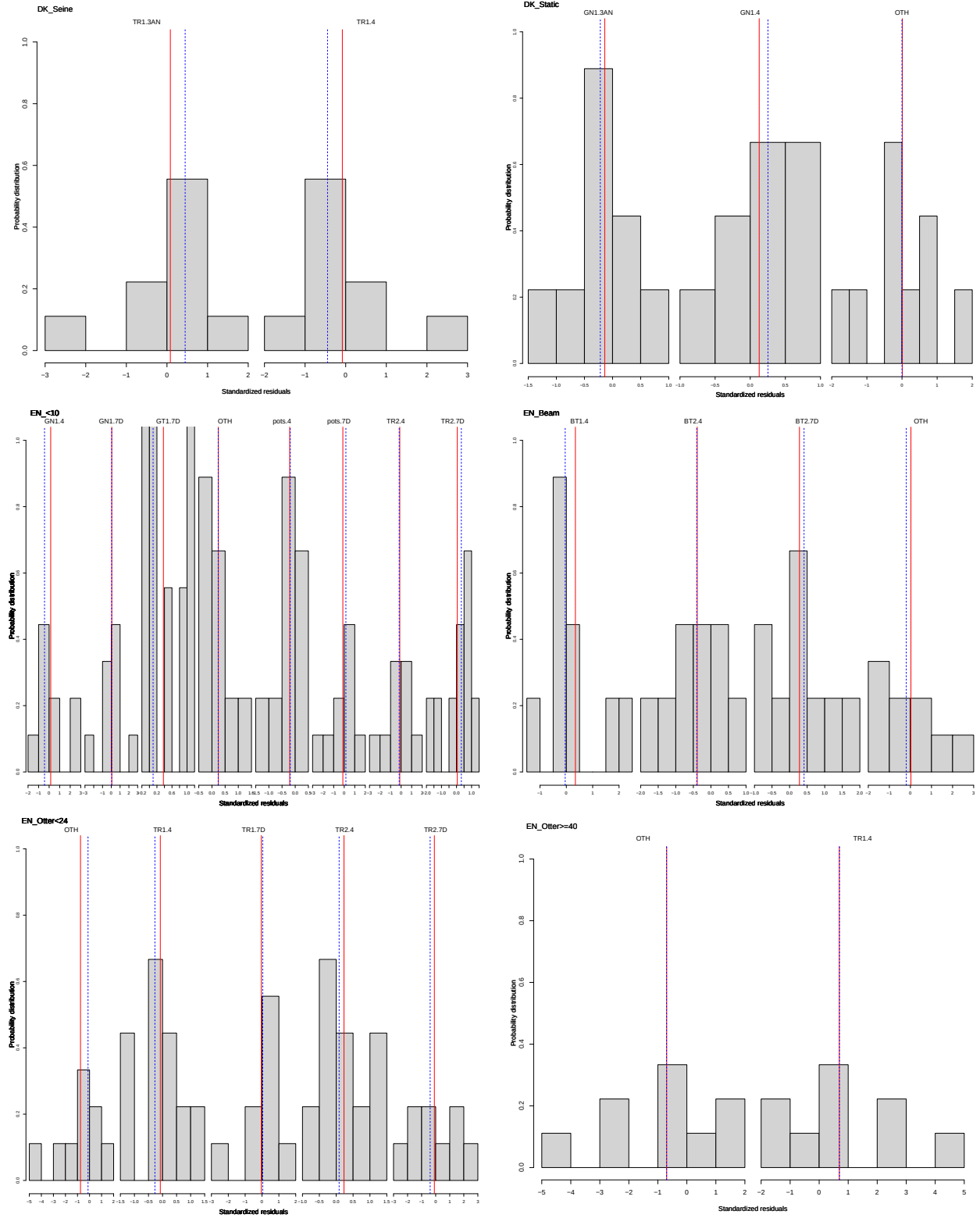


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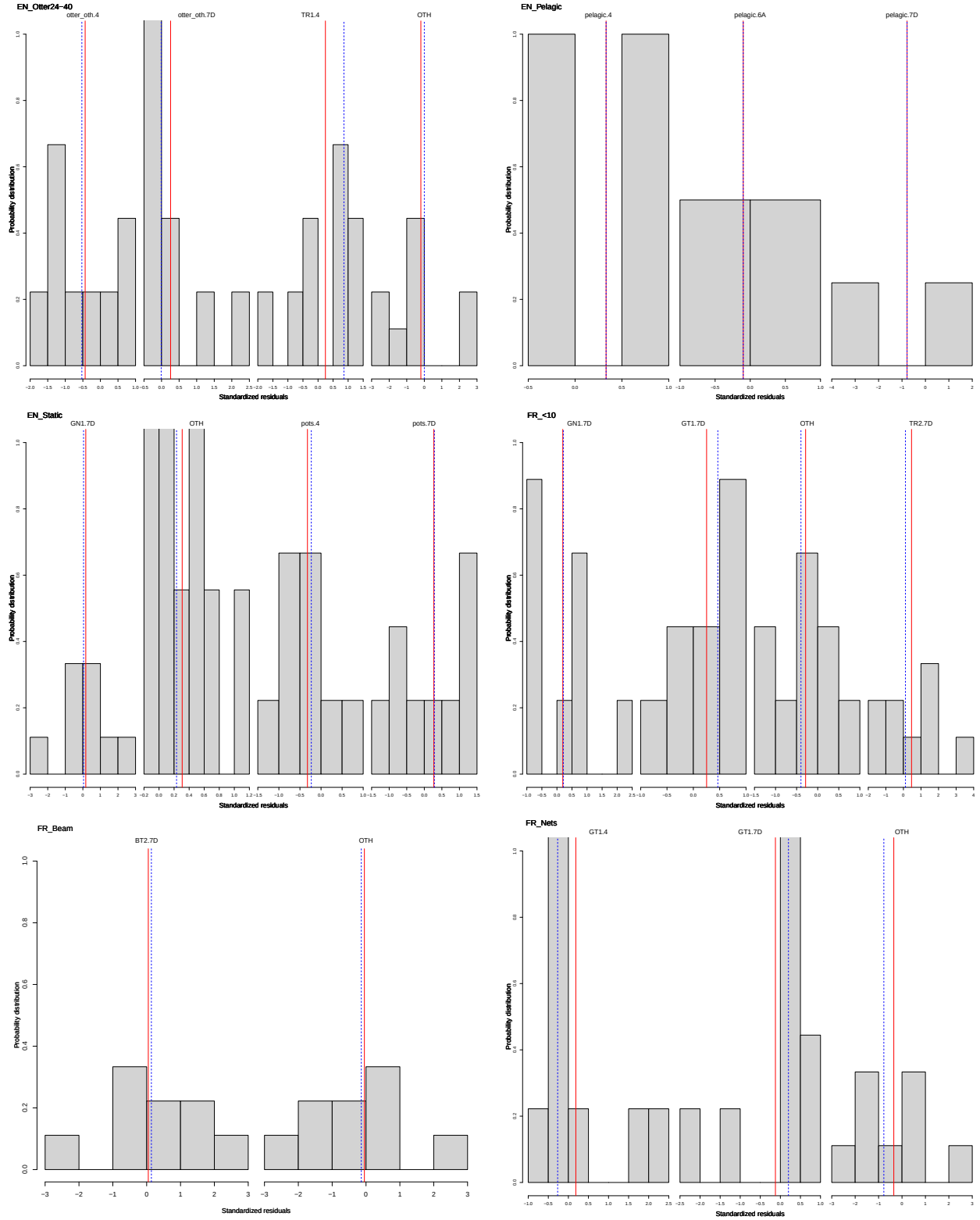


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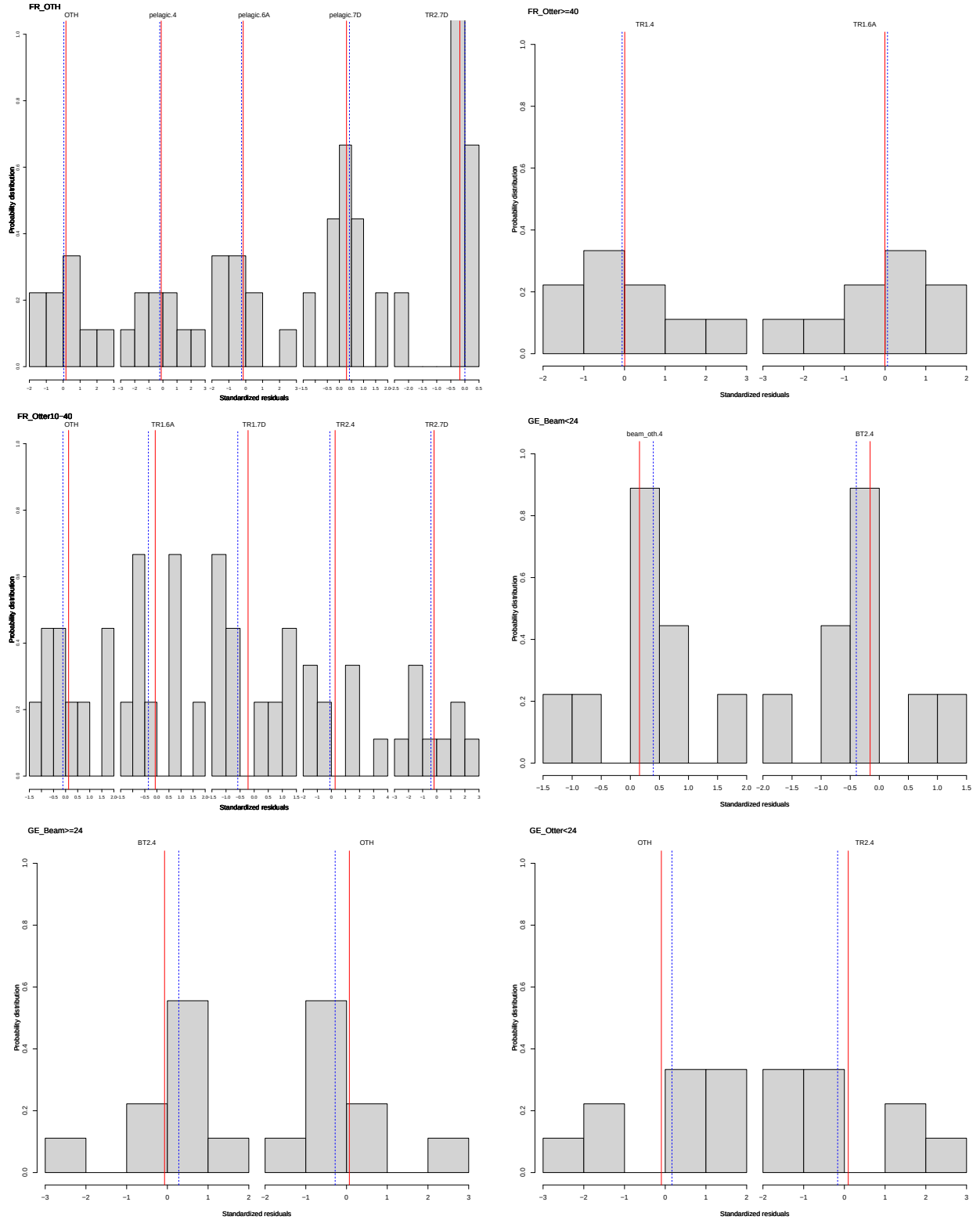


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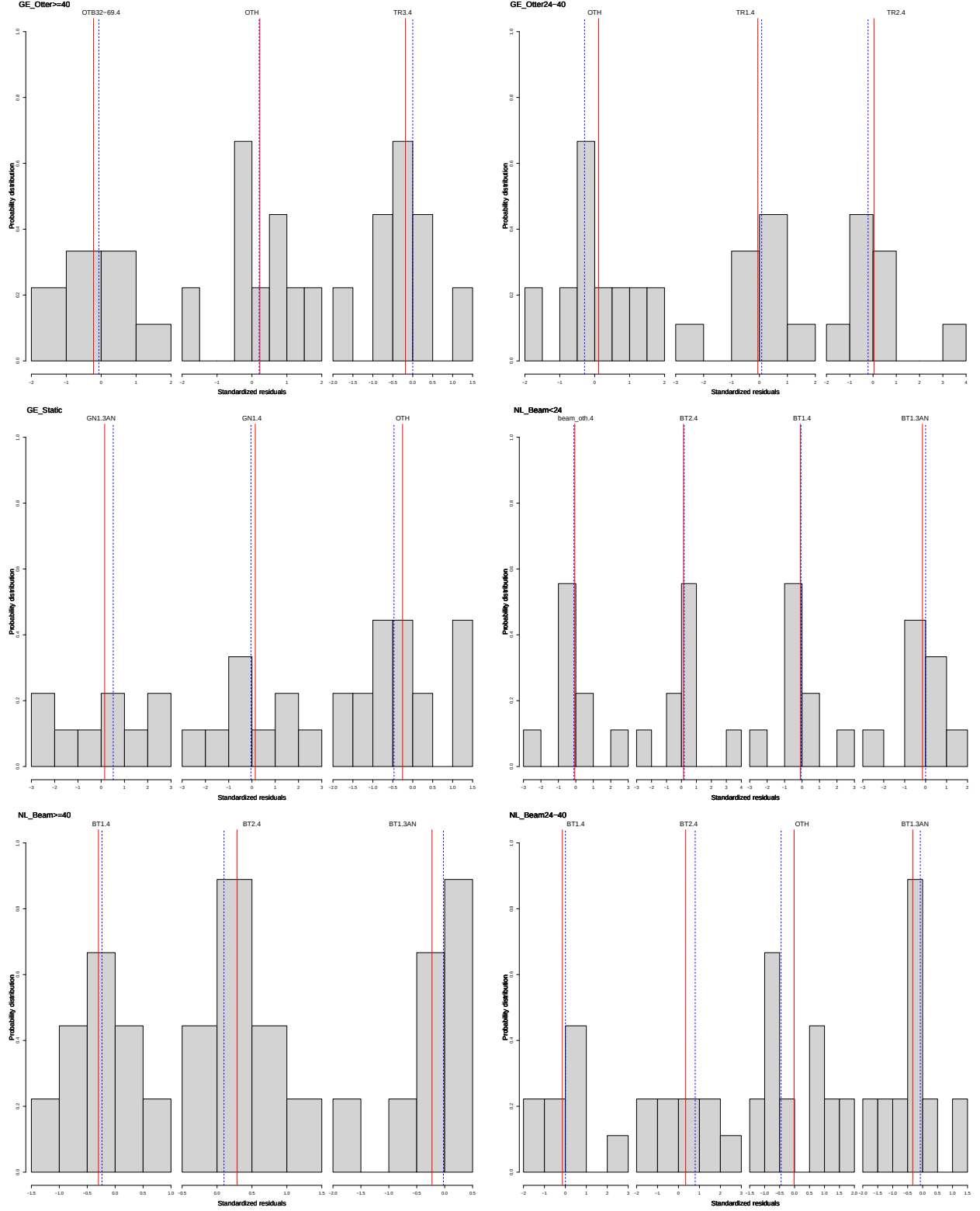


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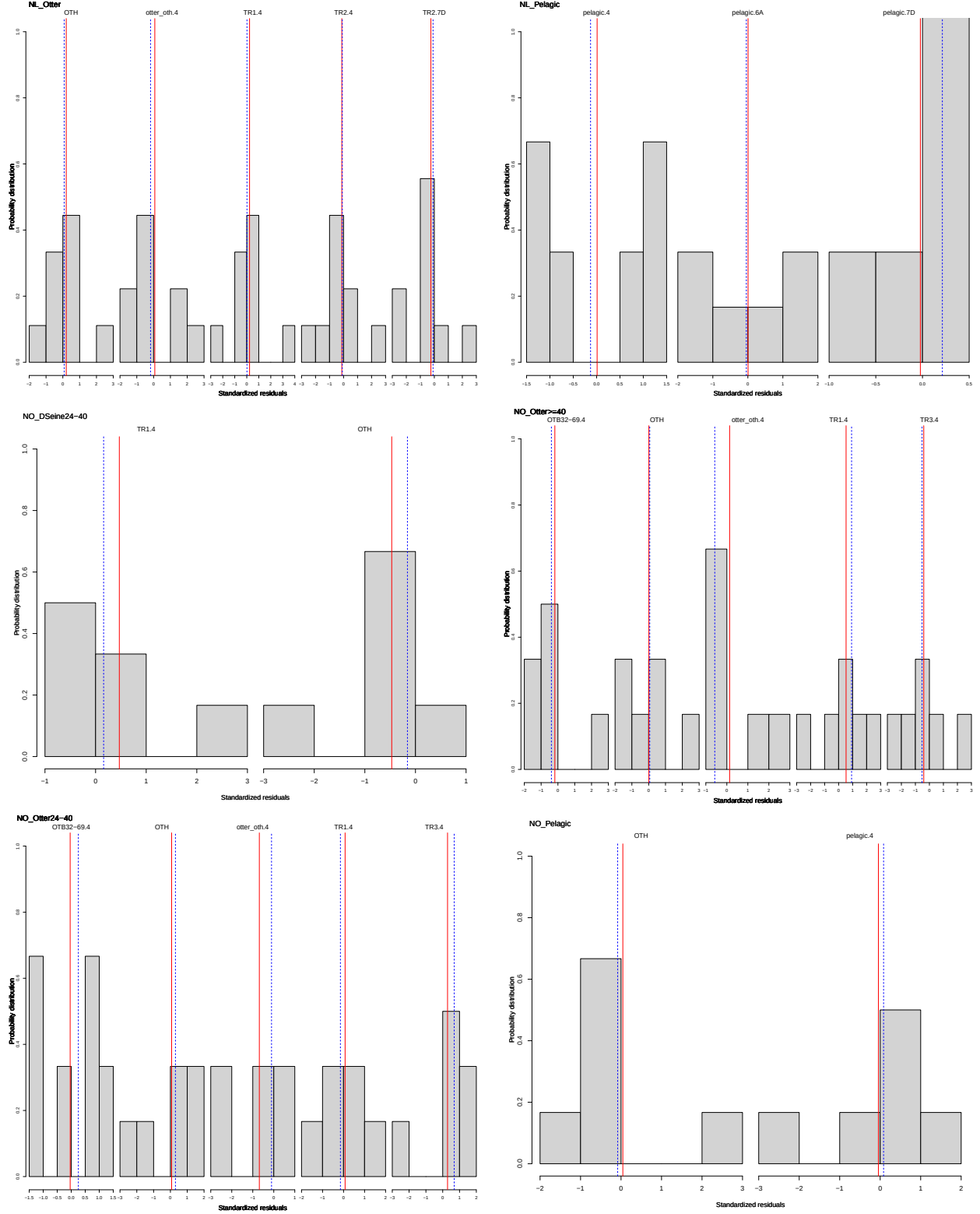


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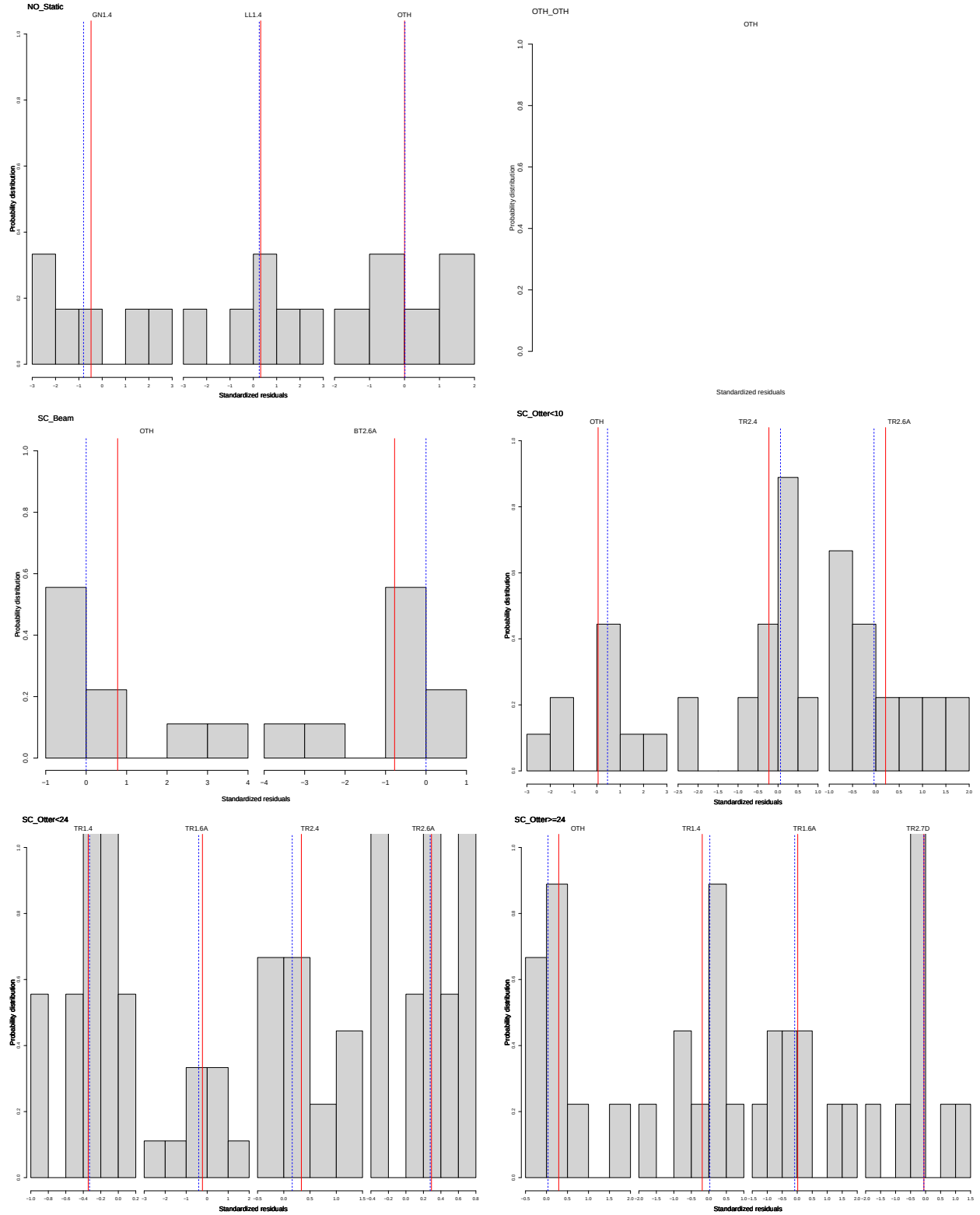


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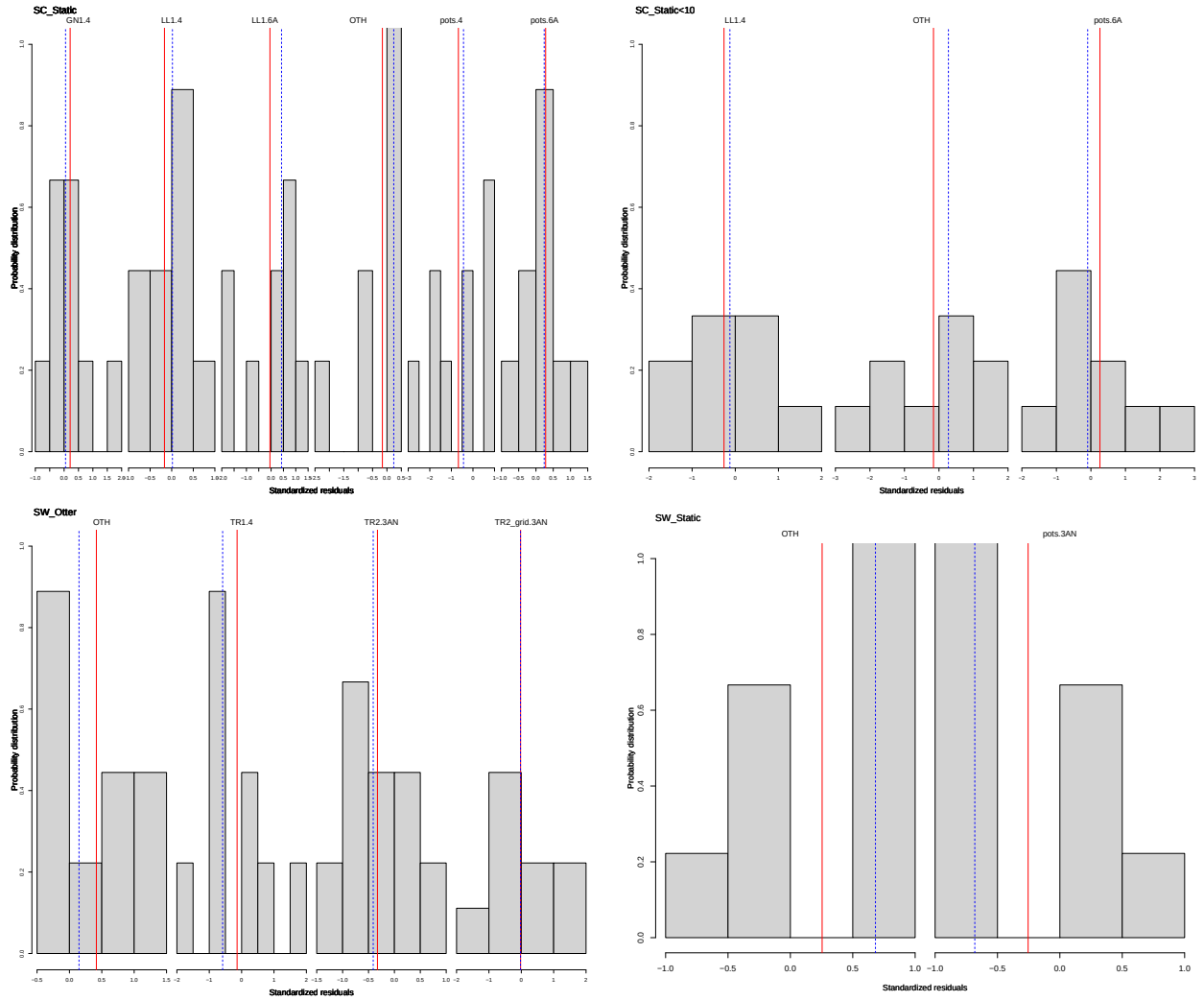


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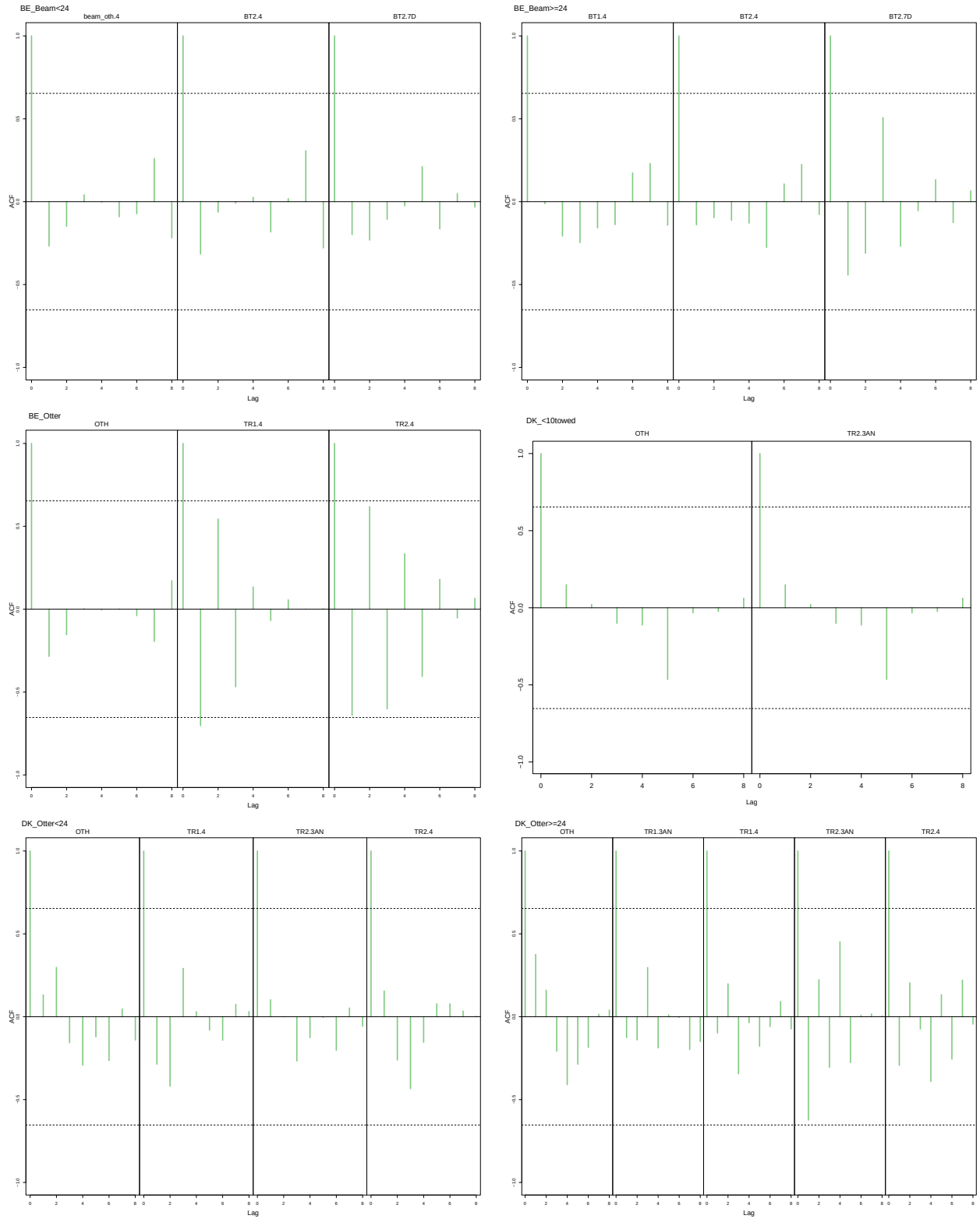


Figure 5: Autocorrelation in the the current status-quo effortshare standardized residuals. The dimension "row" (green) corresponds to the correlation across years. The maximum lag is set to be the number of years in series minus 2, because no status Quo for the first year can be applied, and lag only occurs after the first year. The dashed horizontal lines represent the 95% confidence interval. Correlations beyond these lines are therefore considered non-zero.

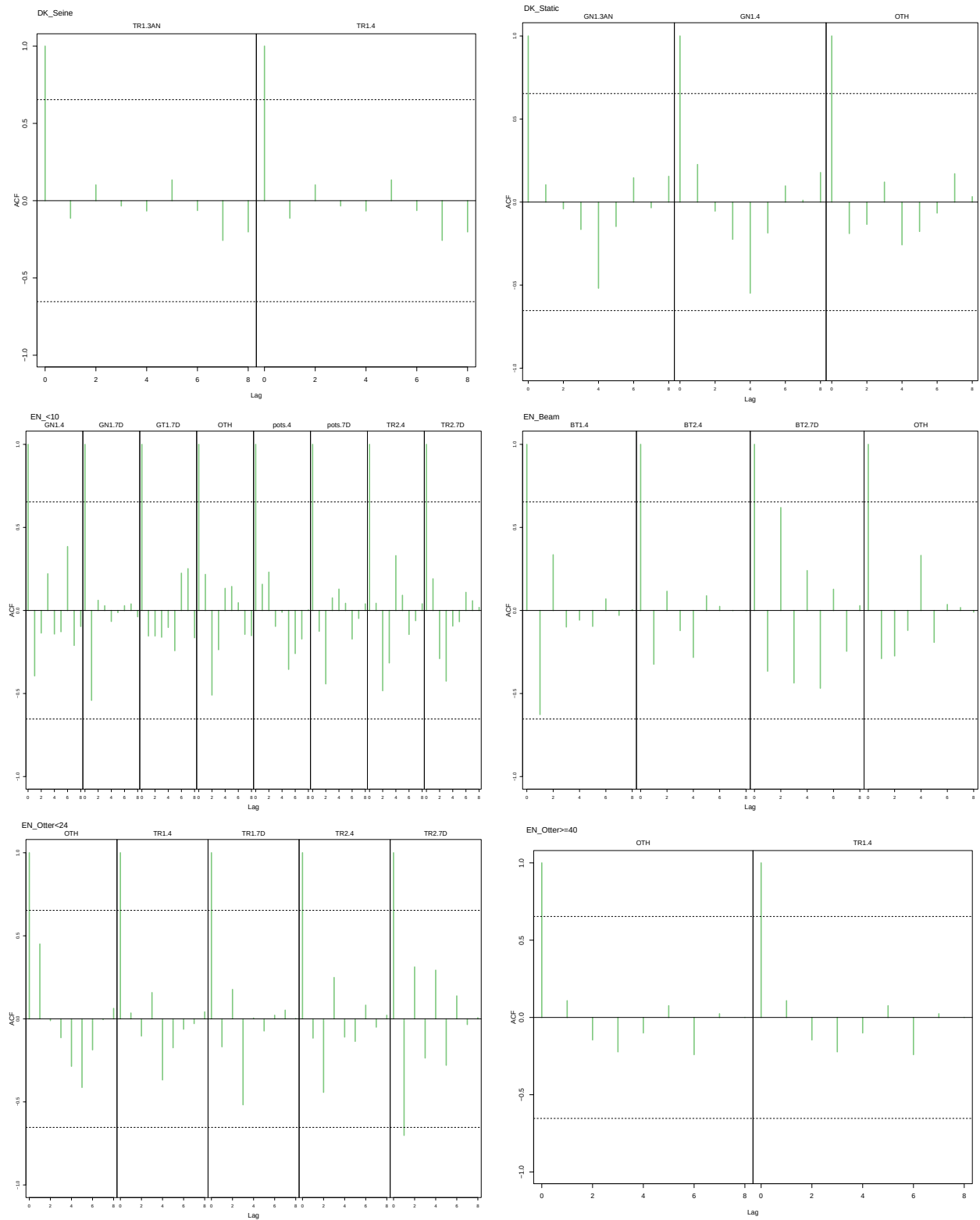


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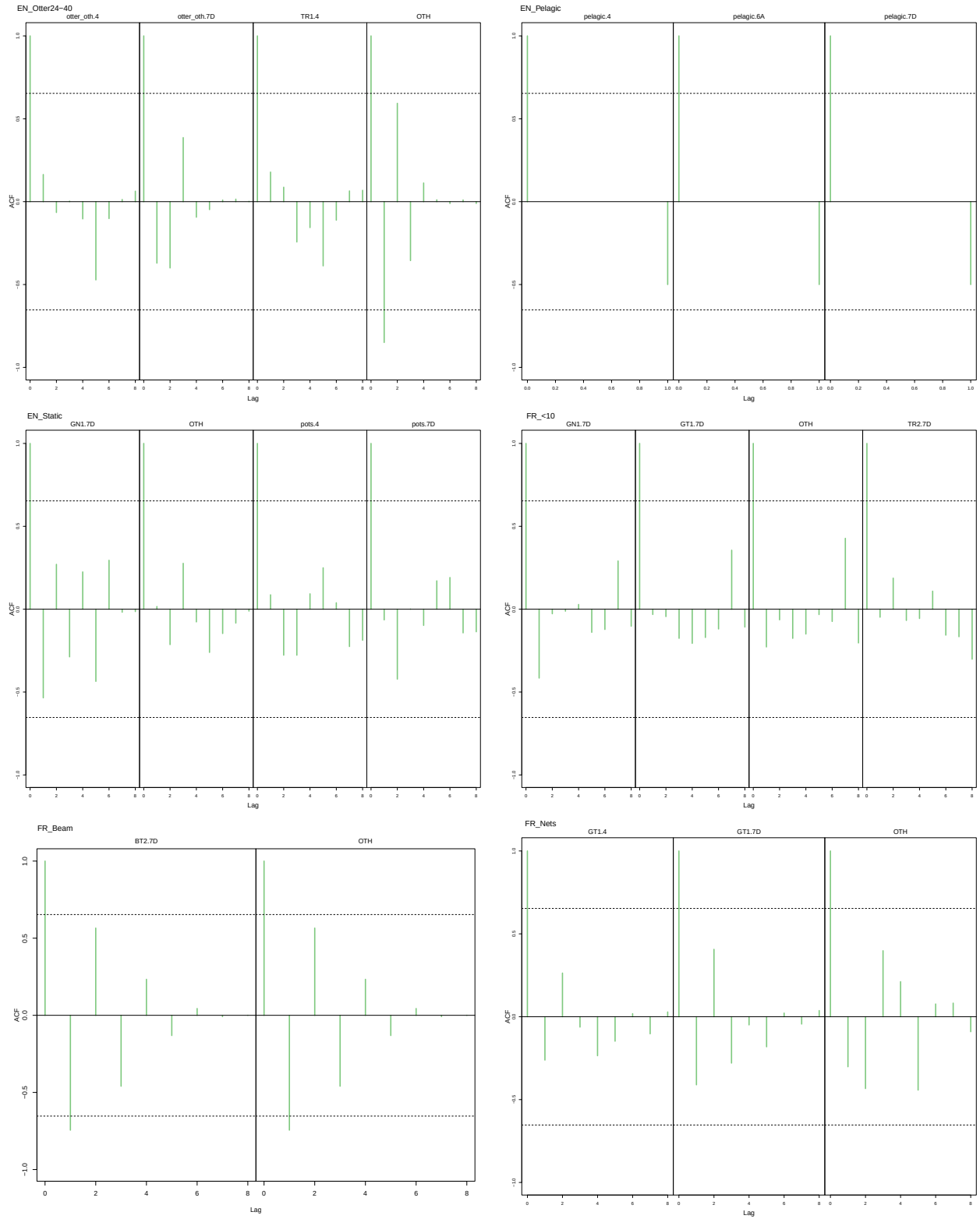


Figure 5 (continued): Autocorrelation in the the current status-quo effortshare standardized residuals. The dimension "row" (green) corresponds to the correlation across years. The maximum lag is set to be the number of years in series minus 2, because no status Quo for the first year can be applied, and lag only occurs after the first year. The dashed horizontal lines represent the 95% confidence interval. Correlations beyond these lines are therefore considered non-zero.

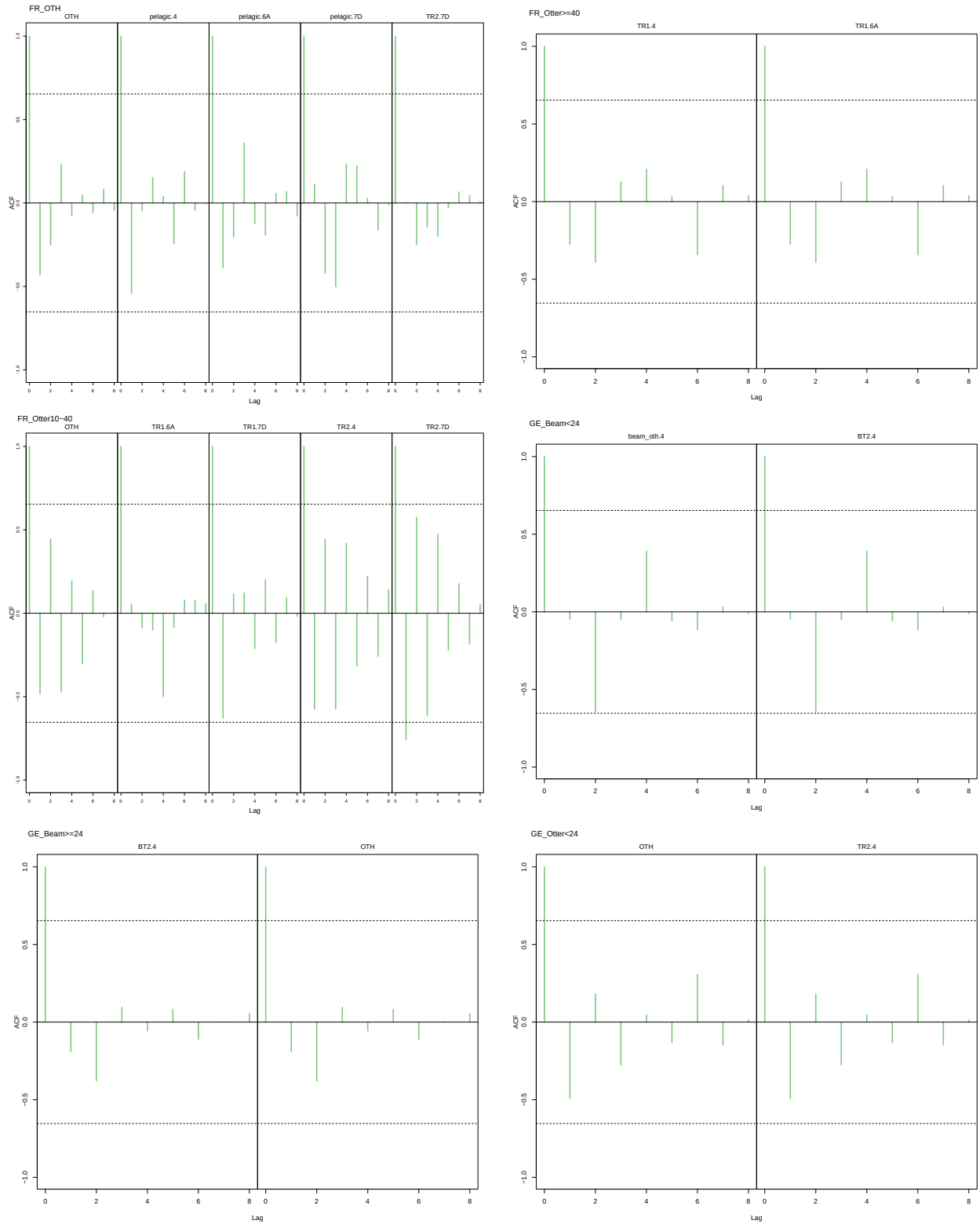


Figure 5 (continued): Autocorrelation in the the current status-quo effortshare standardized residuals. The dimension "row" (green) corresponds to the correlation across years. The maximum lag is set to be the number of years in series minus 2, because no status Quo for the first year can be applied, and lag only occurs after the first year. The dashed horizontal lines represent the 95% confidence interval. Correlations beyond these lines are therefore considered non-zero.

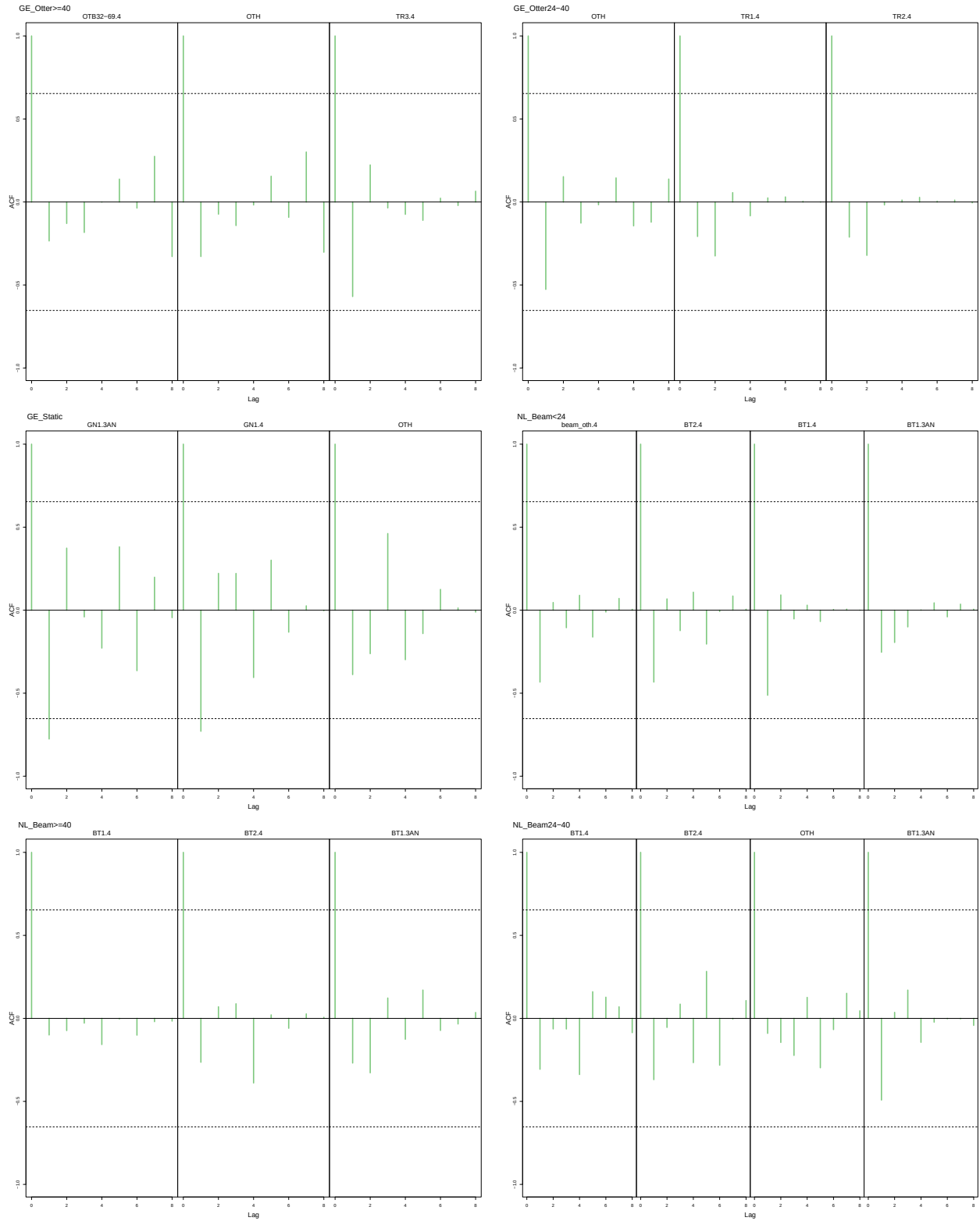


Figure 5 (continued): Autocorrelation in the the current status-quo effortshare standardized residuals. The dimension "row" (green) corresponds to the correlation across years. The maximum lag is set to be the number of years in series minus 2, because no status Quo for the first year can be applied, and lag only occurs after the first year. The dashed horizontal lines represent the 95% confidence interval. Correlations beyond these lines are therefore considered non-zero.

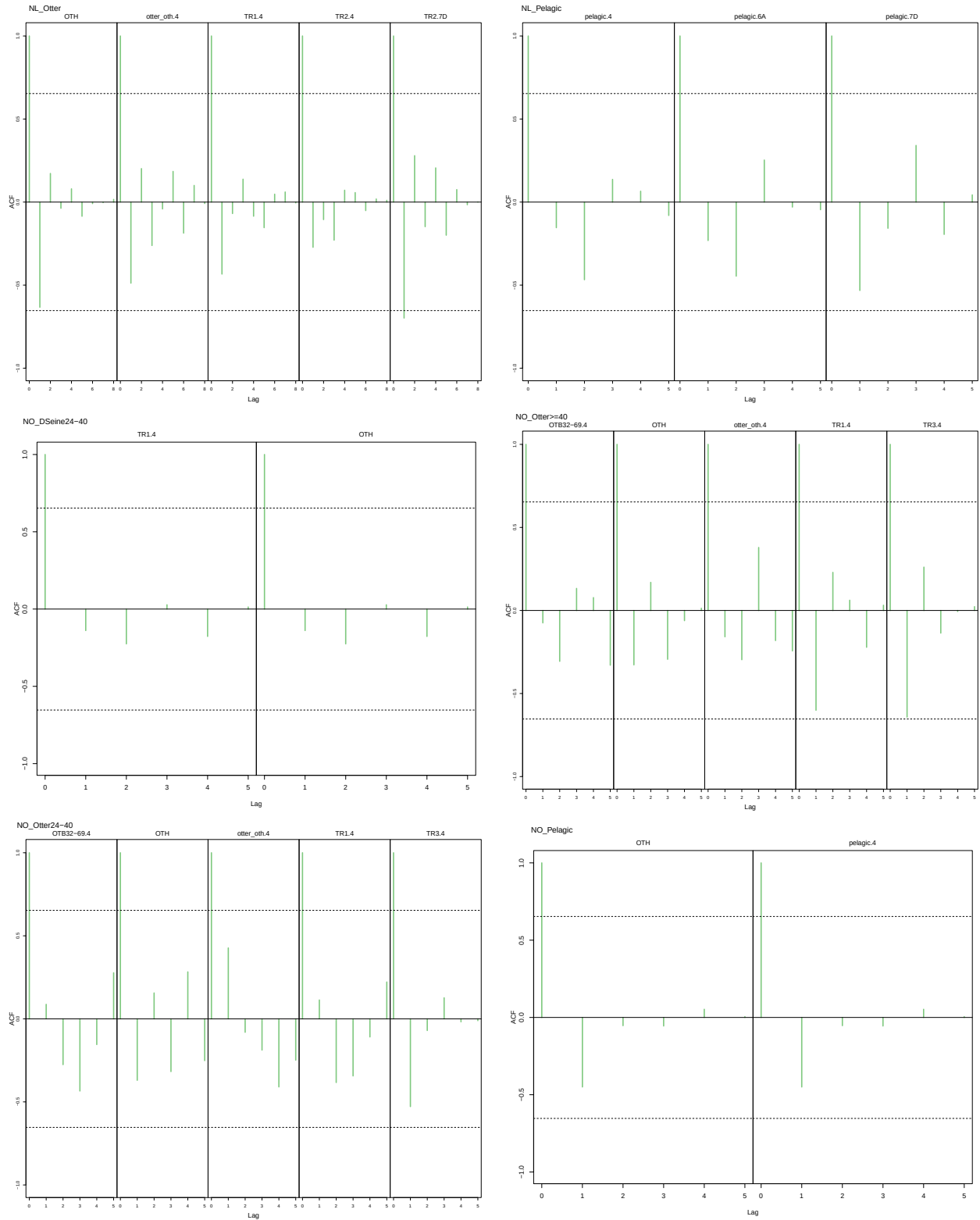


Figure 5 (continued): Autocorrelation in the the current status-quo effortshare standardized residuals. The dimension "row" (green) corresponds to the correlation across years. The maximum lag is set to be the number of years in series minus 2, because no status Quo for the first year can be applied, and lag only occurs after the first year. The dashed horizontal lines represent the 95% confidence interval. Correlations beyond these lines are therefore considered non-zero.

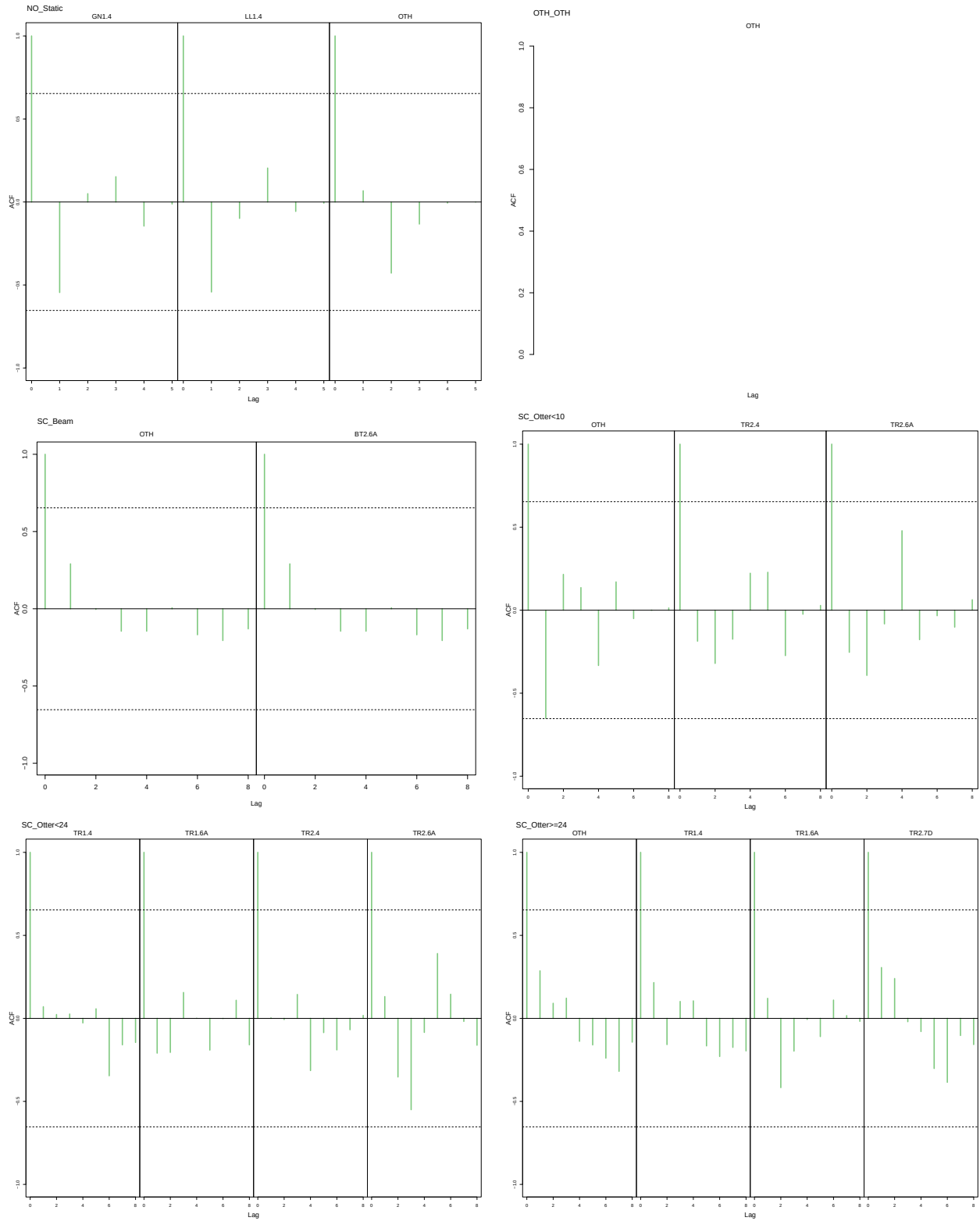


Figure 5 (continued): Autocorrelation in the the current status-quo effortshare standardized residuals. The dimension "row" (green) corresponds to the correlation across years. The maximum lag is set to be the number of years in series minus 2, because no status Quo for the first year can be applied, and lag only occurs after the first year. The dashed horizontal lines represent the 95% confidence interval. Correlations beyond these lines are therefore considered non-zero.

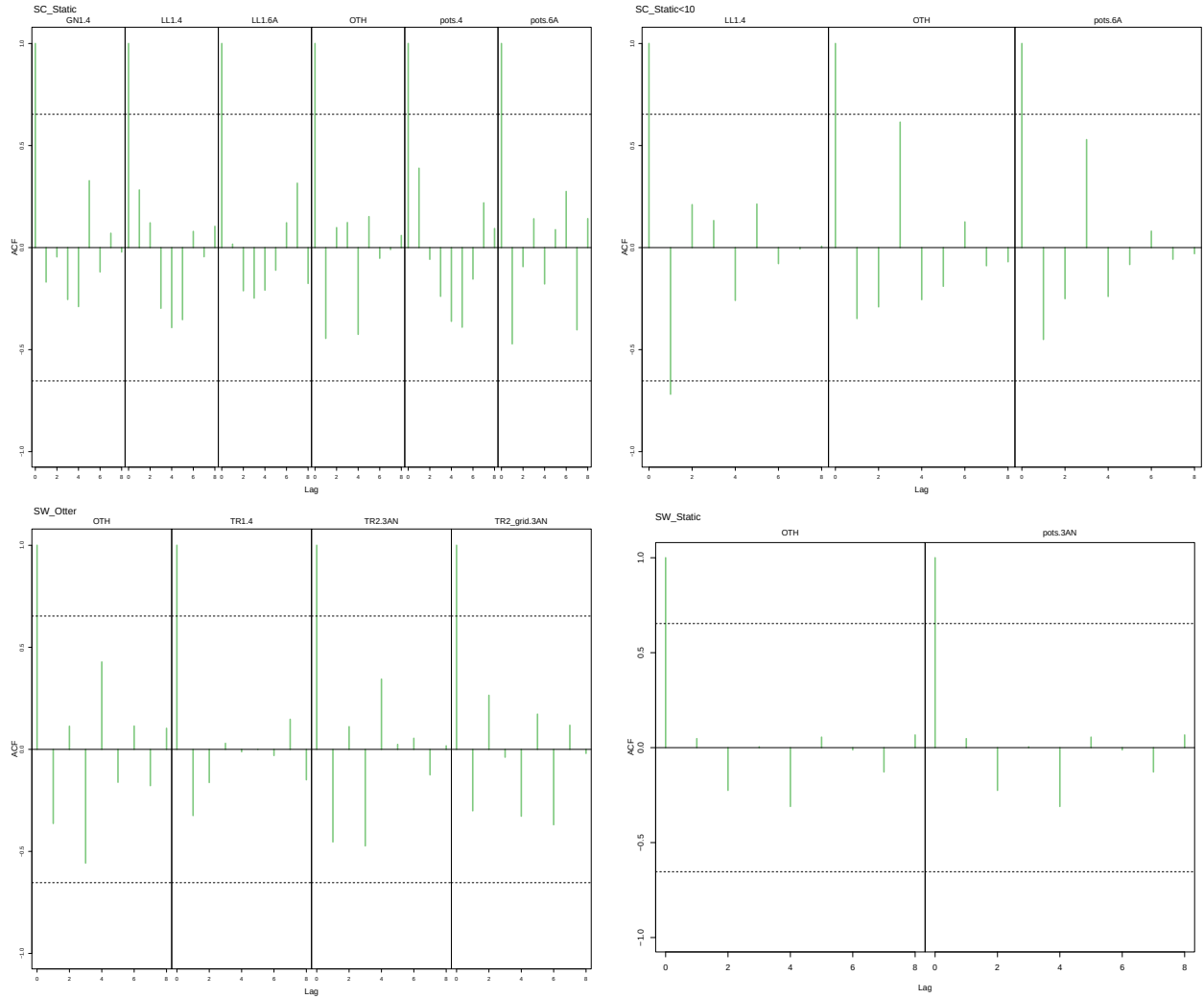


Figure 5 (continued): Autocorrelation in the the current status-quo effortshare standardized residuals. The dimension "row" (green) corresponds to the correlation across years. The maximum lag is set to be the number of years in series minus 2, because no status Quo for the first year can be applied, and lag only occurs after the first year. The dashed horizontal lines represent the 95% confidence interval. Correlations beyond these lines are therefore considered non-zero.

SENSITIVITY OF THE NORTH SEA MIXFISH FORECAST TO UNCERTAINTIES IN FUTURE LANDING SHARES PER FLEET (TASK 3)

Thomas Brunel¹

One of the key assumptions in the mixed fisheries models used to provide the ICES advice is about how the TAC advice for each stock is allocated in quotas for the different fleets. For each fleet, the fishing effort corresponding these quotas for each of the stocks are calculated, and used as the basis for the different mixed fisheries scenarios (i.e. "MIN", "MAX"...). The assumption made at WGMIXFISH is that future landing shares (for the present year and the next year for which the advice applies) are equal to the landing shares in the last year where data are available (typically the year prior to the current year). This document presents an evaluation of the uncertainty in the future landing shares related to this *status quo* assumption and compares it with uncertainty from alternative assumptions based on past landing shares. Additionally, the document explores a different approach to future allocation, based on the actual historic quotas per country rather than observed landings per fleet..

1 TASK 3.1 : UNCERTAINTY IN CURRENT ASSUMPTION ON LANDING SHARES

The analysis is based on the catch and effort data per fleet collated for the 2022 North Sea mixed fisheries advice. The so-call "fleet object" contains detailed information (landings/discards number at age, effort, catchability...) on the activity of the fleets, covering the period 2012 to 2021.

1.1 VARIABILITY IN HISTORICAL LANDING SHARES

To get a first idea of what might be a good assumption for future landing shares, it can be useful to look at the historical variations in the landing shares per fleet.

Figure 1 presents three contrasting examples of temporal variability in landing shares. It illustrates how the landing shares per fleet can vary in relation to changes in the national shares, and changes in allocation between fleets within countries.

In the case of the landing shares of North Sea for the Dutch fleet, values are rather stable in time, with a slight increase for the larger beam trawlers and a slight decrease for the medium sized ones (first row). This pattern is the consequence of a slight increase in the Dutch contribution to the total landings for this stock (second row) and stable distribution of the national landings across fleet (with a slight increase for the larger vessels, and a corresponding decrease in the mid-sized vessels).

In the case of the French landing shares of Eastern Channel plaice, the proportions of the total landings taken by these fleets decreased for all fleets (top row), but had a sudden increase in 2018 for the main fleet (Otter trawlers). The French contribution to the landings also showed a jump in 2018, after a period of constant decrease (second row). When this increase occurred in 2018, the part of the French landings taken by the otter trawlers increased.

For landing shares of haddock for the Scottish fleets showed a strong temporal trend, with an increase for the larger otter trawlers, and a decrease of the smaller ones. This was mainly the results of changes

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in the contribution of these two fleets to the Scottish catch, and not to changes in the UK share (mostly Scotland) which was overall stable over this period.

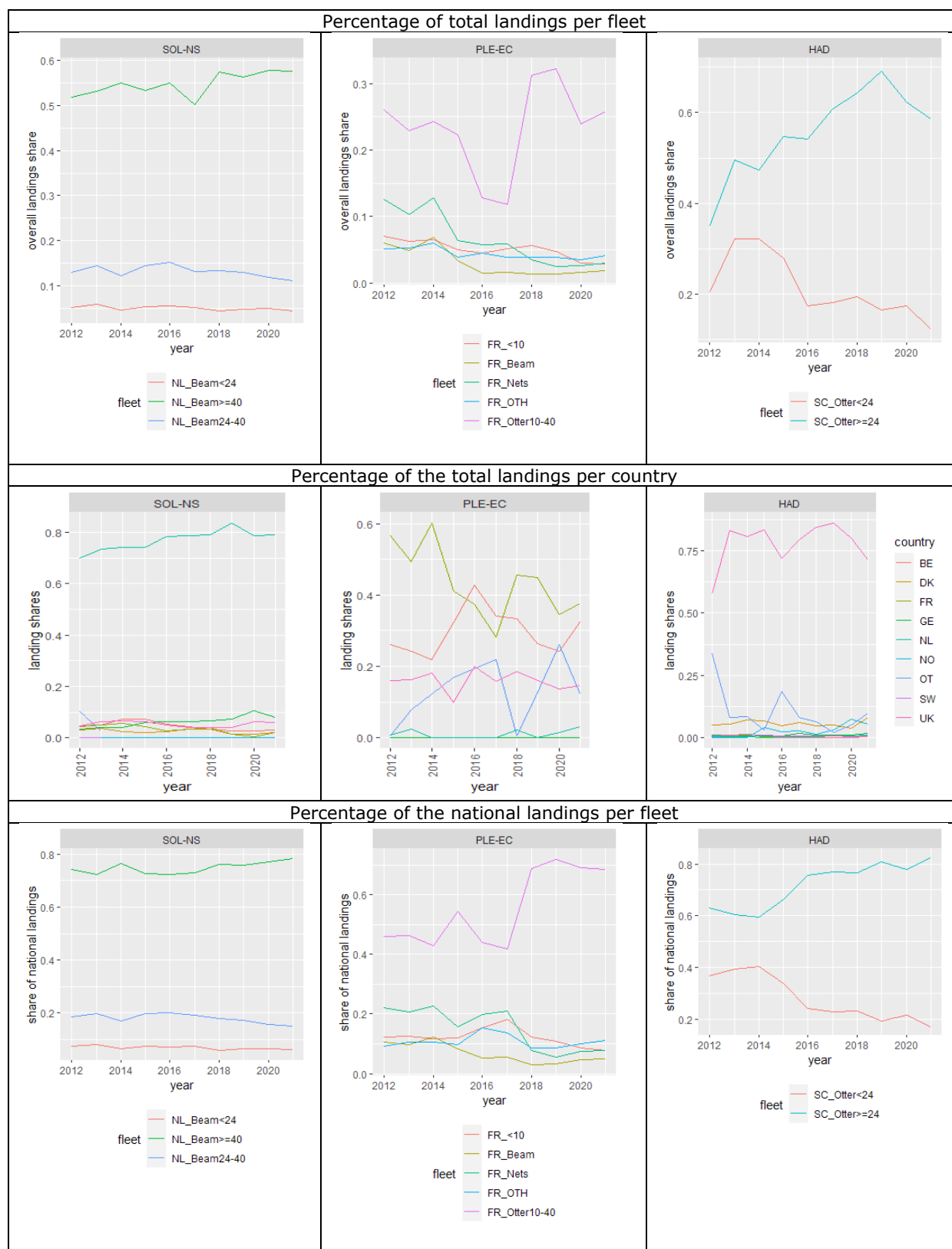


Figure 1 : illustration of the temporal variability in landing shares (first row) in relation to the variability in allocation of landings between countries (second row), and amongst fleets at the country level (third row) for three examples (North Sea sole for the Netherlands, Eastern Channel plaice for France and haddock for Scotland).

Based on these examples, it appears that in some cases, the assumption made in mixed fisheries models might be quite appropriate. For example, landing shares of sole for the Dutch fleet in a given year are probably very well approximated by landing shares two years earlier (i.e. time lag between advice year and last data year). However this assumption will potentially produce larger errors in the case of eastern channel plaice for the French otter trawlers, for which the landing shares are highly variable. For the landing shares of haddock for Scottish fleet, this assumption will result in a systematic error (bias), due to the strong trend in the data.

1.2 QUANTIFICATION OF THE UNCERTAINTY IN THE CURRENT ASSUMPTION FOR FUTURE LANDING SHARES AND IN ALTERNATIVE ASSUMPTIONS

The uncertainty associated to the assumption on future landing shares was examined by computing retrospectively the values corresponding to the assumption for a given year, and comparing it to the actual value, based on the data.

In addition to the assumption used at WGMIXFISH, three alternative assumptions were tested. The assumptions tested were :

- AR1 : the landing shares in year $y+1$ (for a given fleet and a given stock) is based on the prediction of an autoregressive model fitted on the proportions for the years 2012 to the year $y-1$.
- Ave : the landing shares in year $y+1$ (for a given fleet and a given stock) is based on the average of the three previous years
- Lm : the landing shares in year $y+1$ (for a given fleet and a given stock) is based on the prediction from a linear model fitted on the proportions for the years 2012 to the year $y-1$.
- sQ : the landing shares in year $y+1$ (for a given fleet and a given stock) is based on the values observed for $y-1$.

The predicted values based on these assumptions were calculated for each fleet and each stock for the years 2017 to 2021 (in order to leave enough years to fit the AR1 and Lm models).

To describe the predictive power of each assumption, the following indicators were calculated on a fleet/stock basis, based on the predictions for 2017 to 2021 :

- bias in prediction was measured by the average over the years of ratio of the predicted values over the observed ones. A mean ratio of 1 indicates that the prediction is unbiased, a ratio larger than 1 indicates over-estimation (and conversely lower than 1 indicates under-estimation).
- Error magnitude was measured as the mean of the absolute percentage error (MAPE). The value of the MAPE indicates by how much, on average, the prediction differs from the observed, as a percentage of the observed value
- Error autocorrelation was measured by computing the temporal autocorrelation in the difference between prediction and observation, at a one-year lag.

Figure 2 shows the distribution of fleet specific values these three indicators for each stock. The distribution of the indicators values within each stock were often quite large (note that outliers were removed from figure 2 to improve readability) indicating that the performance of each assumption could be very different amongst the fleets for a given stock.

Overall, the bias appear to be small (most median values close to one), although in many cases, there were fleets with large positive or negative bias (e.g. values larger than 1.5 or lower than 0.5). The sQ assumption had in general a narrower distribution of value (although the Lm assumption also had for the some stocks), and a median of the values often the closest to 1. On the other hand AR1 and Ave had wide distribution and often median values further away from 1.

The magnitude of the error (MAPE) differed amongst stocks, with stocks such as cod, north sea sole or witch for which the median of the distribution was above a 50% error, and stocks such as North Sea plaice or Eastern channel sole for which the median was around 25%. None of the assumption performed clearly better than the others. Although the sQ assumption led to clearly lower MAPE values for some stocks (plaice and sole in the eastern channel), it did not perform clearly better than the other assumptions for the other stocks.

The 1 year lag autocorrelations also varied greatly amongst stocks with the median of the values are close to 0 (haddock, witch, plaice and sole in the Eastern channel) and stocks positive autocorrelation (cod). Negative autocorrelation was often observed for sQ assumption (North Sea plaice and sole, turbot, whiting, witch and Eastern channel sole).

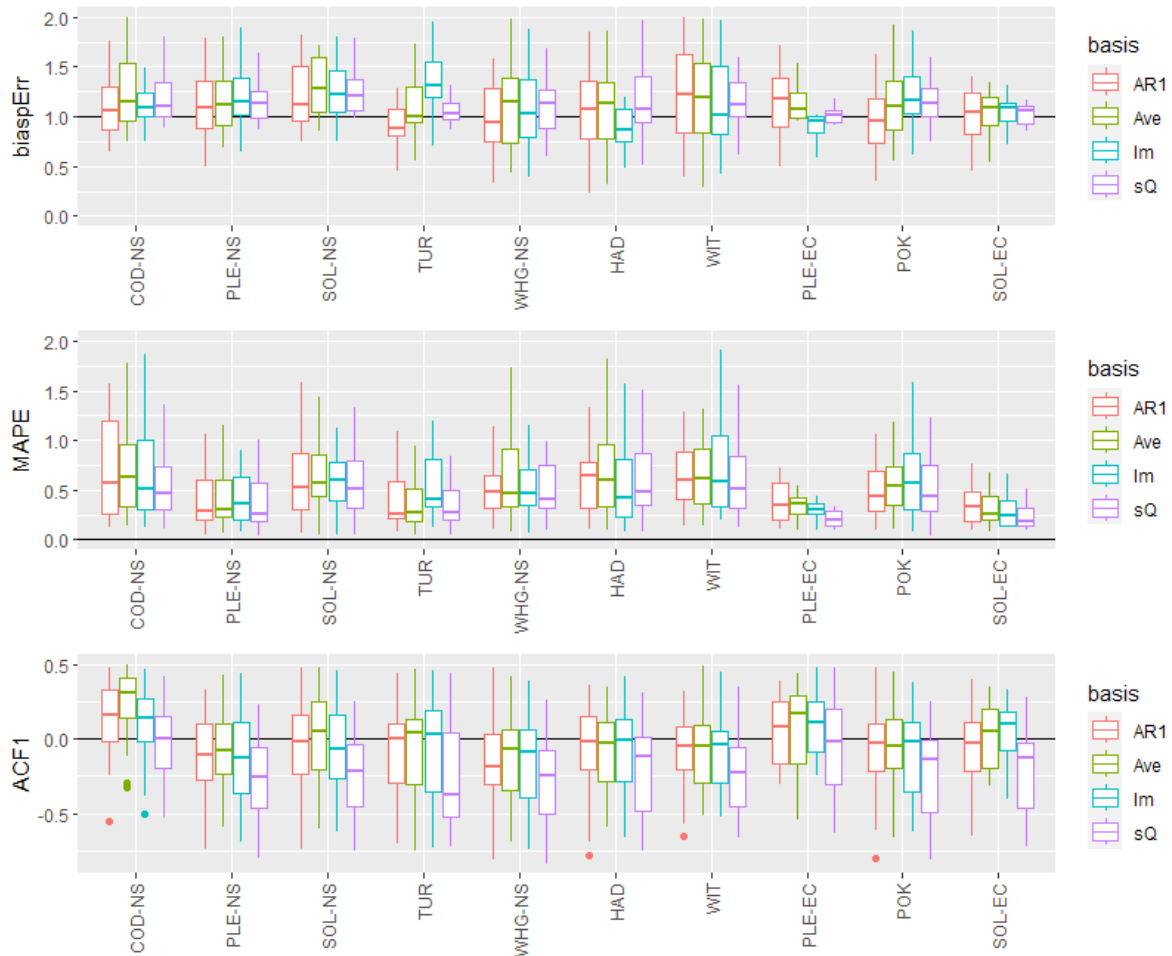


Figure 2 : distribution of indicators of bias, error magnitude and autocorrelation for predictions of fleets landing shares based on four different (see text for definition). Outliers were removed to improve the readability of the figure.

In order to get a more synthetic comparison of the performance of the 4 assumptions in predicting landing shares, the same approach as presented for catchability and effort share assumption was applied. It consisted in:

- ranking the four assumptions on the basis of their prediction error for each data point (year/fleet/stock combination) and looking which assumption ranks best overall,
- computing the average rank for each assumption,
- looking at which assumption gets the lowest MAPE, either fleet by fleet, or stock by stock.

The overall comparison of the performance of the assumptions showed that the sQ assumption performed best in 55% of the cases (smaller prediction error for a larger proportion of the fleet/stock combinations). The sQ assumption also performs best in term of mean error (lowest MAPE) and average rank. The performance of the other assumptions is lower, and none of the three is clearly better than the two others.

Table 1 : ranking of the performance of the 4 assumptions in predicting future landing shares, based on all fleets and stocks. P(Best) : proportion of the fleet/stock combination for which each assumption give the best prediction ; MAPE : mean absolute percentage error ; mean rank : mean across all fleet/stock combinations of the rank of each assumption.

	p(Best)	MAPE	Mean rank
AR1	15.6 %	48.1 %	2.9
Im	19.5 %	52.6 %	2.6
Ave	15.7 %	43.4 %	2.7
sQ	55.3 %	39.7 %	1.8

2 TASK 3.2 : FORMULATING ALTERNATIVE SCENARIOS USING THE FIDES DATABASE

At WGMIXFISH, it is common practice to allocate TACs to countries and fleets based on the latest available landing data. However, some stakeholders in the North Sea have challenged this approach, arguing that their landings do not accurately reflect their quota shares for certain species, like cod. This can lead to incorrect assessments of the choking effect of these stocks, as some countries' true quota shares may be higher than estimated based on recent landings.

To address this issue, WGMIXFISH explored using information on actual fishing quotas and exchanges to better reflect each country's actual fishing opportunities. They turned to the Fisheries Data Exchange System (FIDES), which contains annual records of quotas and transfers for all species managed under a quota regime in the EU.

Although WGMIXFISH initially used this data in their mixed-fisheries advice for 2019 and 2020, they later withdrew it for unknown reasons. In this section, we revisit the potential usefulness of FIDES for making assumptions about future quota allocations in mixed-fisheries models.

2.1 CONTENT OF THE FIDES DATABASE

2.1.1 Reconstruction of quotas per stock

The data from FIDES contains annual quotas (initial and final, after transfers and exchanges) per country by species and for the different management areas for the different commercial species. The North Sea mixed fisheries model takes into account the fleets active in the North Sea (defined as covering areas 7d, 4 and 3a) and also incorporates for each country, the "other" fleet that aggregates all the catches taken outside the North Sea for those stocks that have a distribution wider than the North Sea (e.g. saithe and haddock also distributed in 6a). The mixed fisheries model also has a fleet named "OTHER" that mainly

accounts for the catches of Norway (for which no detail data is available to WGMIXFISH, until 2022) and an aggregation of all the minor métiers.

A first step to the utilisation of FIDES in mixed-fisheries models consisted in making a selection of the quotas in the database that correspond to the stocks modelled by WGMIXFISH. In some instances, quantities appeared twice in FIDES and a selection of the relevant occurrence had to be made. That was mainly the case of stocks for which part of the TAC from EU countries were taken in Norwegian waters (e.g North Sea plaice, Saithe prior to 2018), but not discounted from the quotas listed in EU waters. For the more recent years, the EU quotas in Norwegian water were already subtracted from the quotas in EU waters.

Overall, there was a good agreement (figure 3) between the sum of the initial quotas in the FIDES database and the agreed TAC (as published in the ICES advice sheets). There was only one noticeable difference, for North Sea plaice in 2019, which was a year where only part of the EU quota taken in Norwegian waters was removed from the quotas in EU waters.

The sum of the final quotas, however, frequently exceeded the initial quotas. There must be quota transfers from area to area that we are not able to track. But that suggests that the TAC that is set in MIXFISH equal to advices, may not correspond to the sum of the real quotas available to the fleets

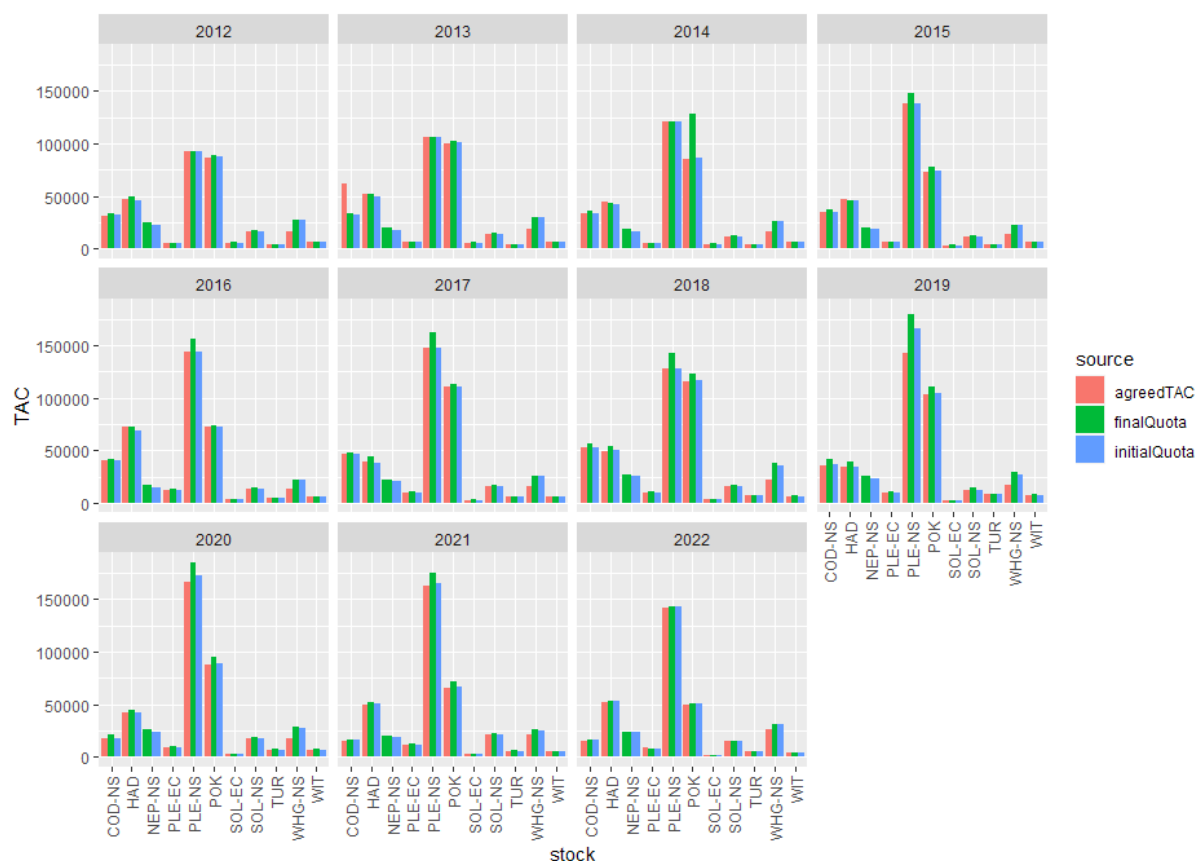


Figure 3 : comparison of the agreed TAC and the sum of the quotas (initial and final) from the FIDES database for the stocks included in the North Sea mixed fisheries model.

2.1.2 Quota transfers and exchanges :

The figure 4 shows that the sum of the quota acquisitions (positive differences between final and initial quota) is always larger than the sum of quota sold or traded (negative bars) for the stocks considered in

the mixed fisheries models. There are differences amongst countries, with France and to a lesser extent Germany generally trading quota, while UK, Denmark and the Netherlands generally acquiring quota.

These differences between initial and final quotas in the FIDES databased were compared with the reports on quota swaps² in the case of the Netherlands, for the year 2018 (figure 5). Both sources broadly agreed. They indicate that the Netherlands exchanged around 2000t of the North Sea cod quota and acquired plaice quota, although the amounts different (11 000t according to FIDES, compared to 5500 t from the swap records).

A number of reasons may explain this unbalance between quota acquisition and quota trade, but they could not be investigated fully here. Those differences could be linked, for example, to transfers from other areas, to exchanges involving stocks that were not included in this analysis (because they are not part of the North Sea mixed fisheries model, such as the pelagic stocks), or to interannual transfers.

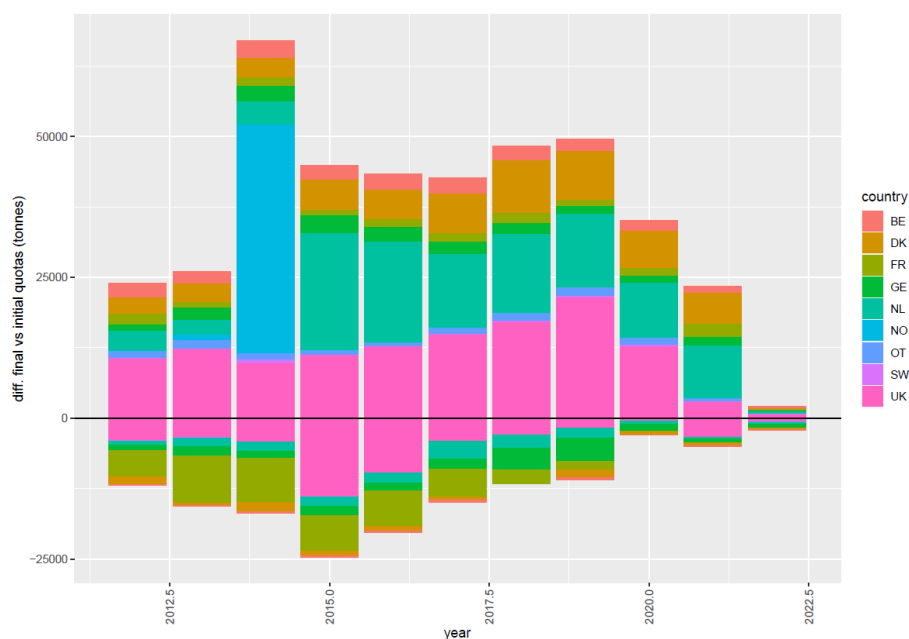


Figure 4 : cumulated positive (bars above 0) and negative (bars below 0) differences between final quotas and initial quotas per country

²https://circabc.europa.eu/ui/group/9d6098eb-e128-45ae-a4ca-5703b31d8257/library/2bcbd1b1-521e-48a1-9f82-7d42ad72e475?p=1&n=10&sort=modified_DESC

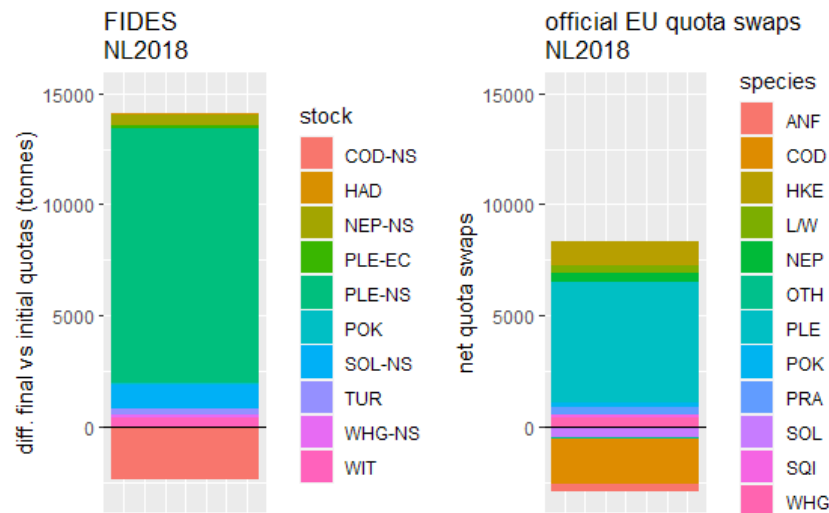


Figure 5 : cumulated positive and negative differences between final and initial quota from the FIDES database for the Netherlands in 2018 (left) and net quota swaps for the Netherlands in 2018 from EU reports on quota swaps

2.1.3 quota consumption

Quota consumption expressed using as reference the initial quota often show values very different from 100% (value of 1 on figure 6), but after quota exchange, values get closer to 100%. For example in the case of cod, the Netherlands use typically around 50% of their initial quota, but after quota exchange, they use almost always close to 100% of their final quota. On the other hand, the UK who are acquiring quota (partly from the Netherlands) are able to have almost no overshoot of their final quota (while the initial quotas would have been overshoot). Other examples where countries were able, though quota exchange, to adjust their final quotas to their needs include UK, Denmark and the Netherlands for Saithe, the Netherlands for eastern Channel plaice (initial quota of 0) of France with North Sea sole.

There are also several instances where undershot (both based on initial and final quotas), as for example North Sea plaice (especially in the recent years) or haddock.

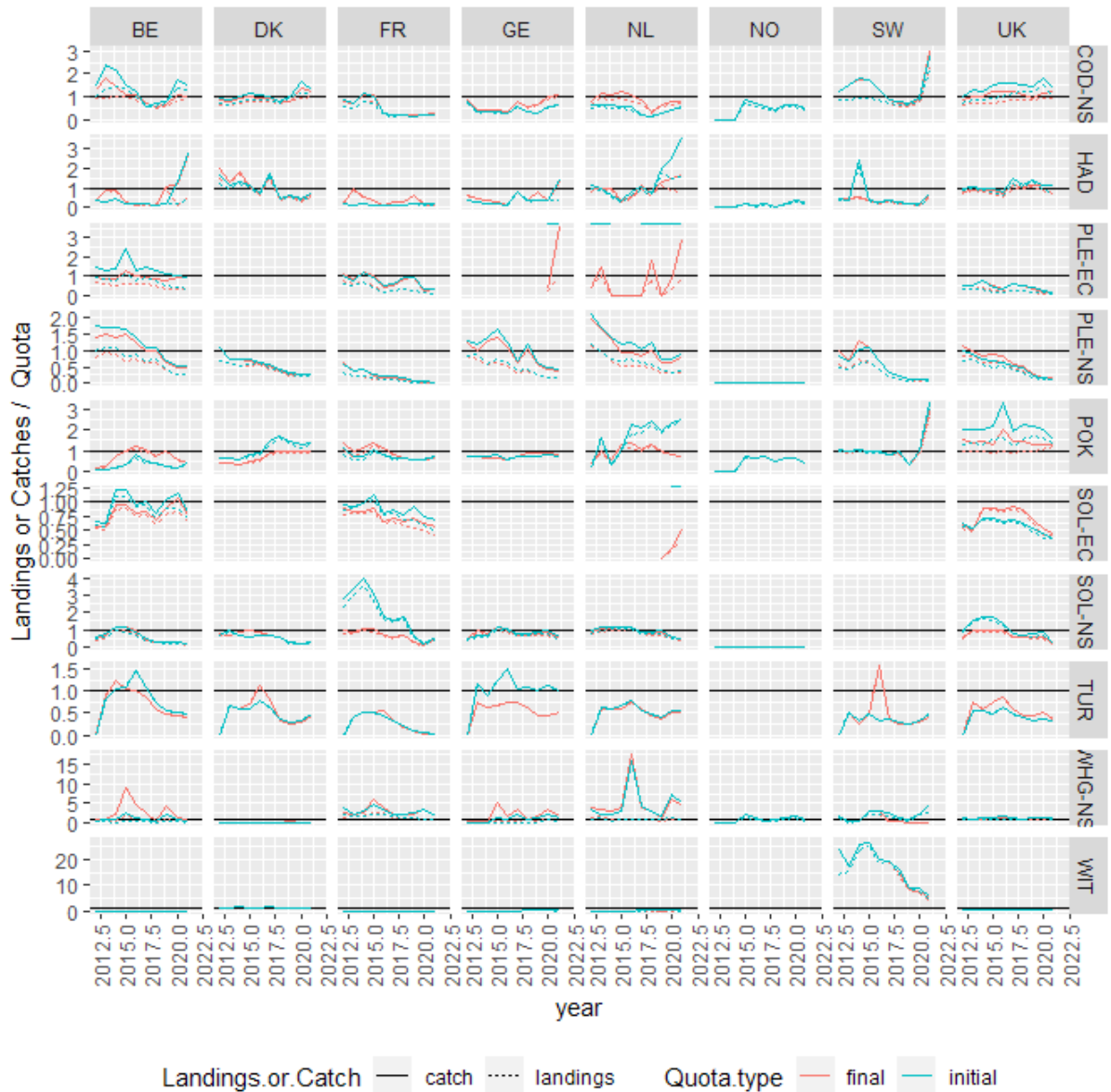


Figure 6 : rate of quota consumption (national level) expressed as realised catch or landings (solid and dasher lines respectively) expressed as a proportion of initial or final quotas (red and blue respectively). Note that for turbot and witch, this figure is not relevant since there are not TAC defined specifically for these stocks (combined TAC). Note also that for whiting, the area 7d is part of the quota for area 7, which is not included in the calculations here, which explain the very high consumption rates.

2.2 PROPOSING ALTERNATIVE ASSUMPTIONS FOR FUTURE LANDING SHARES

Using a similar approach as in section 1, the performance of two assumptions for future landing shares, based on FIDES initial and final quotas, was assessed, against the sQ assumption currently used at WGMIXFISH. As fishing quotas are defined at the country level (the further allocation between fleets being the responsibility of each member state), the analysis was conducted at the country level (i.e. landing shares are here shares per country and not per fishing fleet). The two alternative assumptions for future landing shares that were tested against the sQ one were:

- TAC shares based *initial* quotas in FIDES (from year minus one), which would represent the official allocation keys

- TAC shares based *final* quotas in FIDES (from year minus one), which would represent the official allocation keys and the most recent quota trading practices.

The figure 7 shows, per country and stock, the differences between the predicted and observed landing shares for each of the 3 assumptions (expressed as a proportion of the mean landing share per country/fleet). In general, using the most recent landing shares as a predictor for future values is the best performing assumption. In many cases, the three assumptions seem to perform similarly (eg. Cod and haddock for UK, North Sea plaice and sole for the Netherlands). In other occasions, both assumptions based on FIDES provide a clearly wrong basis for prediction (North Sea plaice and cod for France). In some occasions, predictions based on final quota in FIDES and the sQ assumption perform equally well (cod for the Netherlands, whiting for Germany and Belgium).

Overall, the average error (figure 8) is lower for the sQ assumption, higher for the assumption using final quotas, and the highest for the assumption using initial quotas.



Figure 7 : prediction error relative to mean landing share ($(pred. - obs.)/mean(obs.)$) for the current assumption based on landing shares, and the assumptions based on FIDES quotas.

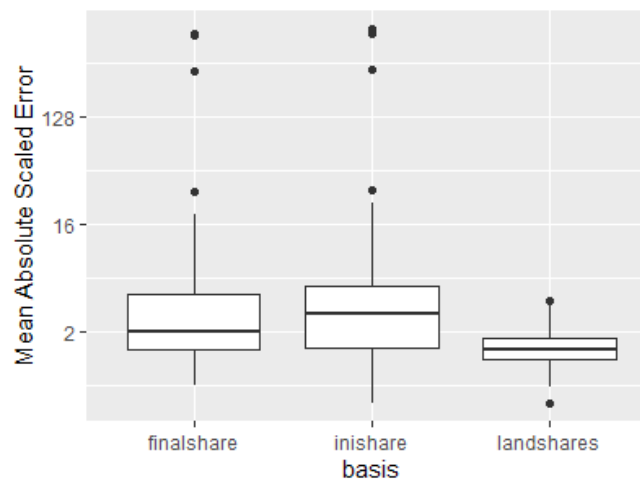


Figure 8 : distribution of the mean error for the 3 assumptions

3 CONCLUSION

- Uncertainty associated to the current assumption on landing shares

The current assumption seems to provide a generally unbiased prediction for future landing shares (although some bias can occur for some stocks), but has variable levels of uncertainty associated (on average, mean error between 20% and 50% but can be higher). There is also a large variability around these overall values. Most of the very high values occasionally observed, often correspond to fleets that have very small (or no) landings share for a particular stock, and for which an minimal increase in landing shares would correspond to a very large proportion of their average share. Overall, autocorrelation in error is negative, meaning that a larger error one year tends to be followed by a small error (or possibly of the opposite sign) the following year.

- Alternative assumptions using recent landing data

The assumptions alternative to sQ shares do not, overall provide a better basis. The ranking of the assumptions gives a clear advantage to the currently used one. This means that although landing shares are difficult to predict, the best approximation for future values is the latest observed one.

On the fleet by fleet basis, there is a small percentage of the cases where an alternative assumption performs better than the one currently used. However, it does not seem realistic to use case specific assumptions (e.g. the best performing one for each fleet/stock combination), as the best assumption may vary from year to year, and this can only be assessed retrospectively.

- Alternative assumptions using official quotas

The exploration of the FIDES database indicated that initial quotas are usually in line with the agreed TACs, but that cumulated quotas after exchange can sometimes be higher. None of the two alternative assumptions to predict future landing shares based on quotas from FIDES provided a better basis than the one currently used at WGMIXFISH. The initial quotas before exchanges are clearly not a good basis for assumptions on future landings shares, as countries generally exchange large quantities to accommodate the needs of their fleets (to increase their fishing opportunities of their target stocks or anticipate the risk of being choked by certain stocks). Final quotas after exchange are also not a better

basis, as countries maybe still – consistently through the years – over (or, less likely, underuse) their fishing opportunities.

- Scenarios to be test as sensitivity test

In order to assess the sensitivity of the mixed fisheries forecast to the assumption on landing shares, two sensitivity tests will be conducted, in which the model will be run using the current assumption and alternative one and the different model output (landings per stocks, fleet efforts) will be compared.

- o Considering that none of the alternative assumptions using past landing shares give a better basis than the current assumption, none of these assumptions will be used as the basis for a sensitivity test. Instead, as a way to quantify the impact of the actual error in the current assumption for landing shares, a first sensitivity test will consist in comparing a run in which the sQ assumption is used, with a run in which the actual observed landing shares are used. This will be done by using the data from the 2022 WGMIXFISH (last data year 2021) and running the model using the configuration used for the 2021 advice. A second run will then be done replacing the sQ assumption for landing shares in 2022 by the actual values.
- o Although this was not observed in our results (nor was it carefully analysed), one can imagine situations where landing shares based on official allocation keys (initial quotas in FIDES) could represent a plausible (or at least worth investigating) scenario. For examples in cases where a stock suddenly becomes limiting for all fleets (after a strong drop in advice for example), countries normally trading their quotas may tend to keep it to prevent any potential choke effect. The second sensitivity test will consist in rerunning the model with the same configuration as for the 2022 advice, but replacing the sQ assumption by an assumption in which landings shares at the country level are based on initial quota shares from FIDES.

ANNEX 12: SENSITIVITY OF FLBEIA OUTPUT TO THE STATUS-QUO ASSUMPTIONS MADE FOR CATCHABILITY, EFFORT PROPORTIONS AND LANDING PROPORTIONS FOR THE NORTH SEA CASE STUDY INTRODUCTION

The results of Tasks 3.1 and 3.2 highlighted that the status-quo assumption in the North Sea mixed fisheries model is the most robust compared to three other assumptions explored to configure future catchability, effort proportions per métier and landing proportions per fleet in the mixed fisheries model. It is therefore of interest to test how this assumption affects the outcome of mixed fisheries scenarios used for considerations. One way to do this is to compare mixed fisheries projections done using true parameter values with projections done using status-quo assumption for these parameters. To have multiple points for comparison, the model can be run for 5 different starting years (Figure 1) to produce 5 sets of results, both for the assumption and for the true parameter values.

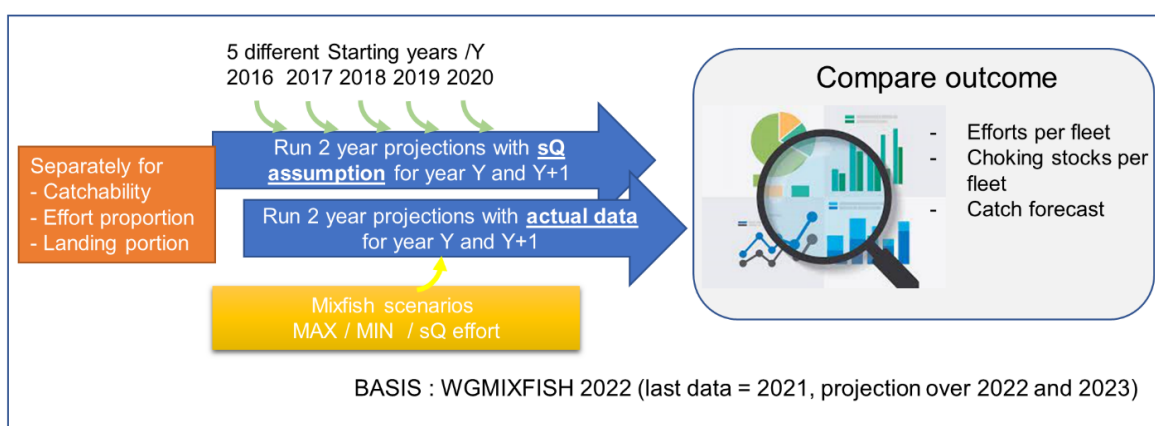


Figure 1: Retrospective approach to test the sensitivity of mixed fisheries projections to the assumption made on key parameters for the North Sea case study

This approach does not intend to reproduce past mixed-fisheries considerations. Firstly, because the framework has changed recently, and only the considerations of the last two years was based on FLBEIA runs. Secondly, because this would require a full reconditioning of the model for each retrospective run (including the selection of the fleets and collation of the corresponding data) which is a substantial task. However, since the aim was to compare the model outcome with the status quo assumption for model conditioning, or with the real data, it was not necessary for the considerations to be identically reproduced.

1 APPROACH

Using the North Sea mixed fisheries model conditioned in 2022, true values for catchability, effort and landings proportions are available up to 2021 (last data year). We performed a five-year retrospective analysis where a three-year projection was run starting at different historical time (2020 to 2016, Figure 1). For each starting year, the model was run once with the parameter values unaltered (true values), and a second time after applying the status quo assumption, i.e. parameter values for the starting year and the following one were set equal to the value in the year preceding the starting year, as would be the case in a real situation for the last year of data available. This is similarly to what is done when configuring the mixed-fisheries models to produce considerations. Each of the runs above (5 starting years, true vs. assumed parameters) were repeated for different mixed fisheries scenarios. However, the mixed fisheries scenarios run differed according to the parameter of interest, as explained below.

1.1 Scenarios to test sensitivity to catchability and effort proportions assumptions

Running the three mixed fisheries scenarios currently used in the mixed fisheries considerations (i.e. 'min', 'max', and 'status-quo effort') is not relevant for all parameters.

Indeed, for catchability, the 'true' values of catchability per métier are calculated as a function of observed catch, observed effort per métier, and stock biomass. As a result, if one of these variables changes, the catchability will also change. In the three mixed fisheries scenarios used for mixed fisheries considerations, the effort will vary depending on the scenario. In the status-quo effort scenario, the effort is set to the last observed effort. In the min scenario, the effort per fleet stops as soon as the first stock share of that fleet has been caught; and in the max scenario, the effort per fleet corresponds to the effort needed for all stock shares of the fleet to be caught. In addition, in the min and max scenarios, the catch target in the stock advice year is set to be the stock advice catch for the stocks included in the model. The biomass of the stocks in the model will also be affected by the changes in effort and catch in each scenario. Because of the changes in effort, biomass and catches, the true catchability estimated from observed data is not true anymore. A similar reasoning applies when testing of the sensitivity to effort proportion per métier.

To test the sensitivity of the catchability and effort proportions assumptions in the mixed fisheries projections, it is therefore necessary to run a fixed effort scenario set to the true observed effort to keep the consistency between the effort, catches, and biomass in the model. For these two parameters, the only valid scenario to test the sensitivity to the status quo assumption is therefore running with the actual observed efforts of the fleets.

1.2 Scenarios to test Sensitivity to stock landing proportions per fleet

Regarding the sensitivity to the assumption on future landing proportions per fleet, the situation is the opposite. The landings proportions affect the quotas that are allocated to each fleet for all stocks, which in turn define the effort per fleet in the 'min' and the 'max' scenario. Therefore, the assumption on landing proportions will have an impact on the outcome of these two scenarios. For the status quo effort scenario, or a scenario using the actual realized effort, future effort is set and is therefore independent from the quotas per fleet. The outcome of such a scenario is therefore per definition insensitive to the assumed landing proportions, and this scenario will not be run in this case.

1.3 Error quantification

To quantify the sensitivity of the model output to the assumptions on model configuration, we compare the catches in the stock advice year per stock and the SSB per stock in the stock advice year +1 for the run done using a status quo assumption for the parameter and the run using the actual value. When 'max' and 'min' scenarios are run, efforts per fleets are also compared. For each of these quantities, we compute the relative error expressed as:

$$\text{Relative error} = (\text{quantity}_{\text{SQ assumption}} - \text{quantity}_{\text{true}}) / \text{quantity}_{\text{true}}$$

In order to summarize the value of these errors across the 5 runs (retro years), the mean percentage error is computed as a measure of overall bias (value close to zero means no bias). The mean of the absolute percentage error (or MAPE) is also calculated as a measure of the magnitude of the error.

In addition, when 'max' and 'min' are run, we extract the most and least limiting stocks. When only the set effort scenario is run, we calculate a proxy for choke and least limiting species by extracting the stock with the minimal and maximal quota uptake per fleet. We then compare the results for both assumptions.

2 RESULTS

2.1 Catchability assumption

Errors in catch in the stock advice year due to the status-quo catchability assumption is largest for the Nephrops stocks in FU32 (NEP32) and other parts of the North Sea (NEPOTH-NS, Figure 1). This is mainly due to the fact that these stocks often have a catchability of zero back in time (more often than for the other stocks). It is therefore an artifact due to the non-reconditioning of our model when run back in time. In practice, the stocks with null catchability for specific métier (no catches in the terminal year) would be removed as caught stocks for this métier when conditioning the model.

Error in advised catch for the fish species is lower and overall less than 25 % (median estimate, Figure 2). In terms of mean and mean absolute relative errors across retrospective years, the mean error is below 30% for most roundfish stocks and below 20 % for flatfish (Table 1). The error increases slightly for some stocks when computed on the absolute scale.

Median relative error in spawning stock biomass (SSB) due to the status-quo catchability assumption is below 20% for all stocks (Figure 3). Mean relative error is less than -15 % for all stocks but this increase to a maximum of 21 % when on the absolute scale (Table 2).

Comparing the proxies for choke and least limiting species between the two catchability assumptions illustrate very limited differences due to assuming status-quo catchability in the mixed fisheries projections (Figure 4). This is explained by a majority of fleets for which the choke or least limiting stocks are unchanged between catchability assumptions (Figure 5). For instance, in stock advice year 2021, 30 out of 46 fleets have the same choke species between catchability assumptions and 33 out of 46 have the same least limiting stock.

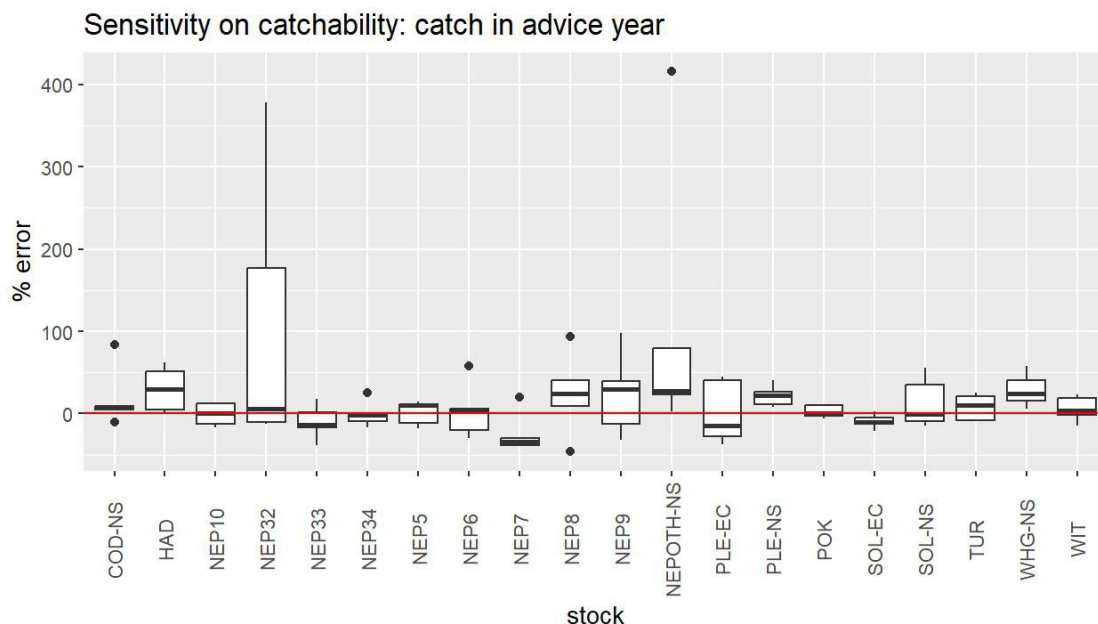


Figure 1: Relative error in catch (%) in the stock advice year due to using status quo catchability for all species in the North Sea model

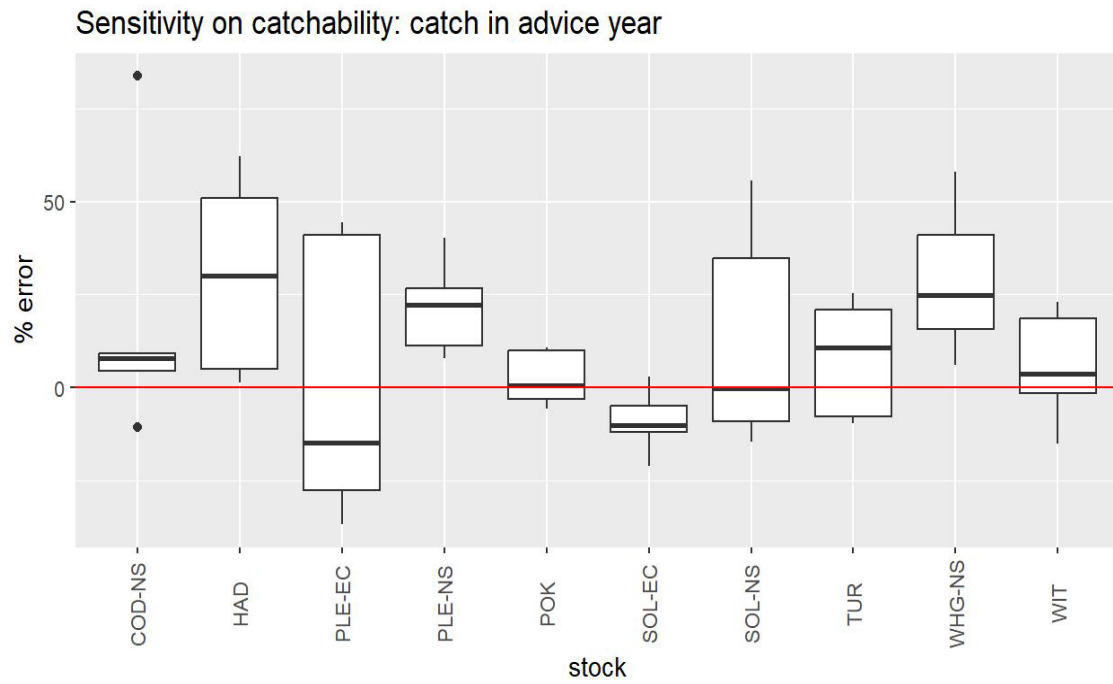


Figure 2: Error in catch (%) in the stock advice year due to using status quo catchability for all fish species in the North Sea model

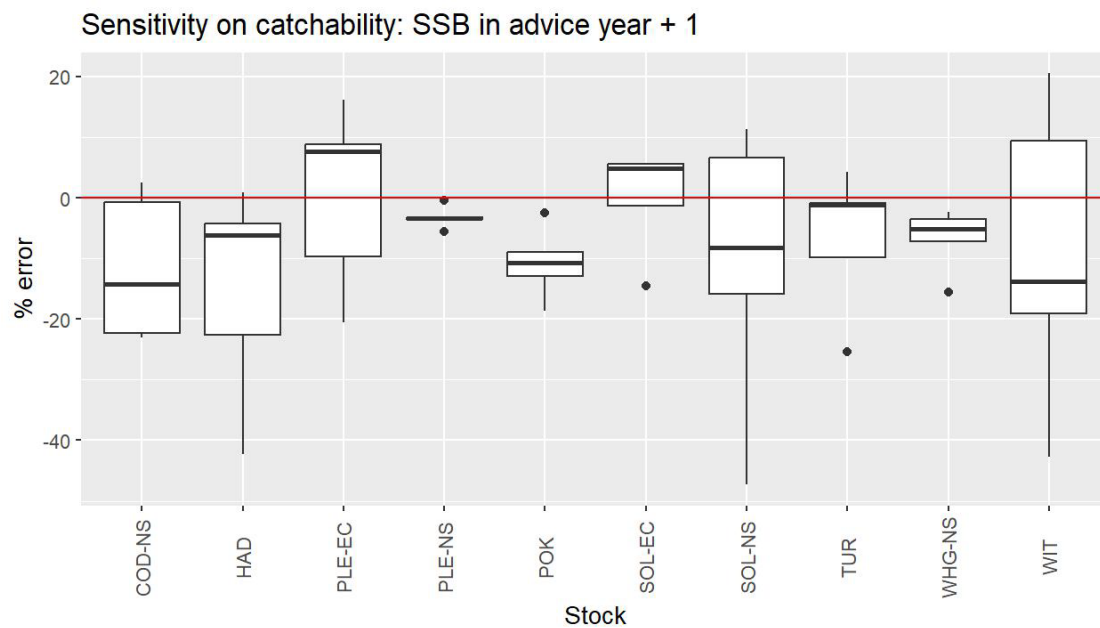


Figure 3: Error in SSB (%) in the year after the stock advice year due to using status quo catchability for all fish species in the North Sea model. The Nephrops stocks have a fixed population assumption in the forecast, so SSB is unchanged and not presented

Table 1: Mean percentage errors (MPE, %), and mean absolute percentage errors (MAPE, %) in catch considerations

stock	MPE	MAPE
COD-NS	18.9	23.1
HAD	29.9	29.9
NEP10	-0.7	11.3
NEP32	107.4	116.7
NEP33	-10.0	17.7
NEP34	-0.2	10.7
NEP5	1.4	13.0
NEP6	3.1	23.4
NEP7	-24.5	32.5
NEP8	24.2	42.8
NEP9	24.6	42.2
NEPOTH-NS	109.8	109.8
PLE-EC	1.2	33.0
PLE-NS	21.6	21.6
POK	2.5	6.0
SOL-EC	-9.1	10.3
SOL-NS	13.3	22.8
TUR	7.9	14.9
WHG-NS	29.1	29.1
WIT	5.7	12.4

Table 2: Mean relative errors (MPE, %), and mean absolute relative errors (MAPE, %) in SSB in the year after the considerations year

stock	MPE	MAPE
COD-NS	-11.6	12.6
HAD	-14.9	15.3
PLE-EC	0.5	12.6
PLE-NS	-3.2	3.2
POK	-10.7	10.7
SOL-EC	0.1	6.4
SOL-NS	-10.7	17.9
TUR	-6.6	8.3
WHG-NS	-6.7	6.7
WIT	-9.1	21.1

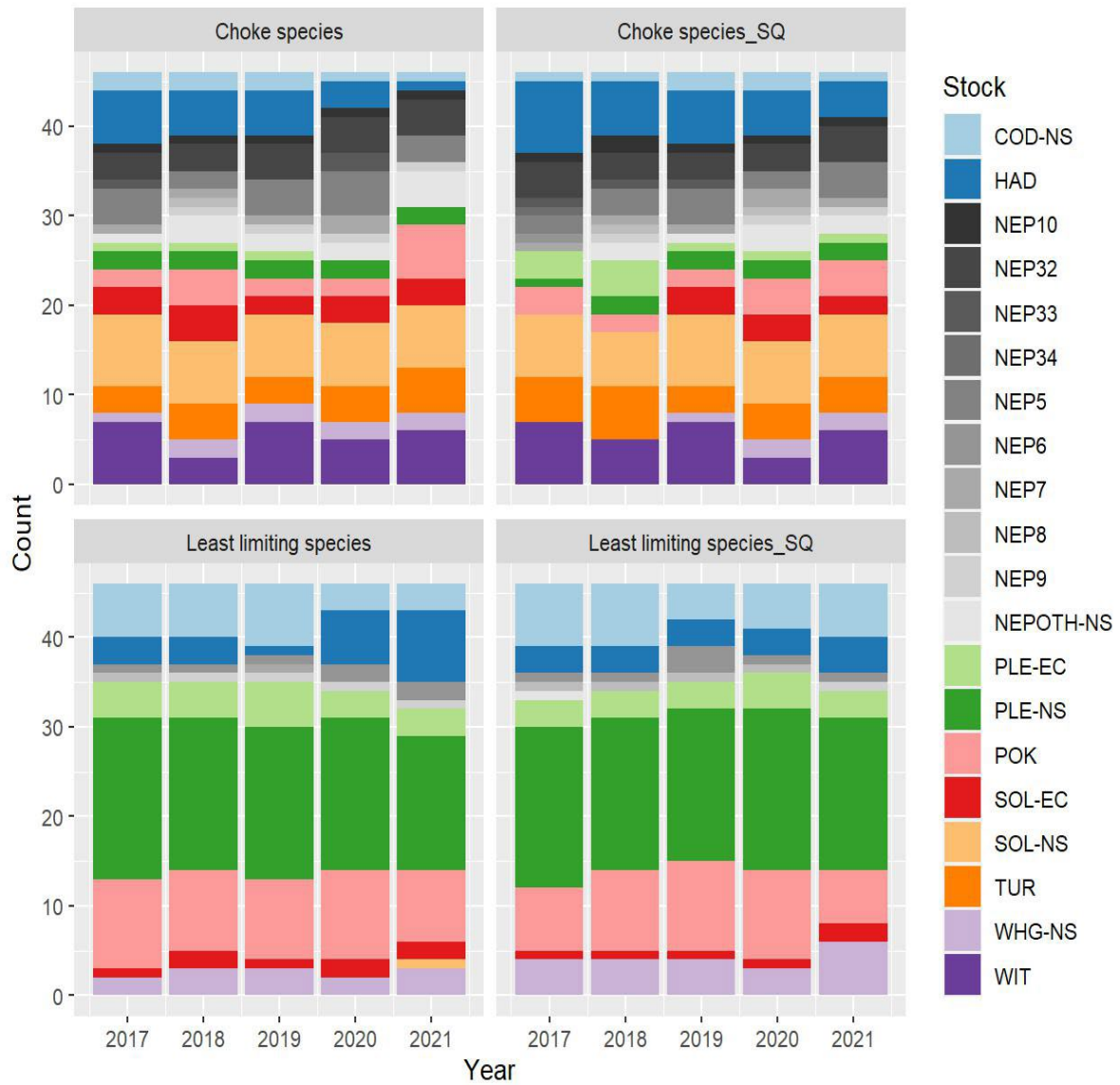


Figure 4: Choke and least limiting species proxy per catchability scenario. The year is the stock advice year. The first column are the results using true catchability. The second column are the results using status quo catchability. The choke species proxy corresponds to the stock with minimal catch in the stock advice year and the least is the one with maximal catch



Figure 5: Number of fleets where the catchability assumption changes or not the choke or least limiting stock proxy per considerations year.

2.2 Métiers effort proportion per fleet assumption

Errors in catch in the considerations year due to the status-quo effort proportions assumption is largest for the *Nephrops* stocks in FU33 (NEP33) and *Nephrops* stocks in FU8 (NEP, Figure 1).

Error in advised catch for the fish species is lower than for the *Nephrops* and at most 1.07 % (median estimate, Figure 2). In terms of mean and mean absolute relative errors across retrospective years, the mean error is below 4 % for all roundfish stocks and below 3.6 % for flatfish (3). The error increases slightly for some stocks when computed on the absolute scale.

Median relative error in SSB due to the status-quo effort proportions assumption is below 6 % for all stocks (median estimates Figure 3). Mean relative error is also less than -6 % for all stocks and increases to a maximum of 6.89% when on the absolute scale (4).

Comparing the proxies for choke and least limiting species between the two effort proportion assumptions illustrates very limited differences, due to assumed status-quo effort proportions in the mixed fisheries projections (Figure 4). This is explained by the majority of fleets for which the choke or least limiting stocks remaining unchanged between effort proportion assumptions (Figure 5). For instance, in considerations year 2021, 44 out of 46 fleets have the same choke species between effort proportion assumptions, furthermore, they have the same least limiting stock.

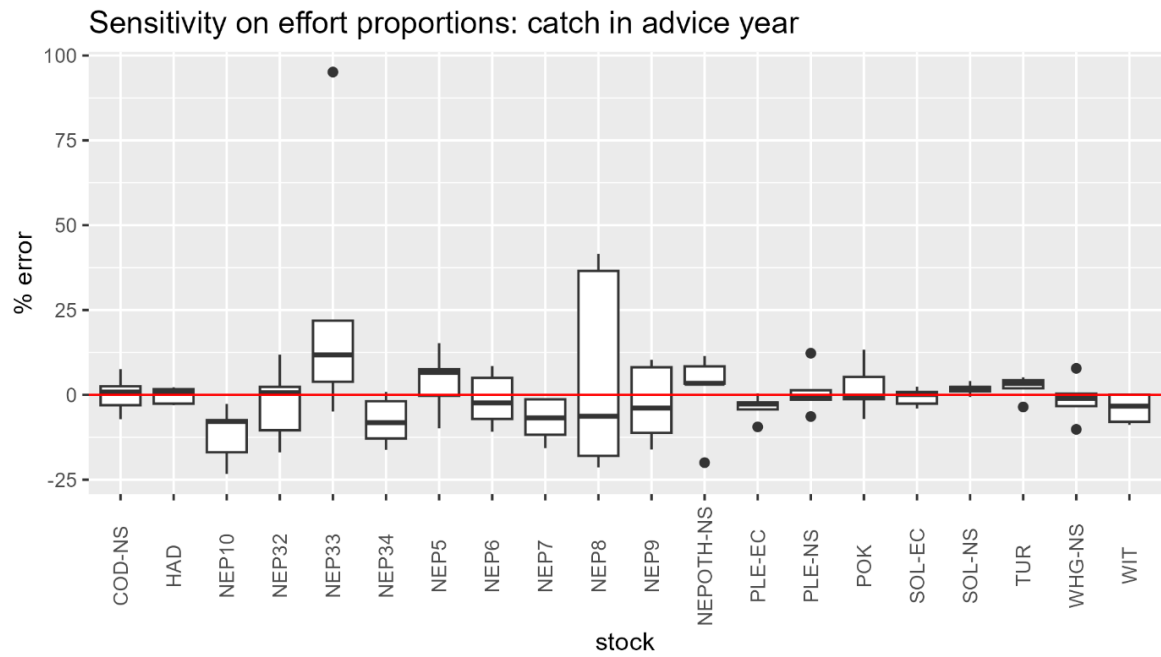


Figure 1: Relative error in catch (%) in the considerations year due to using status quo effort proportions for all species in the North Sea model.

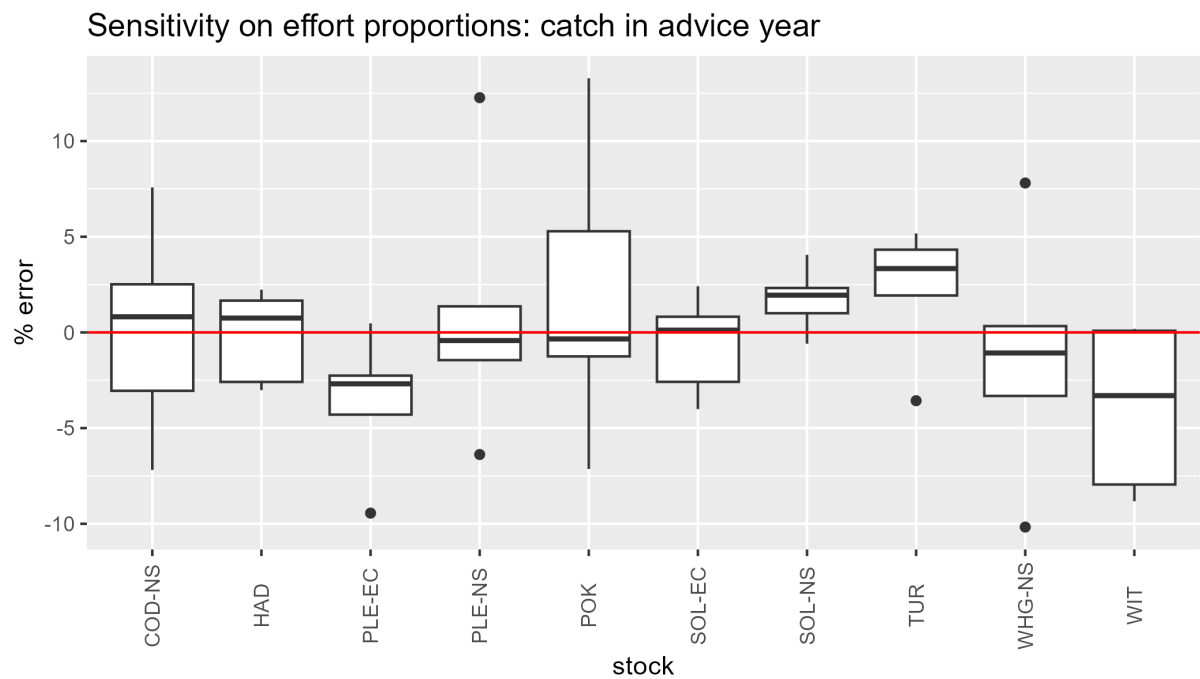


Figure 2: Error in catch (%) in the considerations year due to using status quo effort proportions for fish in the North Sea model.

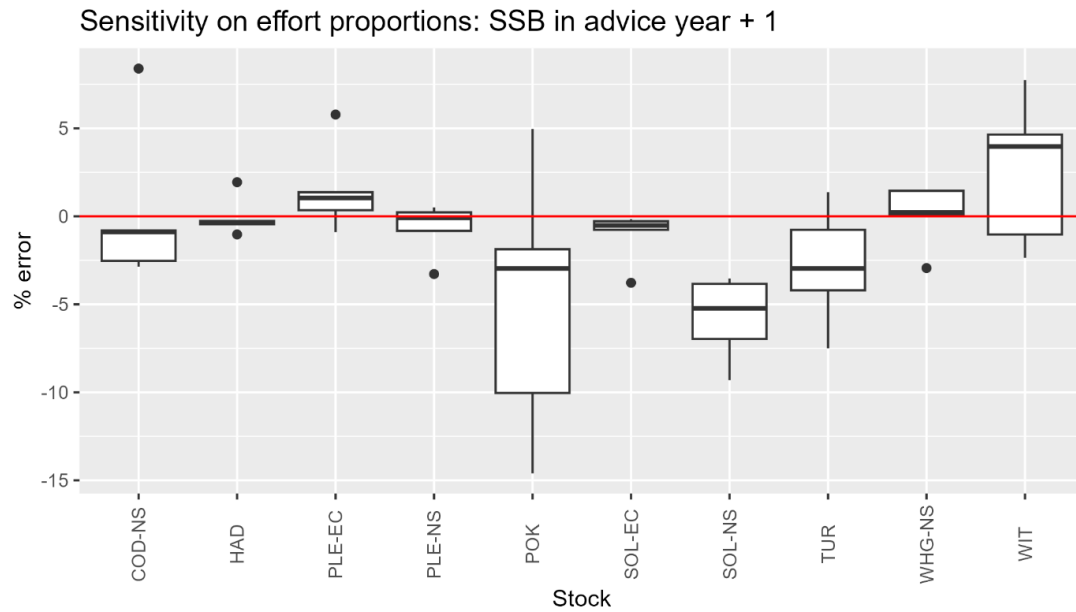


Figure 3: Error in SSB (%) in the year after the considerations year due to using status quo effort proportions for all fish species in the North Sea model. The *Nephrops* stocks have a fixed population assumption in the forecast, so SSB is unchanged and not presented.

Table 3: Mean percent errors (MPE, %), and mean absolute percent errors (MAPE, %) in catch considerations.

stock	MPE	MAPE
COD-NS	0.1	4.2
HAD	-0.2	2.0
NEP10	-11.7	11.7
NEP32	-2.5	8.4
NEP33	25.5	27.5
NEP34	-7.6	8.0
NEP5	3.9	7.9
NEP6	-1.4	6.8
NEP7	-7.3	7.3
NEP8	6.5	24.7
NEP9	-2.6	9.9
NEPOTH-NS	1.3	9.3
PLE-EC	-3.6	3.8
PLE-NS	1.1	4.4
POK	2.0	5.5
SOL-EC	-0.6	2.0
SOL-NS	1.7	2.0
TUR	2.2	3.7
WHG-NS	-1.3	4.5
WIT	-4.0	4.1

Table 4: Mean percent errors (MPE, %), and mean absolute percent errors (MAPE, %) in SSB in the year after the considerations year.

stock	MPE	MAPE
COD-NS	0.3	3.1
HAD	0.0	0.8
PLE-EC	1.5	1.9
PLE-NS	-0.7	1.0
POK	-4.9	6.9
SOL-EC	-1.1	1.1
SOL-NS	-5.8	5.8
TUR	-2.8	3.4
WHG-NS	0.1	1.2
WIT	2.6	3.9

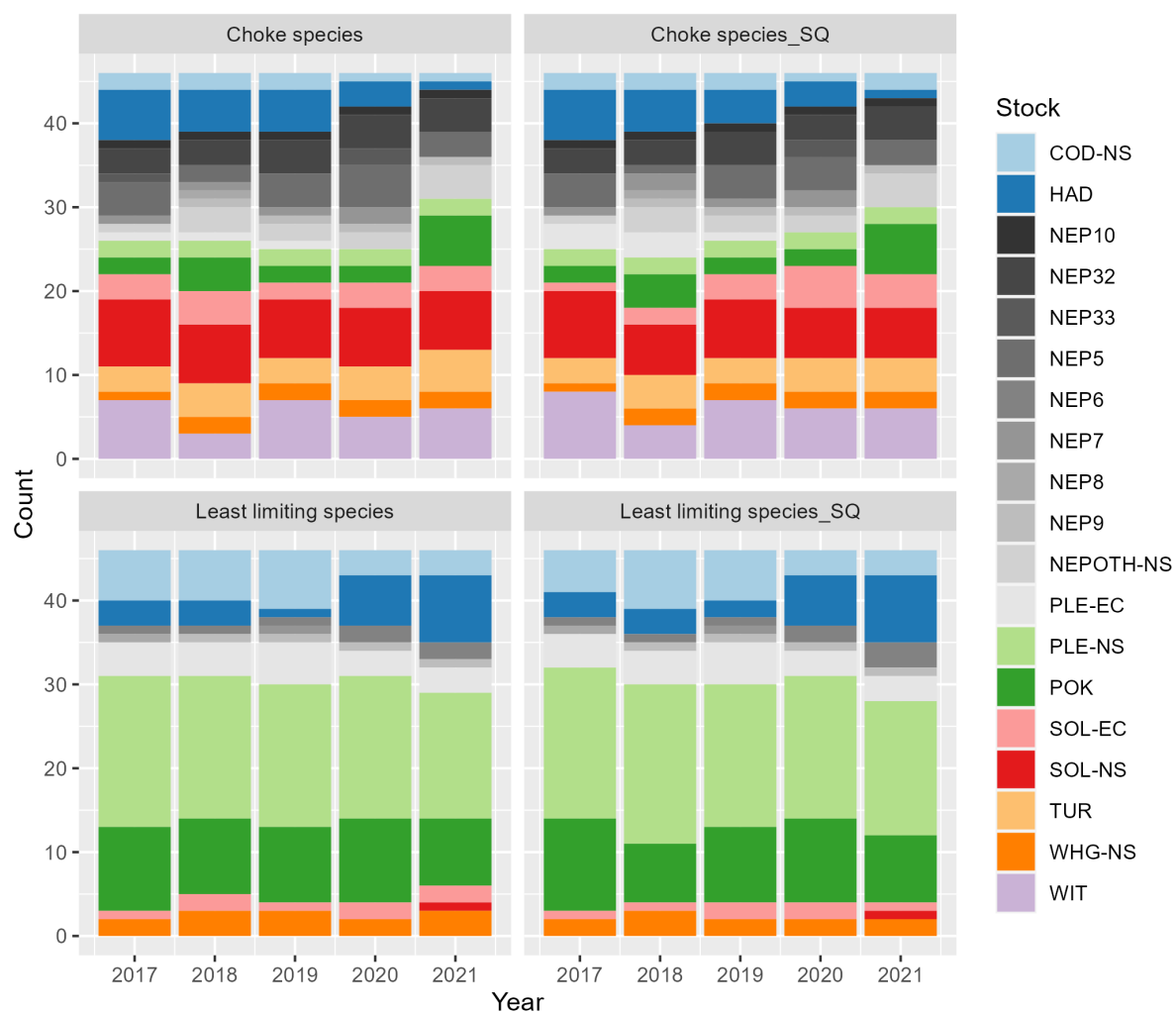
**Figure 4: Choke and least limiting species proxy per effort proportions scenario. The year is the considerations year. The left frames are the results using true effort proportions. The right frames are the results using status quo effort proportions. species proxy corresponds to the stock with minimal catch in the considerations year and the least is the one with maximal catch**



Figure 5: Number of fleets where the effort proportion assumption changes or not the choke or least limiting stock proxy per considerations year

2.3 Fleet Landing proportions per stock assumption

Comparison of the runs using an assumption and the true values for the proportions of landings per fleets show that the errors on forecasted catches and SSB differ between the 'min' and 'max' mixed fisheries scenarios. For most stocks, the errors are quite consistent across years (low variability depicted by the boxplots on Figure 1 and Figure 2). The error on the catch is around 50 % (underestimated) in the 'min' scenario, with variation amongst stocks, and are similar (but overestimated) for the 'max' scenario, with greater differences between stocks.

For all stocks, the impact of the assumption in the 'min' scenario is that it results in lower catches in the considerations year than when the actual landing proportions are used (and consequently higher SSB the year after, Table 5). In other words, using the assumption results in stronger choke effects than with the real data. The real landing proportions from the data are the outcome of the activity of the fleets and therefore are representative for how each fleet have dealt with their potential quota limitations, for instance by increasing their quota for their potential limiting stock through exchange or transfer. It is therefore expected that when using the real (realised) landing proportion, the magnitude of the choke effects would be lower than from a forecast using status quo landing proportions.

Conversely, for most stocks the error is positive in the 'max' scenario. The fleets are likely to not catch their full quotas for the stocks identified as least limiting, therefore the proportion of landing for these stocks for the fleets for which they are least limiting are probably lower in reality than the ones based on the status quo assumption (and hence a higher forecasted catch in the 'max' scenario with this assumption).

Errors for the *Nephrops* stock (especially for the 'max' scenario) are larger than for the demersal fish. This is due to the fact that the simulations use quotas per functional unit, while in reality a single quota is used for the whole of the North Sea. This adds an additional source of discrepancy between the real landing proportions and the ones based on status quo assumptions.

The stocks identified as most or least limiting are highly impacted by the assumption on landing proportions (Figure 3). With the true data, there is a clear principal choke stock

(COD-NS in 2019 and 2020, WIT in 2017, WHG-NS in 2018) and least limiting stock (PLE-NS in 2019-2021, POK in 2017) each year. When using the assumption on landing proportions, the number of stocks identified both as most and least limiting increases substantially. This is unexpected since the actual landing proportions should reflect the outcome of the fleets having dealt with their potential choke issues (and presumably avoided some of them), which would lead to a larger diversity in choking stocks. In addition, the ICES mixed-fisheries considerations, using the status quo assumption, never identifies such a large number of most and least limiting stocks.

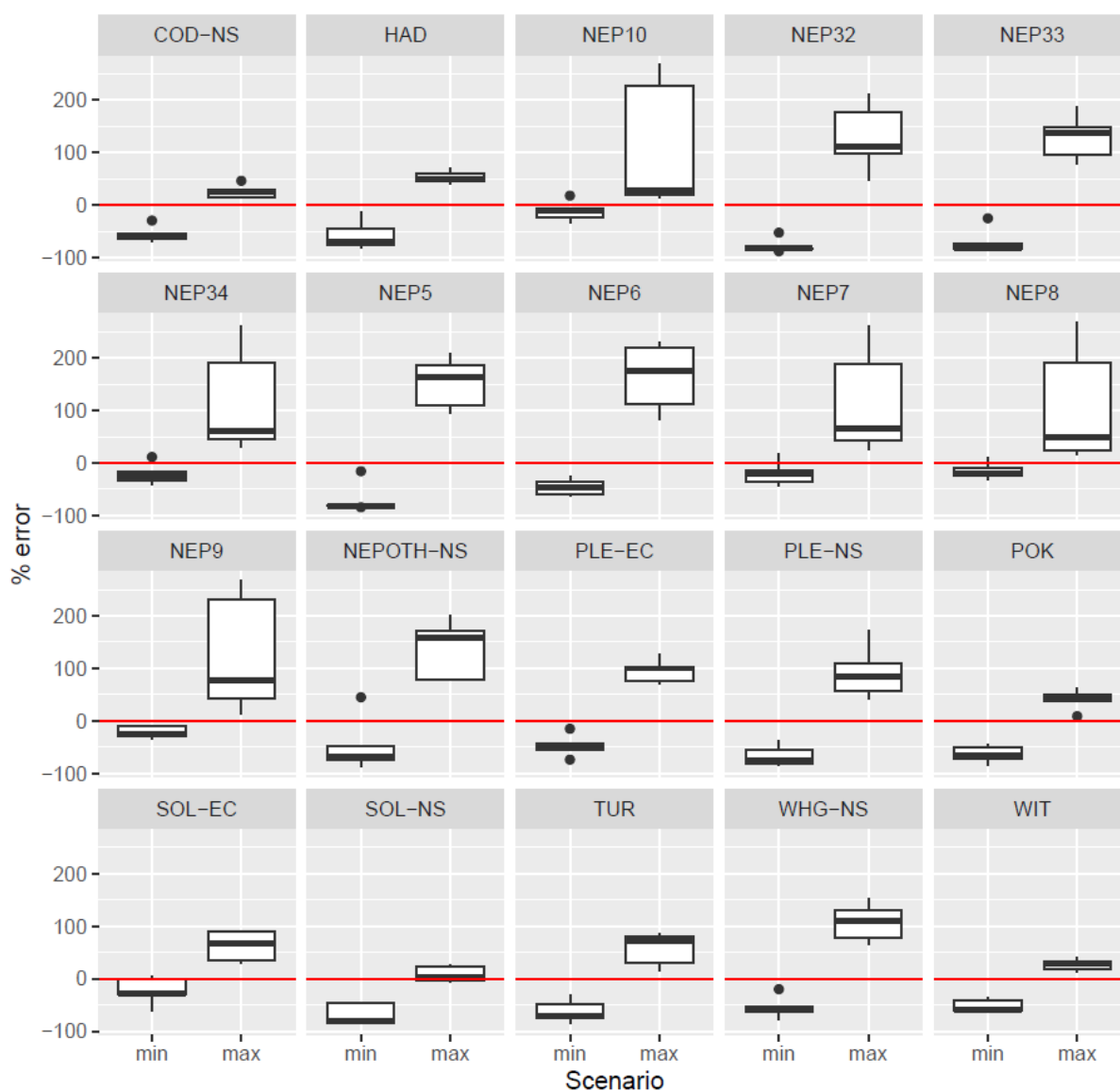


Figure 1: Relative error in catch (%) in the considerations year due to using status quo landing proportion for all fleets in the North Sea model

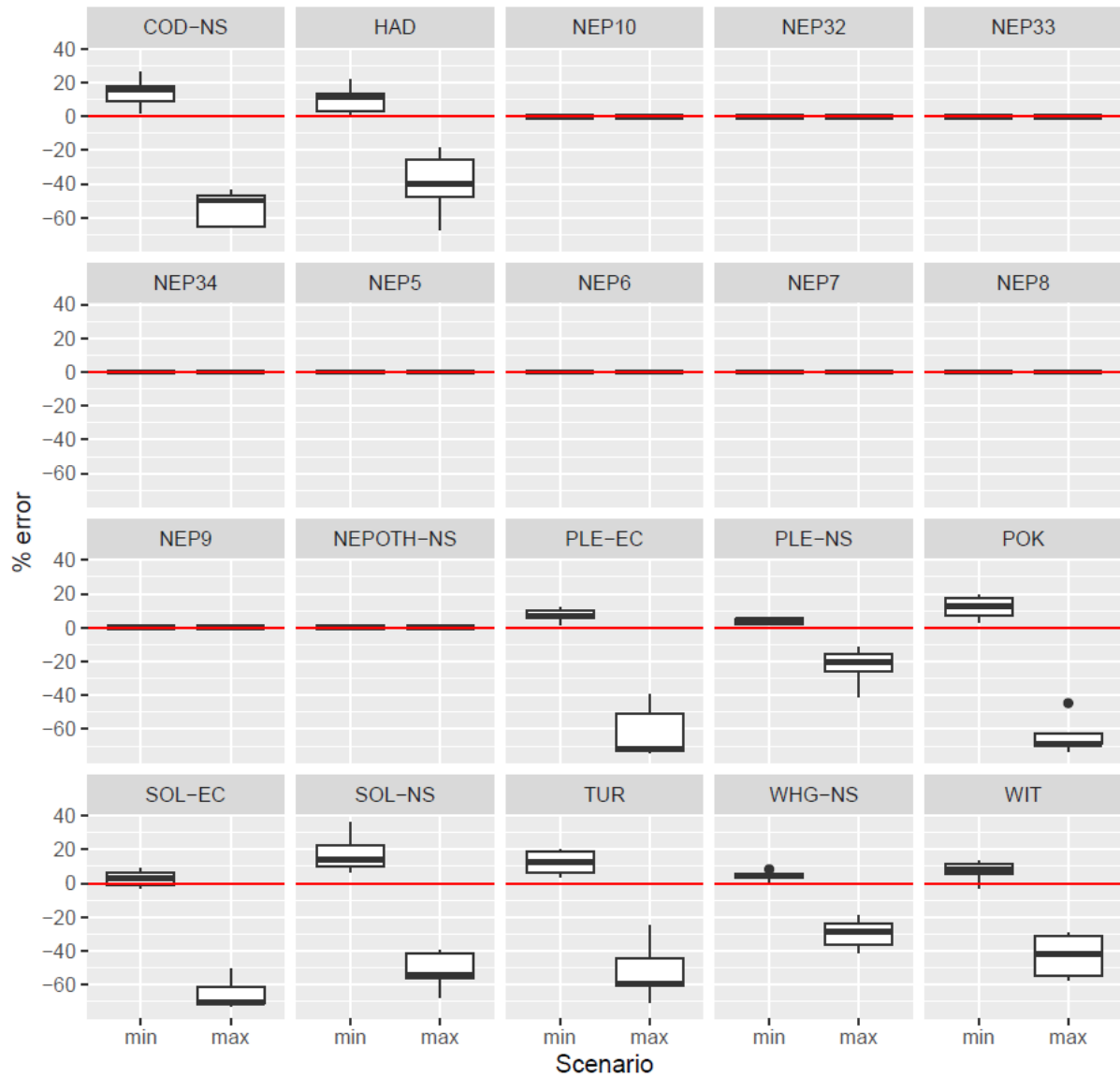


Figure 2: Relative error in SSB (%) in the considerations year +1 due to using status quo landing proportion for all fleets in the North Sea model

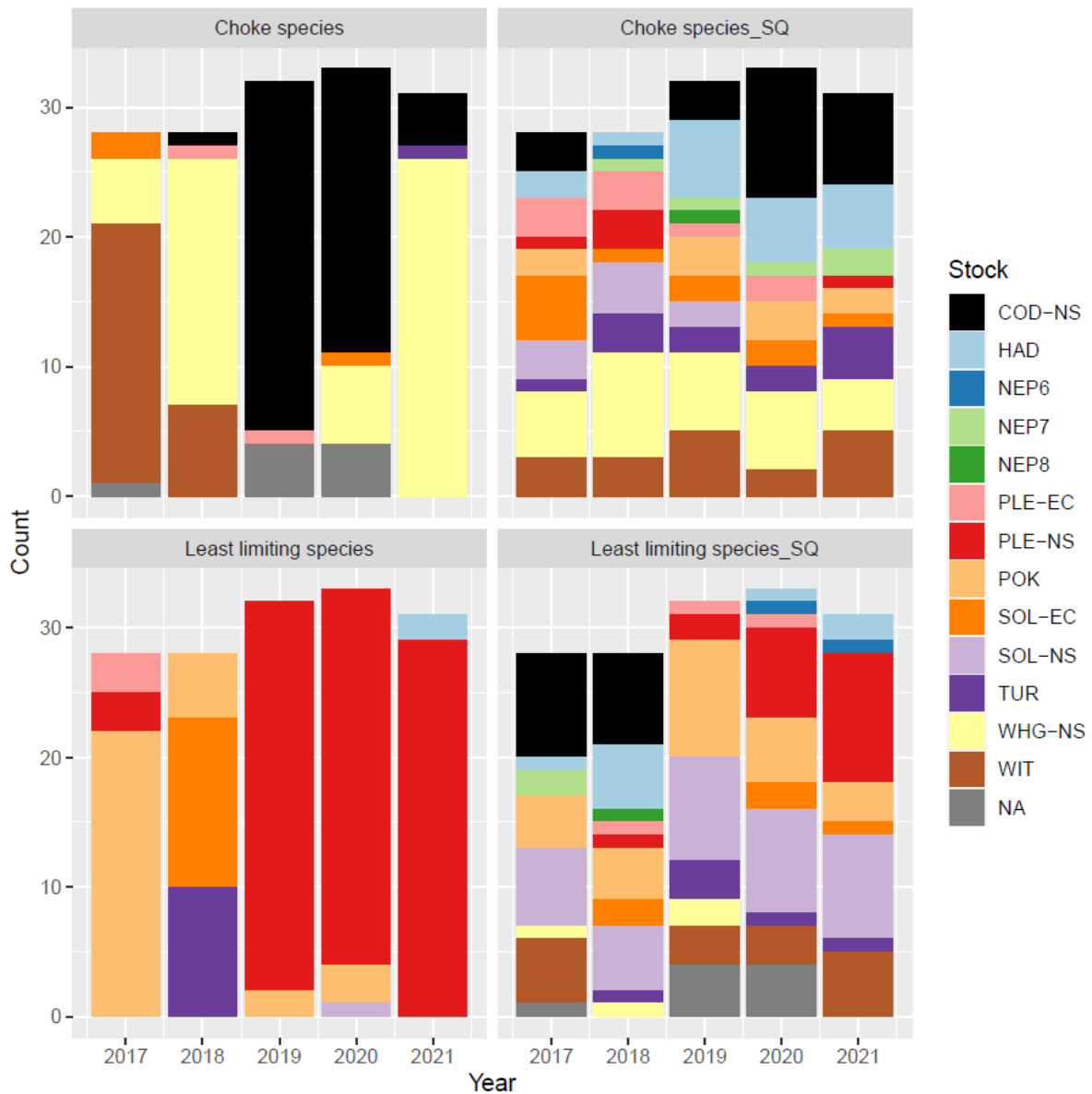


Figure 3: Choke and least limiting species (considerations year) per landing proportion scenario. The first column are the results using true parameter values and the second column are the results using status quo assumption. The choke species corresponds to the stock for which the quota is caught with the smallest effort for each fleet ('min' scenario) and the least is the stock with a quota corresponding to the highest effort ('max' scenario)

Table 5: mean percent error and mean absolute percent error related to the assumption on landing proportions for catch and SSB for the 'min' and 'max' scenarios

	Min scenario				Max scenario			
	catch		SSB		catch		SSB	
	MPE	MAPE	MPE	MAPE	MPE	MAPE	MPE	MAPE
Fish stock								
COD-NS	-55	55	14.2	14.2	26	26	-54.3	54.3
HAD	-57	57	10.0	10.0	53	53	-39.6	39.6
PLE-EC	-48	48	7.2	7.2	95	95	-62.1	62.1
PLE-NS	-67	67	4.0	4.0	93	93	-22.9	22.9
POK	-64	64	11.9	11.9	40	40	-63.6	63.6
SOL-EC	-23	25	2.9	4.5	62	62	-65.4	65.4
SOL-NS	-69	69	17.7	17.7	8	12	-51.8	51.8
TUR	-62	62	12.1	12.1	56	56	-52.1	52.1
WHG-NS	-55	55	4.4	4.4	107	107	-29.8	29.8
WIT	-51	51	7.1	8.2	26	26	-42.7	42.7
Nephrops stocks								
NEP10	-11	18			112	112		
NEP32	-78	78			129	129		
NEP33	-69	69			130	130		
NEP34	-20	25			117	117		
NEP5	-69	69			152	152		
NEP6	-46	46			163	163		
NEP7	-19	26			117	117		
NEP8	-15	19			109	109		
NEP9	-21	21			126	126		
NEPOTH-NS	-47	65			137	137		

3 CONCLUSIONS

3.1 Catchability

Use of the status-quo catchability assumption might induce an error in catch and SSB considerations estimates for the fish species in the North Sea model, varying on average between 0 and 30 %, and 0 and 15 % respectively. The catchability assumption does not seem to induce large differences in most and least caught stocks per fleet, which might indicate that the choke and least limiting stocks would be mostly well identified with the status-quo catchability assumption.

3.2 Effort proportions

The status-quo effort proportion assumption might induce an error in catch and SSB considerations estimates for the fish species in the North Sea model varying on average between 0 and 4 %, and 0 and 6 % respectively. The effort proportion assumption hardly induces a difference in most and least caught stocks per fleet. This might indicate that the choke and least limiting stocks would be mostly well identified with the status-quo effort proportions assumption.

3.3 Landing proportions

Errors are larger as expected, because in this case the results are based on the 'min' and 'max' scenarios (set effort scenarios are not relevant for this parameter). The impact of

the status quo assumption on this parameter does not only affect the calculation of forecasted catches and stock size for a given effort, but also the future effort itself. Indeed, in these scenarios, the efforts correspond to the lower and largest (for the 'min' and 'max' scenario respectively) of the efforts corresponding to the quota of each species, and these quotas are based on the landing proportions used.

The sensitivity of the mixed fisheries forecast to the landing proportion assumption appears high. However, there is no obvious alternative to the status quo assumption. Explorations have been made using FCube at WGMIXFISH (ICES, 2022) in which actual quota shares (before or after exchanges) are used instead of a status assumption. This resulted in some noticeable differences. In particular, some fleets which were strongly choked by COD-NS with the status quo landing proportion assumption had actually underused their quotas (or traded them) in the recent years, and their actual quota share were much higher than assumed based on recent landing proportion. For these fleets, COD-NS was still choking when using quota shares as an assumption for future landing proportions, but for a much higher effort, and their catches were overall much higher. However overall using quota shares does not seem to lead to a better assumption than that of status quo landing proportion, since it is impossible to predict annual exchanges and transfers.

4 LIMITATIONS

Not having re-conditioned to exactly reproduce the previous mixed-fisheries considerations led to more issues than initially foreseen, and has resulted in limitations to the validity of the results presented here.

A first issue is related to the stocks included in the analysis for each métier. For a number of fleets, stocks are included in the catches of their métiers only for some years (the most recent ones). When running the model starting further back in time, those stocks remain in the list of stocks taken by these métiers, even though catches are zero. This leads to setting quotas for zero catch for these stocks, which fully chokes the fleet (appearing as NA on the Figure 3).

A second issue is that the runs were also parameterised using historical ICES mixed-fishery considerations to define the quotas of the fleets. The biological basis for the retrospective runs was the assessments available in 2022, which can differ substantially from the ones used back in time as a basis for both the single stock and the mixedfisheries considerations (due to annual revisions in assessment perception or changes in methods after benchmarks). Therefore, it cannot be expected that most and least limiting stocks in this analysis correspond to those identified in the historical mixedfisheries considerations.

Not having been able to fully re-condition the model for each retrospective year might also be the reason for the unexpected results regarding most and least limiting stocks for the landing proportion assumption.

Reconditioning the model is a very difficult task, which would involve, for each retrospective run, to entirely reconstruct each fleet-object (landing and discards at age per métier for each fleet, and corresponding effort) which is normally achieved after several days of work at each WGMIXFISH meeting. The stock object from the earlier assessments should also be used, and the corresponding assumption on future biology should be updated.

Since the lack of reconditioning is likely an additional source of discrepancy, it can be expected that the analysis presented here overestimates the sensitivity of the model output to the assumptions on configuration. However, it is not possible to establish the magnitude of this overestimation.

5 REFERENCES

ICES. (2022). Working Group on Mixed Fisheries Methodology (WGMIXFISH-METHODS). ICES Scientific Reports. [DOI: 10.17895/ices.pub.20401389](https://doi.org/10.17895/ices.pub.20401389)

ANNEX 13: CHARACTERISING UNCERTAINTY ON THE BAY OF BISCAY DEMERSAL FISHERIES FORECASTS

1 INTRODUCTION

The main objective of the study was to evaluate the sensitivity and uncertainty of catch projections in mixed fisheries models, and to ensure effective conditioning to accurately represent the uncertainty in the output and characterize it. With that aim, an uncertainty analysis and a Global Sensitivity Analysis (GSA) were carried out. These consist of characterising the uncertainty of parameters in the forecast based on historical data or existing knowledge; quantifying the uncertainty in the output indicators; and identifying the parameters that have the highest contribution to the output variance.

The Bay of Biscay demersal mixed fisheries has been selected as a case study for this work, using data on the French and Spanish demersal fisheries operating in the region. Input data was based on the available information from ICES WGMIXFISH 2022 (ICES, 2022) and some improved information on the Spanish fleet from AZTI database, covering 2009-2021 period.

2 METHODOLOGY

2.1 Simulation framework

Simulations were carried out using FLBEIA software (García et al., 2017). In this analysis we have followed the approach and guidelines presented in Garcia et al. (2021), using 5,000 replicates, both for the uncertainty analysis and for each of the GSA matrices.

In present study we have focused on the uncertainty conditioning of parameters directly related with the slots in FLFleet object (which contains most of the fleet-related information), namely: selectivity, catchability, quota-share and effort proportion by métier.

All the code used to carry out present study have been made available in a GitHub repository ⁽¹⁾.

2.2 Uncertainty conditioning

The focus of this case study was on the uncertainty conditioning of parameters directly related with catchability, effort proportion, and quota share.

2.2.1 Catchability

The catchability by fleet was calculated based on the model used for the simulation of catch production. In this case we were using FLBEIA (García et al., 2017) with a Cobb-Douglass function and the catch is given by:

$$C_{fl,mt,st,a} = q_{fl,mt,st,a} \cdot E_{fl} \cdot efs_{fl,mt} \cdot B_{st,a}$$

where fl , mt , st and a are the subscripts for fleet, métier, stock and age respectively. C denotes total catch, q catchability, E effort at fleet level, efs effort proportion of fleet fl in métier mt and B total biomass of stock st and age a . The catchability is then given by:

⁽¹⁾ https://github.com/IrishMarineInstitute/STARMixFish/tree/main/lot_2/TASK_3

$$q_{fl,mt,st,a} = \frac{C_{fl,mt,st,a}}{E_{fl} \cdot ef_{S_{fl,mt}} \cdot B_{st,a}}$$

In the event of a change to the catch production model, the calculation of catchability should be adjusted accordingly, but the methodologies outlined in the remainder of this Annex remain applicable. In the following sections, for simplicity, the subscripts for fleet and métier are omitted, but all the calculations occur at métier level.

2.2.1.1 Decomposition in intensity and selectivity components

To condition catchability we wanted to obtain a unidimensional parameter that measures the intensity with which the fleet catches the stocks. The objective was to be able to incorporate into the analysis the correlation in the yearly intensity the fleets perform in the stocks they exploit.

For each stock in métier, yearly catchabilities per age ($q_{st,y,a}$) are described by the following matrix:

$$\begin{pmatrix} q_{st,11} & \cdots & q_{st,1Y} \\ q_{st,21} & \cdots & q_{st,2Y} \\ \vdots & \ddots & \vdots \\ q_{st,A_{st}1} & \cdots & q_{st,A_{st}Y} \end{pmatrix}$$

Where A_{st} represents the number of age classes in the stock and Y the number of years in the data.

During the process of conditioning catchability, focus was primarily on incorporating the effects of interspecies interactions that occur within each métier. To do so, unidimensional year effects per stock were extracted (intensity) from the age effect (selectivity) by writing catchability in the following form:

$$q_{st,y,a} = S_{st,y,a} \cdot I_{st,y}$$

where S is a proxy of selectivity and I is the intensity with which the stock is fished. We can define $I_{st,y}$ as the mean of the yearly intensities over reference ages, i.e.:

$$I_{st,y} = \frac{1}{a_{\{1_{st}\}} - a_{\{0_{st}\}} + 1} \sum_{a=a_0}^{a=a_1} q_{st,y,a}$$

Then the selectivity would be equal to the ratio between catchability and intensity:

$$S_{st,y,a} = \frac{q_{st,y,a}}{I_{st,y}}$$

In this way, the intensity $I_{st,y}$ includes an absolute level of the catchability, and the selectivity the deviations around the mean.

2.2.1.2 Intensity

For intensity, we analysed the correlation structure between stocks under the assumption that changing the intensity with which one stock is fished, the intensity in the other fish caught together also changes (e.g. when two stocks have a high overlap in space). We assumed intensities are log-normally distributed with a variance-covariance matrix at fleet-métier level. Then in the uncertainty analysis we sampled

catchability using a multi-lognormal distribution with the parameters obtained from the sample $I_{st,y}$ values, where the list of stocks depended on the fleet and métier.

2.2.1.3 Selectivity

We model selectivity using a spline to obtain an overall estimate of the selectivity curve over time from which we can then sample to introduce uncertainty in both the uncertainty and the selectivity analysis.

2.2.2 Effort proportion

To introduce uncertainty in the effort proportion, a Dirichlet distribution was used to model the proportions. The Dirichlet distribution is a versatile extension of the beta distribution, which is commonly applied to model proportions across multiple dimensions. In this case a null model was fitted (i.e. only intercept model) to the observed proportions.

2.2.3 Quota share

Similar to the approach used for effort proportion, uncertainty in quota share was introduced by utilizing a Dirichlet distribution to model the proportions based on a null model consisting of only an intercept model.

2.3 Global Sensitivity Analysis

2.3.1 Background: SOBOL method

Sobol variance decomposition method is based on the decomposition of the output variance as a function of the variance of conditional expectations of the model output on the input factors Sobol (1993).

Sobol (1993) proved that any square integrable function $\varphi(\mathbf{X}) = Y$ in $\Omega = [0,1]^K$ can be decomposed as:

$$\varphi(\mathbf{X}) = \varphi_0 + \sum_i \varphi_i(X_i) + \sum_{i < j} \varphi_{ij}(X_i, X_j) + \dots + \varphi_{12\dots K}(X_1, \dots, X_k)$$

where each individual term is also square integrable and depends solely on the input factors corresponding with its index. This expansion is called high dimensional model representation. Furthermore, if the terms in the equation above have zero mean (i.e. the integral of each term over each of the variables is zero), the terms in the equation above are orthogonal and can be calculated using the conditional expectations of the model output. Mathematically:

$$\begin{aligned}
 \varphi_0 &= \int \varphi(\mathbf{X}) d\mathbf{X} = E(\mathbf{X}) \\
 \varphi_i(X_i) &= \int \varphi(\mathbf{X}) \prod_{k \neq i} dX_k - \varphi_0 = E(Y|X_i) - E(\mathbf{X}) \\
 \varphi_{ij}(X_i, X_j) &= \int \varphi(\mathbf{X}) \prod_{k \neq i, j} dX_k - \varphi_i(X_i) - \varphi_j(X_j) - \varphi_0 \\
 &= E(Y|X_i, X_j) - E(Y|X_i) - E(Y|X_j) - E(\mathbf{X})
 \end{aligned}$$

and so on. Now, if we square on both sides of the first equation, replacing the terms in the right-hand side by the expression obtained in previous equations, and integrate over ω , we get:

$$\int \varphi^2(\mathbf{X}) d\mathbf{X} - \varphi_0^2 = \sum_{s=1}^K \sum_{i_1 < \dots < i_s}^K \int \varphi_{i_1 \dots i_s}^2 dX_{i_1} \dots dX_{i_s}$$

The constants:

$$V = \int \varphi^2(\mathbf{X}) d\mathbf{X} - \varphi_0^2 \quad \text{and} \quad V_{i_1 \dots i_s} = \int \varphi_{i_1 \dots i_s}^2 dX_{i_1} \dots dX_{i_s}$$

correspond with the conditional variances of the model output on the input factor and:

$$V = \sum_{s=1}^K \sum_{i_1 < \dots < i_s}^K V_{i_1 \dots i_s}$$

In variance decomposition methods, the variance is used to characterize the variation in the output of simulation models. Hence, Sobol (1993) proposed to use the ratio between the conditional variances and the total variance as sensitivity measures, i.e.:

$$S_{i_1, \dots, i_s} = \frac{V_{i_1, \dots, i_s}}{V}$$

Hence,

$$\sum_{s=1}^K \sum_{i_1 < \dots < i_s}^K S_{i_1, \dots, i_s} = 1$$

And,

$$\sum_{i=1}^K S_i = 1$$

means that the model is additive and there is no interaction between input factors. On the contrary, values much lower than 1 indicate that the model is highly non-linear.

In simple cases, the sensitivity indices can be calculated analytically. However, in most cases the models are too complex to allow the derivation of analytical expressions for the integrals to obtain the elements in the first equation. For each of the sensitivity indices, the numerical approximation developed by Sobol (1993) requires evaluating the simulation model in a large set of Monte Carlo points. Hence, the computational cost of calculating all the terms in the decomposition is equal to $N \cdot 2^K$, where K corresponds with the number of input factors and N with the base sample size that should be big

enough to ensure the convergence of the method. Hence, the number of model evaluations required can be unapproachable even for relatively low number of factors.

As an alternative, Homma and Saltelli (1996) proposed summarizing the contribution of the input factors to the output variance using two sensitivity indices: first order and total-effect indices. The first is equal to the ratio between the variance of the conditional expectation of the model output on k -th input factor and the total variance of the model output, mathematically:

$$S_k = \frac{V(E(Y|X_k))}{V(Y)}$$

where X_k denotes the k -th input factor, $Y = \varphi(\mathbf{X})$ is the unidimensional output of the simulation model represented by φ and $\mathbf{X} = (X_1, \dots, X_K)$ represents the model input. This index represents the contribution of the k -th input factor to the output variance in isolation.

In turn, the total-effect index is equal to the expected value of the conditional variance of the model output on all the input factors but one, the k -th input factor, denoted here as $\mathbf{X}_{\sim k}$. It represents the contribution to the variance of the k -th input factor alone and in combination with the remaining input factors. Mathematically it is written as:

$$S_{T_k} = \frac{E(V(Y|\mathbf{X}_{\sim k}))}{V(Y)}$$

In this way the decomposition of the output variance can be summarized using just two indices for each factor, the first-order and the total-effect sensitivity indices and the cost of the analysis is reduced to $N \cdot (K + 2)$.

2.3.2 Numerical calculation of the sensitivity indices

We followed the numerical approximations proposed by Saltelli et al. (2010) which are based on the work by Sobol (2001). Saltelli et al. (2010) compared different approaches for calculating the Sobol sensitivity indices using Monte Carlo simulations. Here, we have used the approach that was identified by the authors as the best in terms of convergence rate.

First, two independent matrices of dimension $N \times K_{\text{NG}}$ are constructed, A and B , the so-called sample and re-sample matrices, where N and K_{NG} are the number of base simulations and input factors of the model, respectively. Each row in the matrices correspond with a random sampling point in the input space Ω . The input factors can be multivariate, and therefore, K_{NG} can be larger than the number of effective input factors in the GSA, K . When the input factors are aggregated in groups, instead of considering every input factor alone, the elements in the Sobol decomposition that include this input factor represent the contribution to the variance of all the input factors in the group as a whole, in isolation in the case of index, and in combination with other sets of input factors, in the case of the rest of the elements in the decomposition of variance. Hence, the input factors should be grouped sensibly to obtain meaningful results.

Second, additional K matrices, $\{A_k^B\}_{k \in 1, \dots, K}$, are constructed from the A and B matrices. Each A_k^B matrix is equal to A , except in the columns that correspond to the k -th input factor, which are taken from matrix B . If the k -th input factor is a group all the columns corresponding to this factor are replaced. Finally, the model is applied to each of the rows of A , B , and $\{A_k^B\}_{k \in 1, \dots, K}$ matrices. The numerator in the mathematical expression for the first-order index is then approximated by:

$$V(E(Y|X_k)) = \frac{1}{N} \sum_{i=1}^N \varphi(B_{i.}) \cdot (\varphi(A_{k,i.}^B) - \varphi(A_{i.}))$$

where $A_{i.}$, $B_{i.}$ and $A_{k,i.}^B$ denote the i -th row of matrices A , B , and A_k^B , respectively. In turn, the numerator in the mathematical expression for the total-effect index is estimated as:

$$E(V(Y|\mathbf{X}_{\sim k})) = \frac{1}{2N} \sum_{i=1}^N (\varphi(A_{i.}) - \varphi(A_{k,i.}^B))^2$$

Finally, the total variance $V(Y)$ is approximated by:

$$V(Y) = \frac{1}{N} \sum_{i=1}^N \varphi(A_{i.})^2 - \left(\frac{1}{N} \sum_{i=1}^N \varphi(A_{i.}) \right)^2$$

The convergence of the estimators can be assessed using the bootstrap confidence intervals' width.

2.3.2.1 Application of Sobol to GSA of mixed fisheries considerations using FLBEIA

The numerical approximation of the Sobol indices is a sampling method that basically consist of applying the model iteratively, conditioning the model in a specific way in each iteration. To accelerate the convergence of the method the sampling starts with the sampling of the unit hypercube $U^N = U[0,1]^K$ using Sobol random numbers. Sobol random numbers ensure that the hypercube is sampled in an even way while maintaining randomness. The Sobol random numbers in U^N are then transformed into the original sampling space Ω using quantile transformation for univariate variables and special transformations for multivariate distributions.

Steps in practice in this particular case:

- Generate $2 \cdot N$ samples from U^K using Sobol sampler: $\{(u_{1j}, \dots, u_{Kj})_{j=1}^{2 \cdot N}\}$.
- Transform the $\{(u_{1j}, \dots, u_{Kj})\}$ into the original:
 - Dirichlet distribution (effort and quota shares).
 - Multivariate log-normal distribution (intensity).
 - Empirical quantile transformation (selectivity).
- Divide the $2 \cdot N$ samples in two sets, A and B.
- For the K input factors create the $AB_1, \dots, AB_K$ samples, also known as the $C_1, \dots, C_K$ samples. For any iteration, the AB_j sample is equal to the A sample except in the element of the j-th dimension that equal to the j-th element in the B sample.
- Apply the simulation model φ in all the iterations of the samples, A, B, $AB_1, \dots, AB_K$, i.e., calculate $\varphi(A)$, $\varphi(B)$, $\varphi(AB_1)$, ..., $\varphi(AB_K)$.
- Calculate the sensitivity indices using the equations above.

3 BAY OF BICAY CASE STUDY

Analysis was focused on the French and Spanish demersal fisheries operating in the Bay of Biscay. For ensuring effective conditioning of the models to accurately represent the uncertainty in the output and characterize it using the GSA, input data was based on the available information from ICES WGMIXFISH 2022 (ICES, 2022) and some improved information on Spanish fleet from AZTI database, covering 2009-2021 period.

3.1 Exploratory Data Analysis

In this section we explore the fleet structure in terms of métiers and their relevance, and the stocks caught in each of them.

A graphical representation of the fleets and métiers considered in the case study is shown in Figure 1. The French fleet 'FR_OTB_10<24m' (composed of French bottom otter trawlers 10 to 24m in length) is the most important fleet. The Spanish 'SP_OTB_24<40m' (Spanish 24 to 40m bottom trawlers) is the second most important fleet among the trawlers which are the most mixed gears. Thus, we focus the analysis on these two fleets.

Table 1 shows the contribution of each of the fleets to the total catch in the fishery. The column 'included' indicates if the fleet has been included in the uncertainty and sensitivity analysis or not. The 'FR_MIS_all' fleet has been left out because it is not a 'real' fleet.

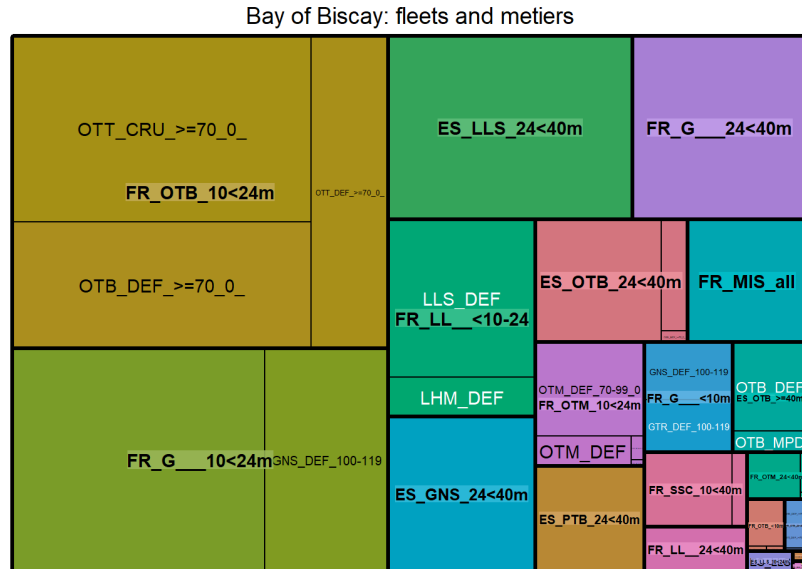


Figure 1: Fleets and métiers included in the Bay of Biscay case study. Each fleet is represented by a different colour. The size of each rectangle is proportional to the average total landings in the fleet over the last three data years (2019-2021).

Table 1: Fleets' contribution to the total catch in the Bay of Biscay fishery.

fleet	catch	p	included
FR_OTB_10<24m	9506	0.276	✓ Yes
FR_G__10<24m	6756	0.196	✗ No
ES_LLS_24<40m	3629	0.106	✗ No
FR_G__24<40m	2592	0.075	✗ No
FR_LL_<10-24	2349	0.068	✗ No
ES_GNS_24<40m	1837	0.053	✗ No
ES_OTB_24<40m	1512	0.044	✓ Yes
FR_MIS_all	1191	0.035	✗ No
FR_OTM_10<24m	1088	0.032	✗ No
ES_PTB_24<40m	925	0.027	✗ No
FR_G__<10m	787	0.023	✗ No
ES_OTB_>=40m	658	0.019	✗ No
FR_SSC_10<40m	619	0.018	✗ No
FR_LL_24<40m	370	0.011	✗ No
FR_OTM_24<40m	228	0.007	✗ No
FR_OTB_<10m	157	0.005	✗ No
FR_OTB_24<40m	93	0.003	✗ No
ES_LLS_10<24m	74	0.002	✗ No
FR_OTM_<10m	1	0.000	✗ No
ES_MIS_all	9	0.000	✗ No
ES_GTR_10<24m	1	0.000	✗ No
ES_GNS_10<24m	12	0.000	✗ No

As a proof of concept, the initial analysis was focused on the analysis and conditioning of the two most important trawl fleets in terms of total landings. These were French bottom otter trawlers 10 to 24m in length (FR_OTB_10<24m) and Spanish 24 to 40m bottom trawlers (ES_OTB_24<40m). As the data time series should be as long as possible for carrying this type of analysis, the longest data time series available to Bay of Biscay mixed fisheries case study was used, covering the years 2009 to 2021. Unresolvable data gaps occurred in the earlier part of the time series, limiting use to the years 2014 to 2021 in some instances.

For the two fleets included in the analysis, Figure 2 shows the catch composition of each of the métiers in the fleet.

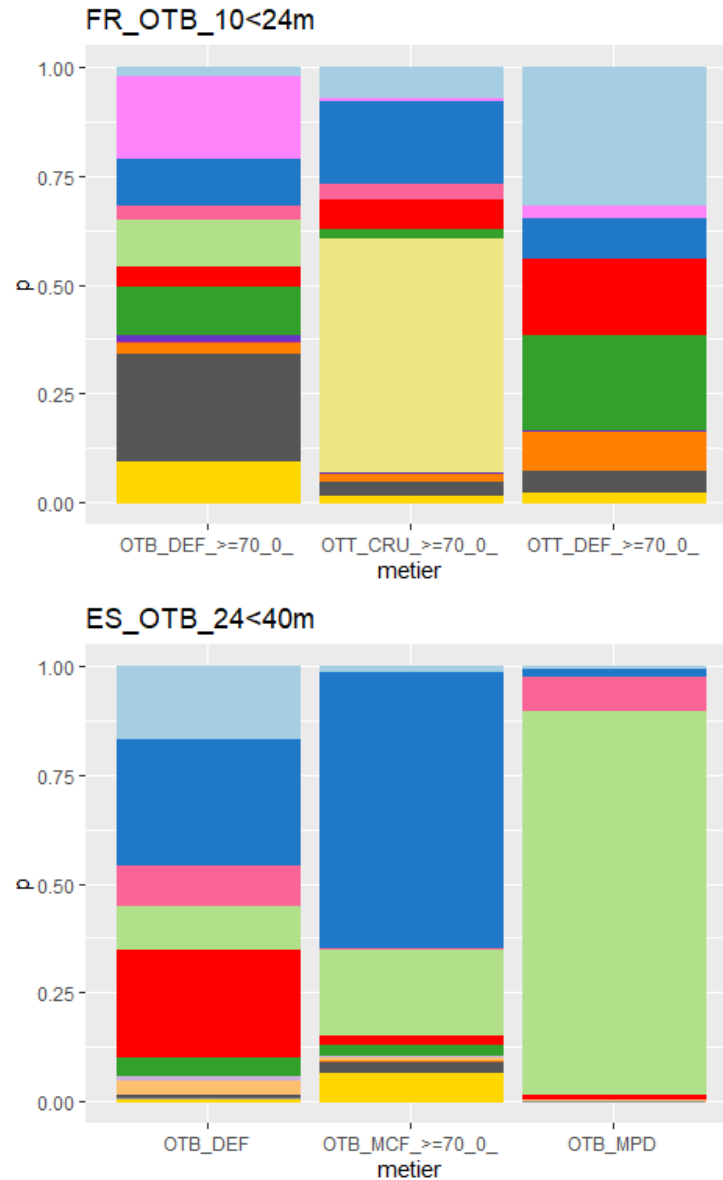


Figure 2: Catch composition for the fleets and included in the Bay of Biscay case study in the period 2019-2021. Each stock is represented by a different colour.

3.2 Uncertainty conditioning

We will focus first in the French and Spanish bottom trawlers, the French because they are the most important ones, and the Spanish ones because we have haul by haul data to investigate the approach described above.

First, we calculate the intensity defined above and then analyse the following properties graphically:

- The time series of intensity.
- The correlation between intensity for a given stock along the métiers.
- The correlation between intensity for a given métier along stocks.

3.2.1 French bottom otter trawlers (FR_OTB_10<24m)

Obtained catchability time series for the French bottom trawler fleet are shown in Figure 3. The variability in intensity was stock and métier dependent. In general, it was below 50 %. The variability in seabass and sole was quite low. There were no clear correlations between the catchability of the stocks (Figure 4). At métier level, in some cases there

were apparent correlations between the catchability of the stock in the three different métiers.

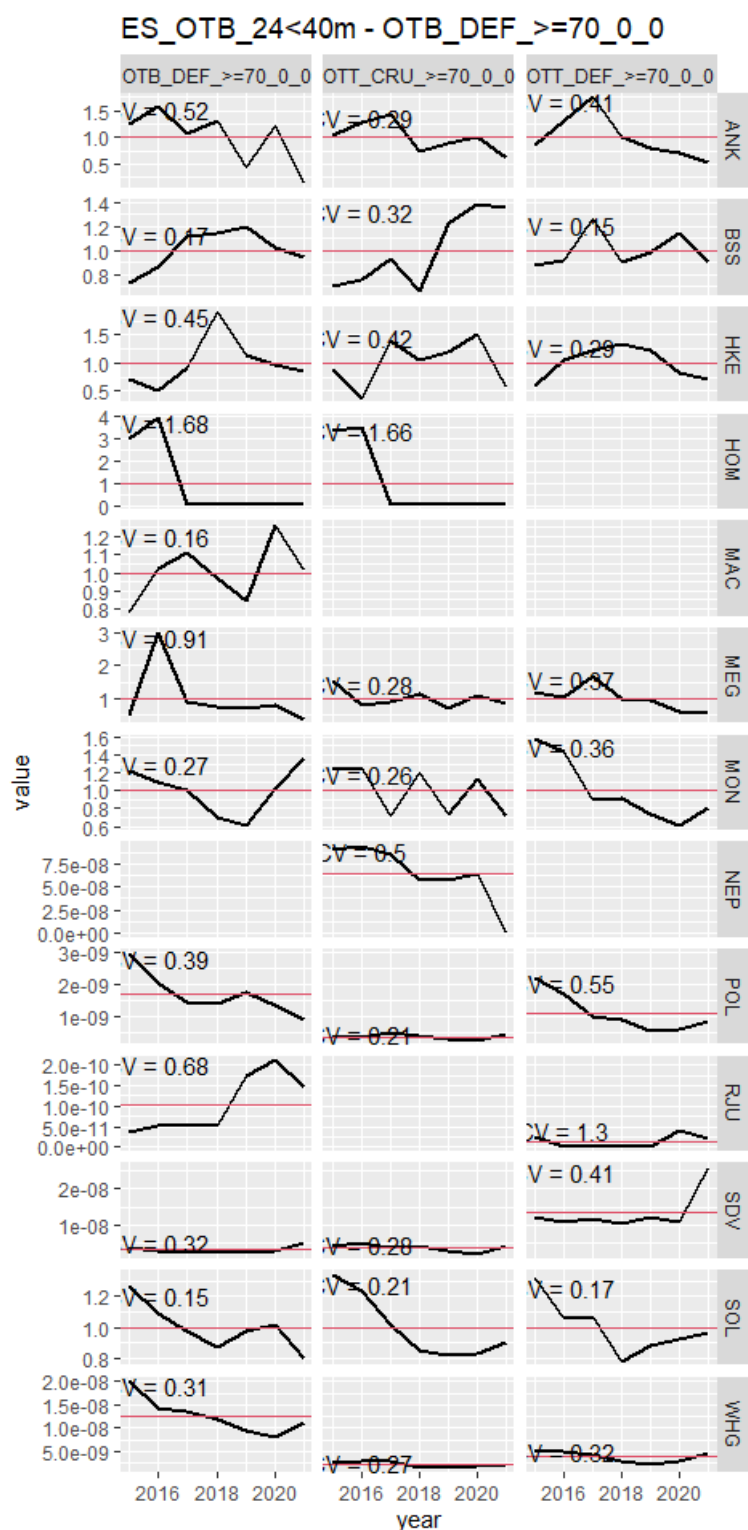
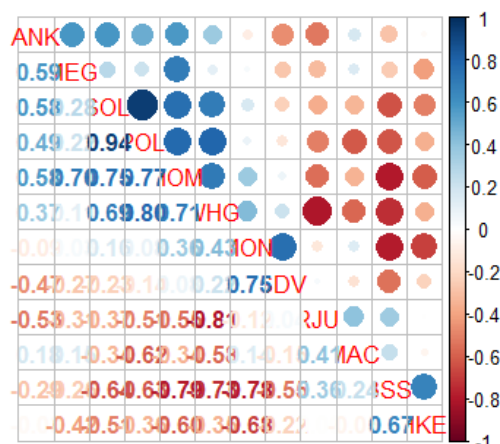
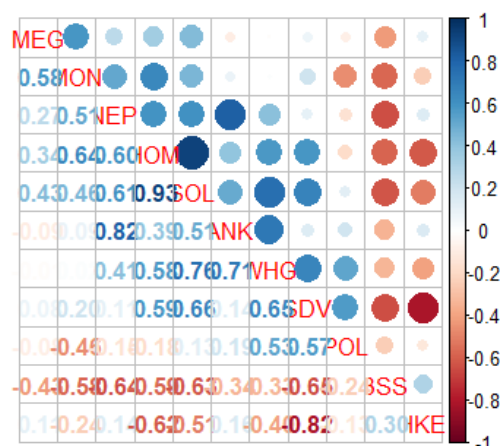


Figure 3: Catchability time series for French bottom trawler fleet by métier (columns) and stock (rows). Stocks' codes correspond to black-bellied anglerfish (ANK), seabass (BSS), hake (HKE), horse mackerel (HOM), mackerel (MAC), megrim (MEG), white anglerfish (MON), Norway lobster (NEP), pollack (POL), thornback ray (RJC), cuckoo ray (RJN), undulate ray (RJU), smooth-hound (SDV), sole (SOL), blue whiting (WHB), and whiting (WHG).

FR_OTB_10<24m - OTB_DEF_>=70_0_0



FR_OTB_10<24m - OTT_CRU_>=70_0_0



FR_OTB_10<24m - OTT_DEF_>=70_0_0

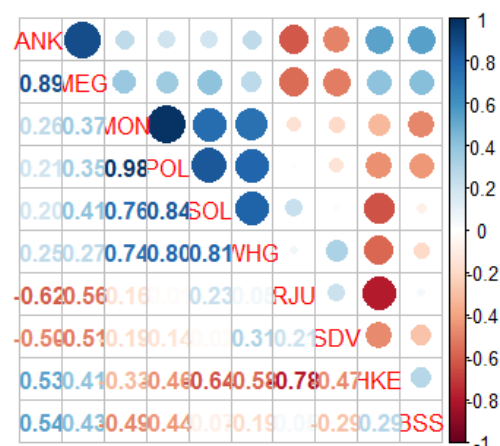


Figure 4: Correlation of catchabilities by fleet and métier among stocks for the French bottom trawler fleet. Stocks' codes correspond to black-bellied anglerfish (ANK), seabass (BSS), hake (HKE), horse mackerel (HOM), mackerel (MAC), megrim (MEG), white anglerfish (MON), Norway lobster (NEP), pollack (POL), thornback ray (RJC), cuckoo ray (RJN), undulate ray (RJU), smooth-hound (SDV), sole (SOL), blue whiting (WHB), and whiting (WHG).

3.2.2 Spanish bottom trawlers (ES_OTB_24<40m)

For the Spanish bottom trawler fleet, the variability in intensity was not very different to the variability in the French fleet (Figure 5). In this case the correlation between the intensity of the same stock for the different métiers was not apparent (Figure 6).

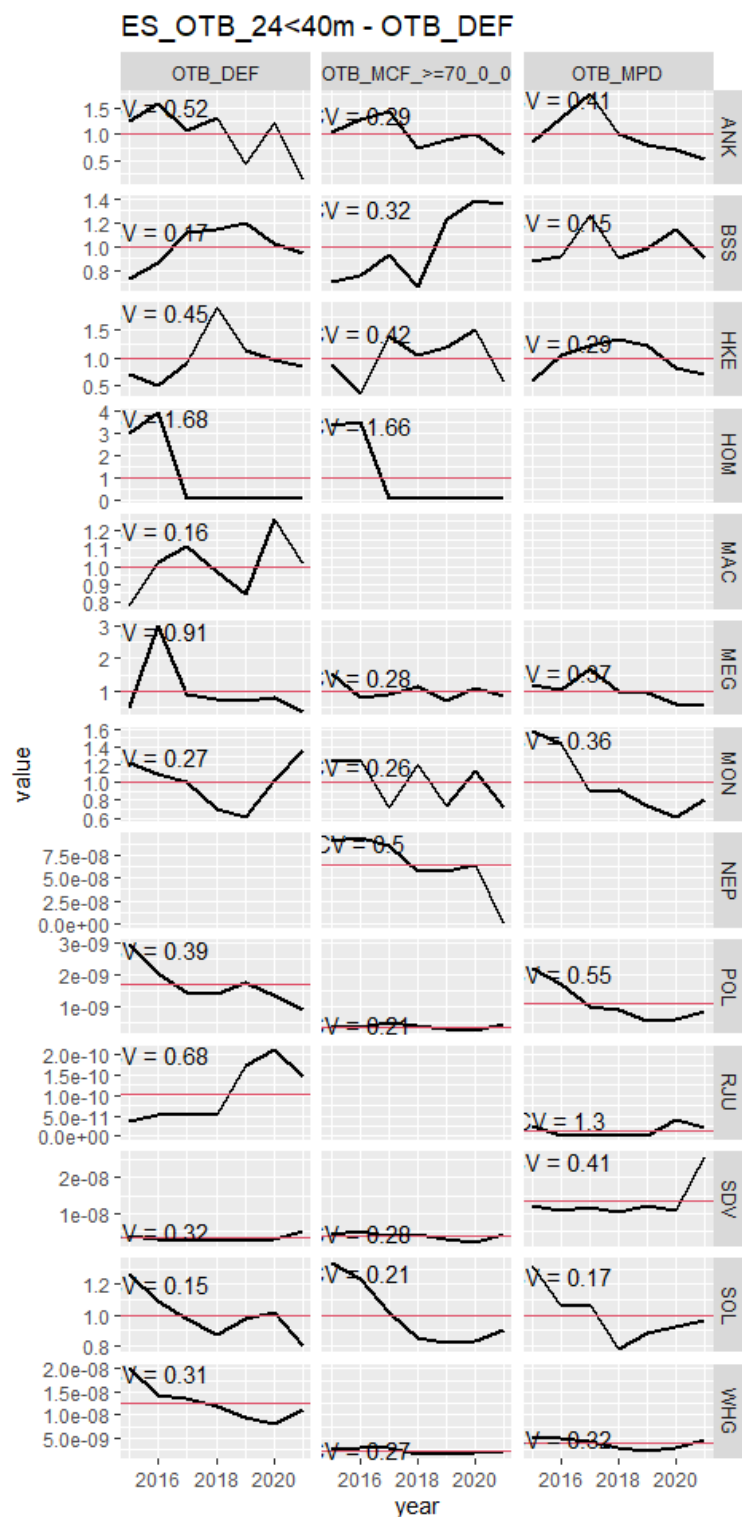
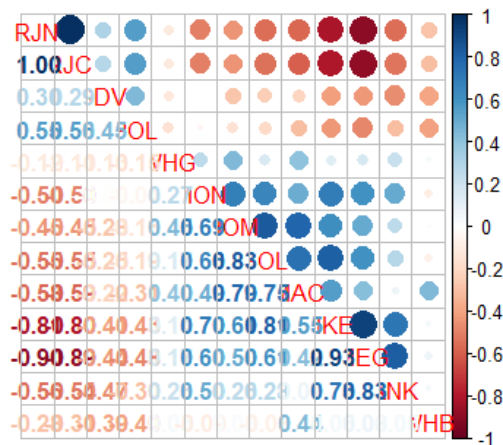
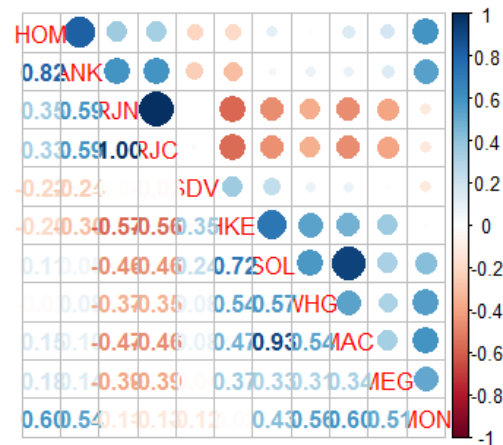


Figure 5: Catchability time series for Spanish bottom trawler fleet by métier (columns) and stock (rows). Stocks' codes correspond to black-bellied anglerfish (ANK), seabass (BSS), hake (HKE), horse mackerel (HOM), mackerel (MAC), megrim (MEG), white anglerfish (MON), Norway lobster (NEP), pollack (POL), thornback ray (RJC), cuckoo ray (RJN), undulate ray (RJU), smooth-hound (SDV), sole (SOL), blue whiting (WHB), and whiting (WHG).

ES_OTB_24<40m - OTB_MCF_>=70_0_0



ES_OTB_24<40m - OTB_MCF_>=70_0_0



ES_OTB_24<40m - OTB_MPD

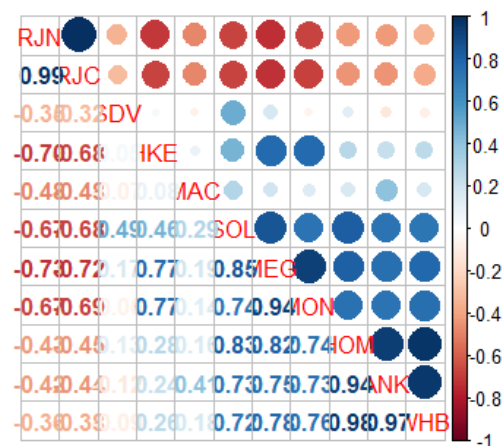


Figure 6: Correlation of catchabilities by fleet and métier among stocks for the Spanish bottom trawler fleet. Stocks' codes correspond to black-bellied anglerfish (ANK), seabass (BSS), hake (HKE), horse mackerel (HOM), mackerel (MAC), megrim (MEG), white anglerfish (MON), Norway lobster (NEP), pollack (POL), thornback ray (RJC), cuckoo ray (RJN), undulate ray (RJU), smooth-hound (SDV), sole (SOL), blue whiting (WHB), and whiting (WHG).

This analysis highlights the importance of considering covariance between catchabilities when introducing uncertainty in those parameters. We have uncertainty in two levels, the stocks and the métiers.

3.2.3 Catchability

Given that certain species intensities ($I_{st,y}$) covary in time (see Figure 4 and Figure 6), uncertainty estimates were obtained by employing a multivariate lognormal distribution based on the within métier variance-covariance matrix of species. In case the multivariate lognormal produced outliers, i.e. values that differ greatly from observed intensities, we applied an envelope that constrained uncertainty estimates to the 95 % confidence interval of observed intensities per stock.

The uncertainty associated with selectivity ($q_{st,a}$, Figure 8), on the other hand, was derived from a generalized additive model (GAM) in which age was incorporated as a spline covariate (Figure 7) and assuming a gamma distribution for selectivity. The resulting uncertainty sometimes fell out of the observed selectivity; thus, we applied an envelope that constrained uncertainty estimates to the 95 % confidence interval of observed selectivity levels.

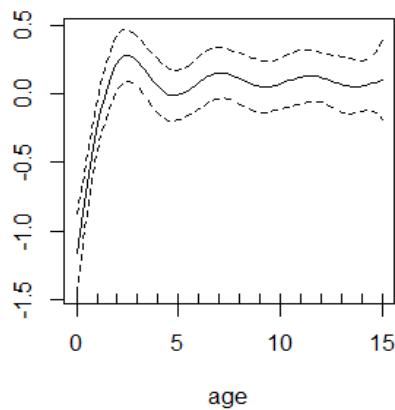


Figure 7: Fitted spline on age in gamma generalized additive model over selectivity ($q_{st,a}$)

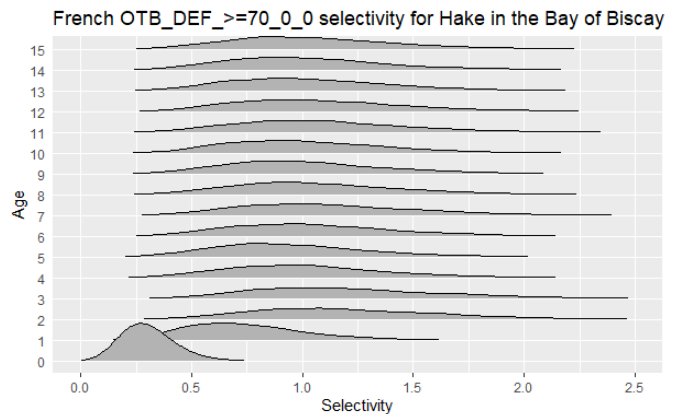


Figure 8: Resulting uncertainty associated to selectivity within a stock and métier.

3.2.4 Quota share

Quota shares by fleet for each of the simulated stocks were calculated based on the proportion of the total catch by stock captured by these fleet. Assuming that this is the final quota obtained by the fleet after the different quota swaps achieved during the year.

4 SCENARIOS

The results are based in 5,000 simulations, which correspond with 175,000 iterations in total for the GSA (5,000 iterations multiplied by the number of effective input factors 33 plus 2).

The following three alternative fleet dynamic scenarios were analysed:

1. 'fixEff' or 'sq_E', where the effort is an input parameter equal to the average of last three years;
2. 'max', where the fleets operate until the last quota is exhausted; and
3. 'min_HOM' or 'min-exhom', where the fleets stop fishing when the first quota, except that of horse mackerel (HOM), is exhausted. This year catch advice for horse mackerel is 0 and if this was included in the simulation the effort would be zero and there would not be any variability in the results.

5 RESULTS

5.1 Uncertainty conditioning

5.1.1 Catchability

Figure 9 to Figure 21 show simulated catchabilities by métier for each of the stocks targeted by the two fleets analysed. Simulated values are based on variability in catchabilities in the period between 2009 and 2021.

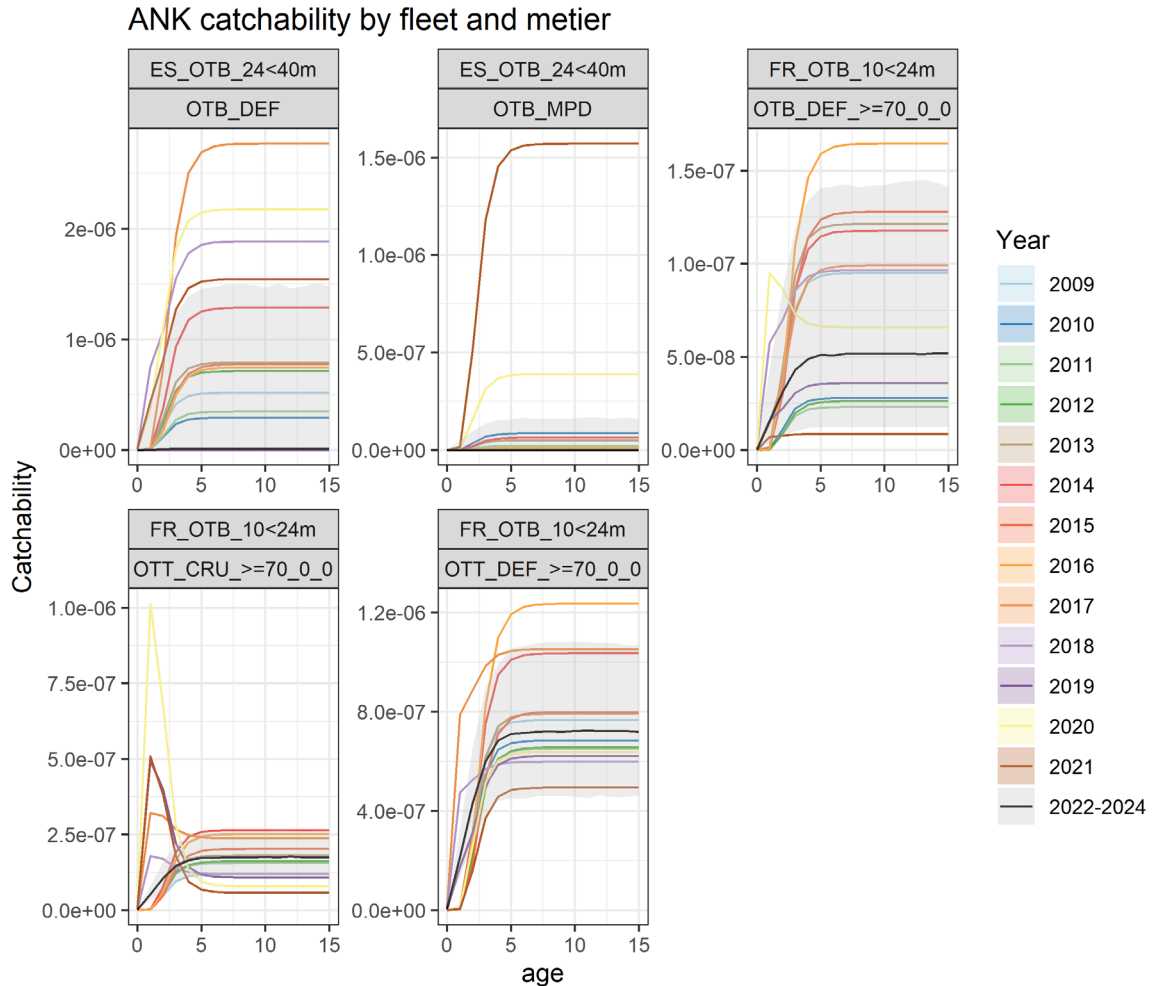


Figure 9: Black-bellied anglerfish (ANK) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

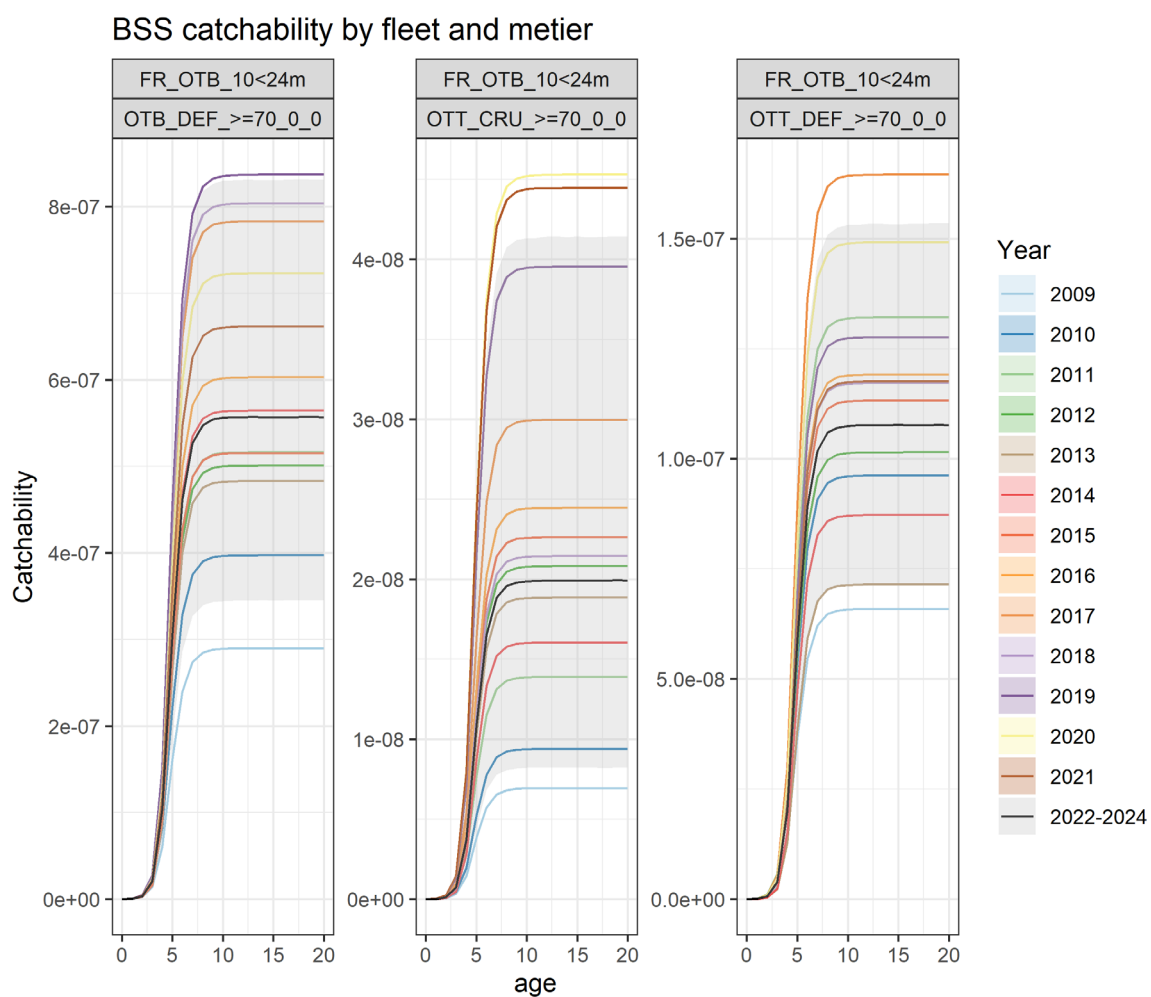


Figure 10: Seabass (BSS) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

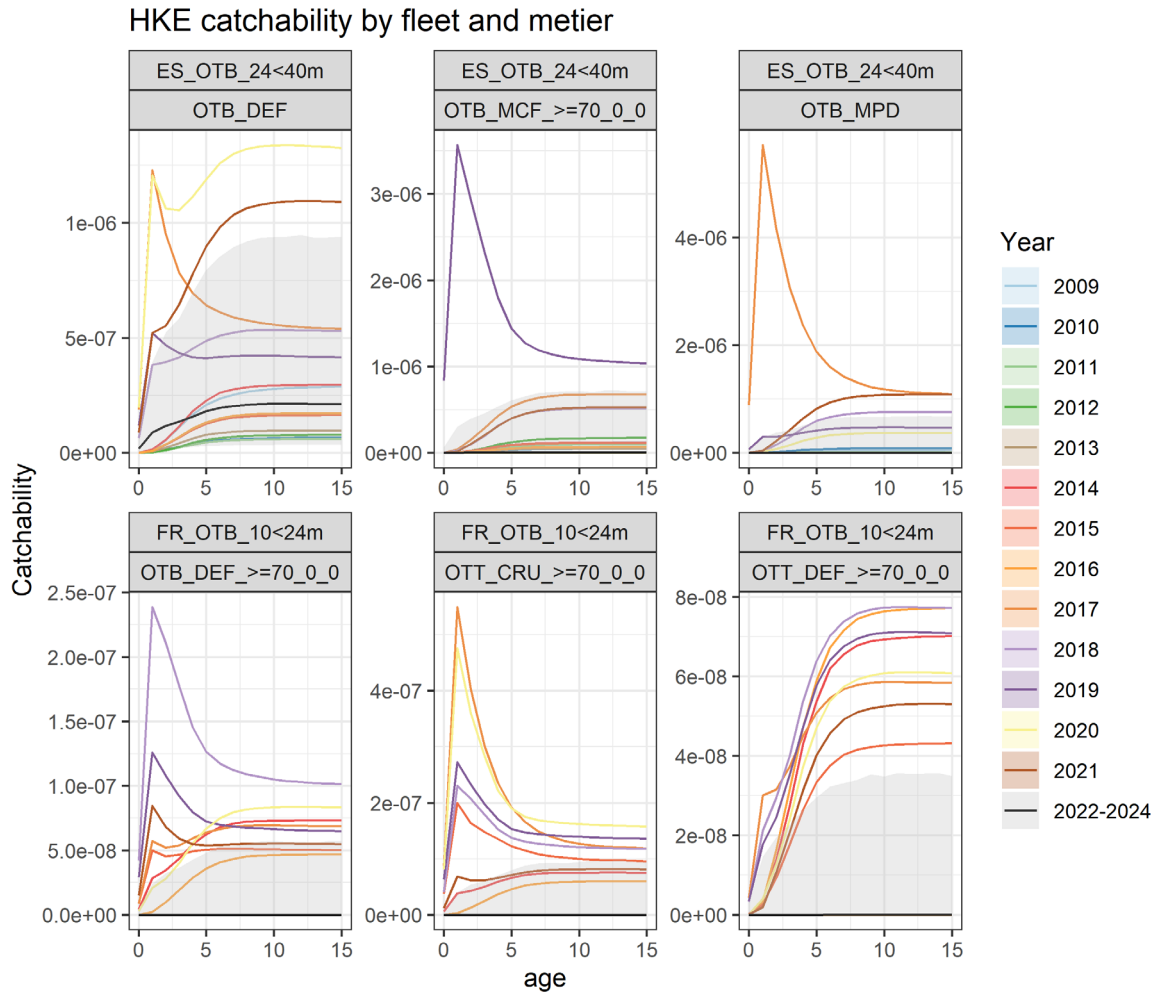


Figure 11: Hake (HKE) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

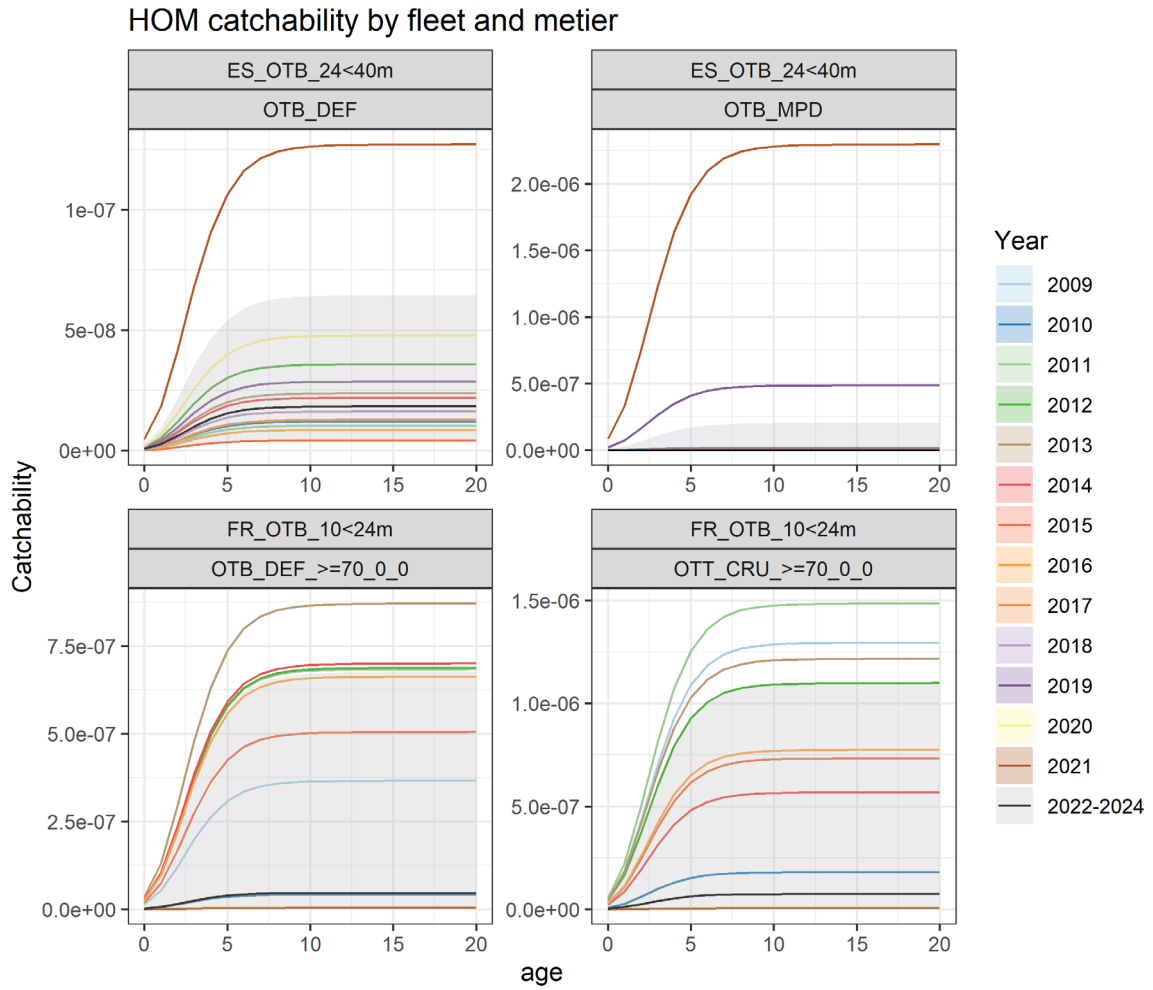


Figure 12: Horse mackerel (HOM) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

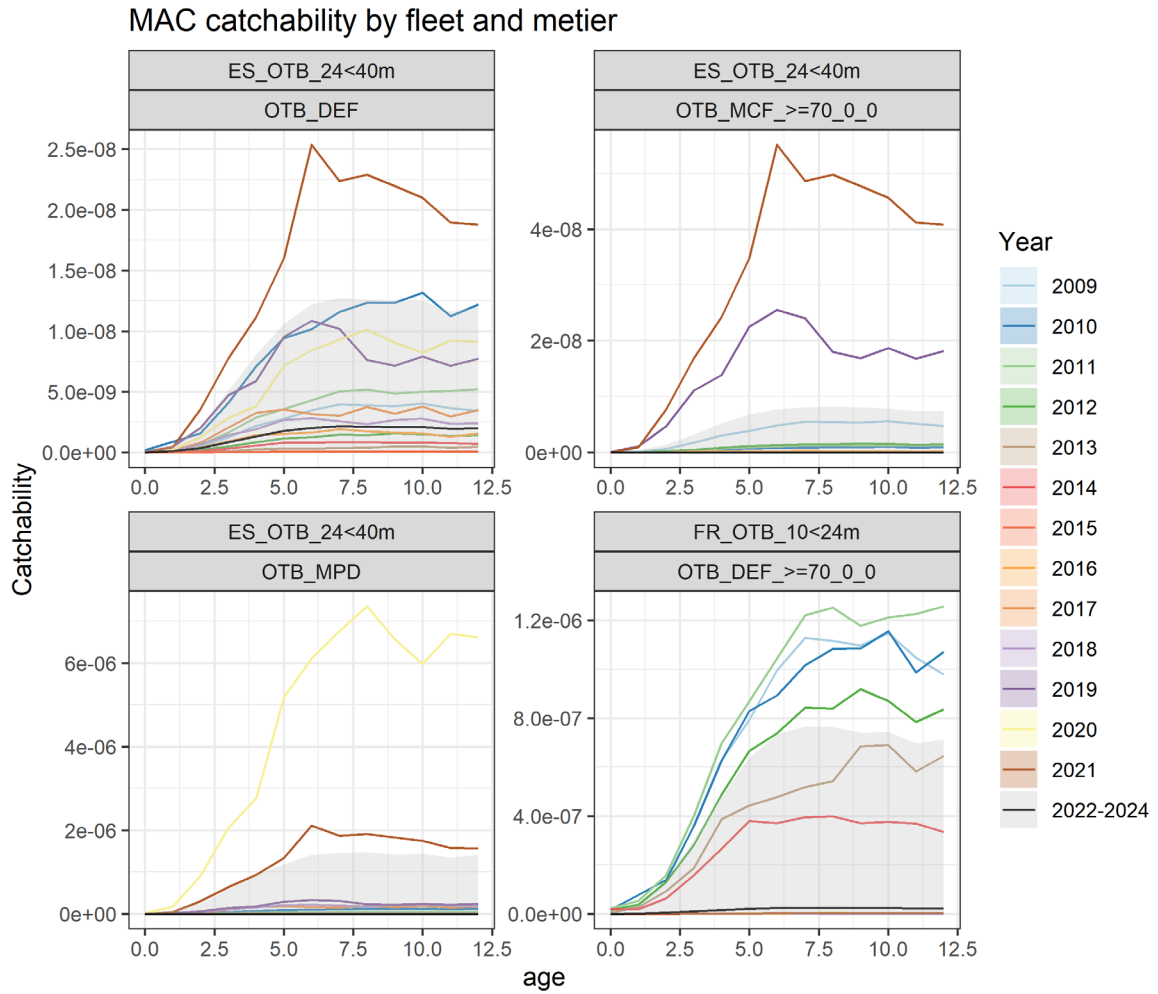


Figure 13: Mackerel (MAC) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

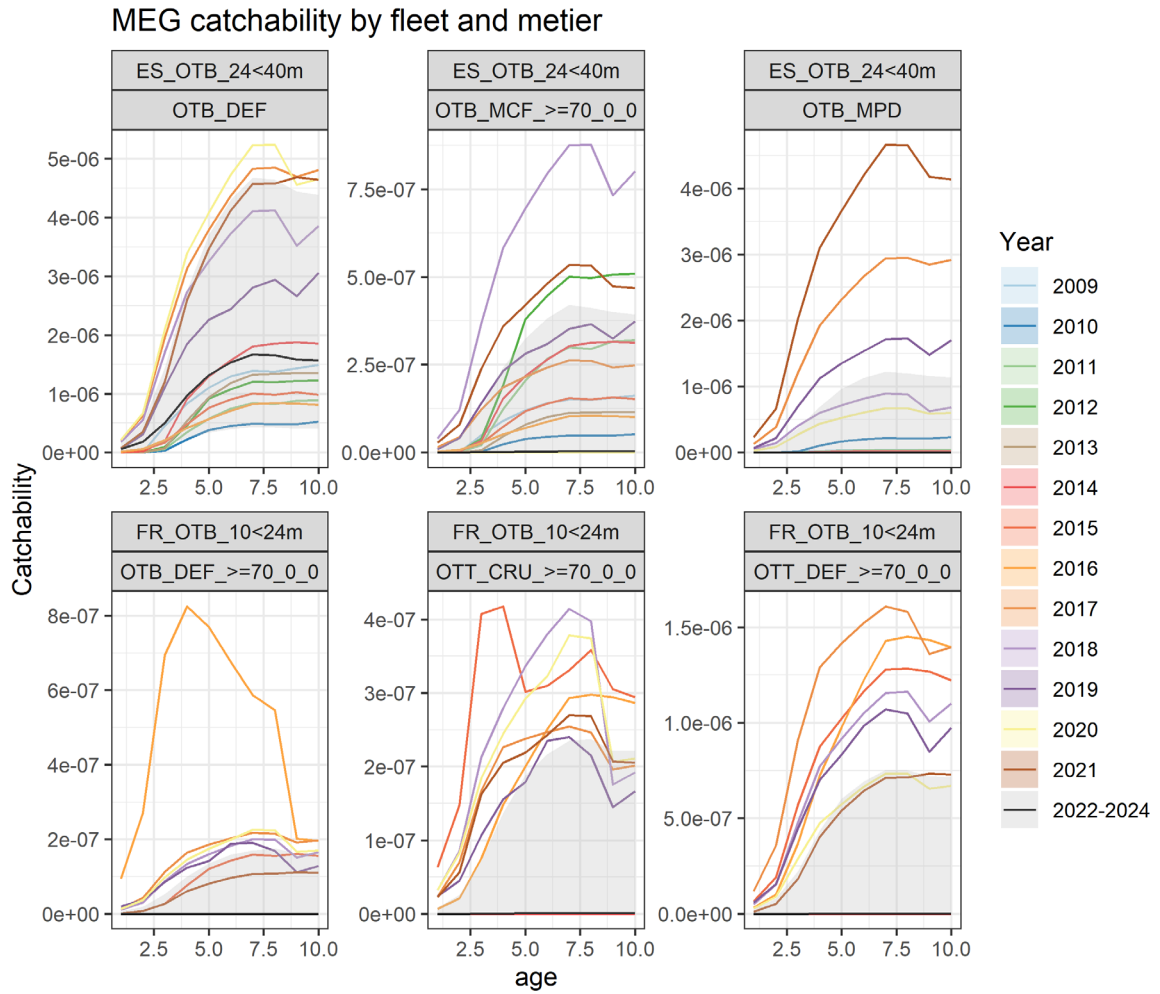


Figure 14: Megrin (MEG) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

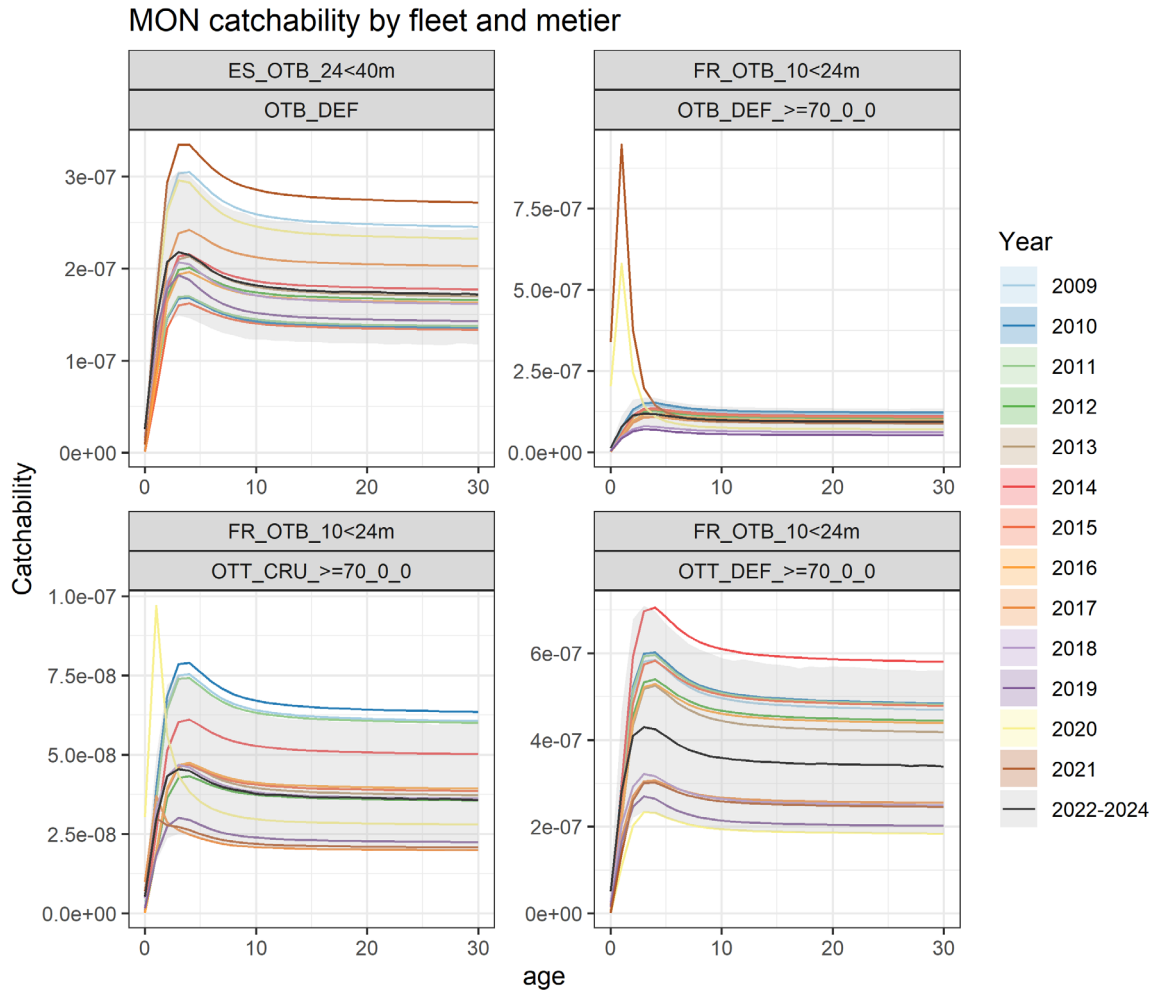


Figure 15: White anglerfish (MON) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

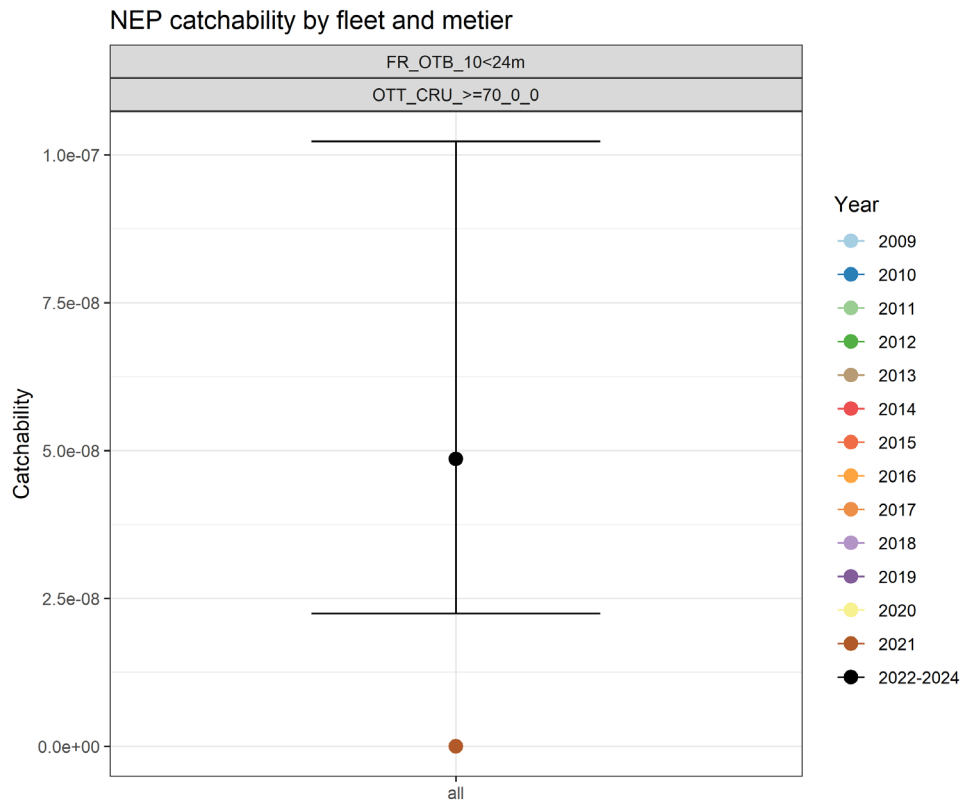


Figure 16: Norway lobster (NEP) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

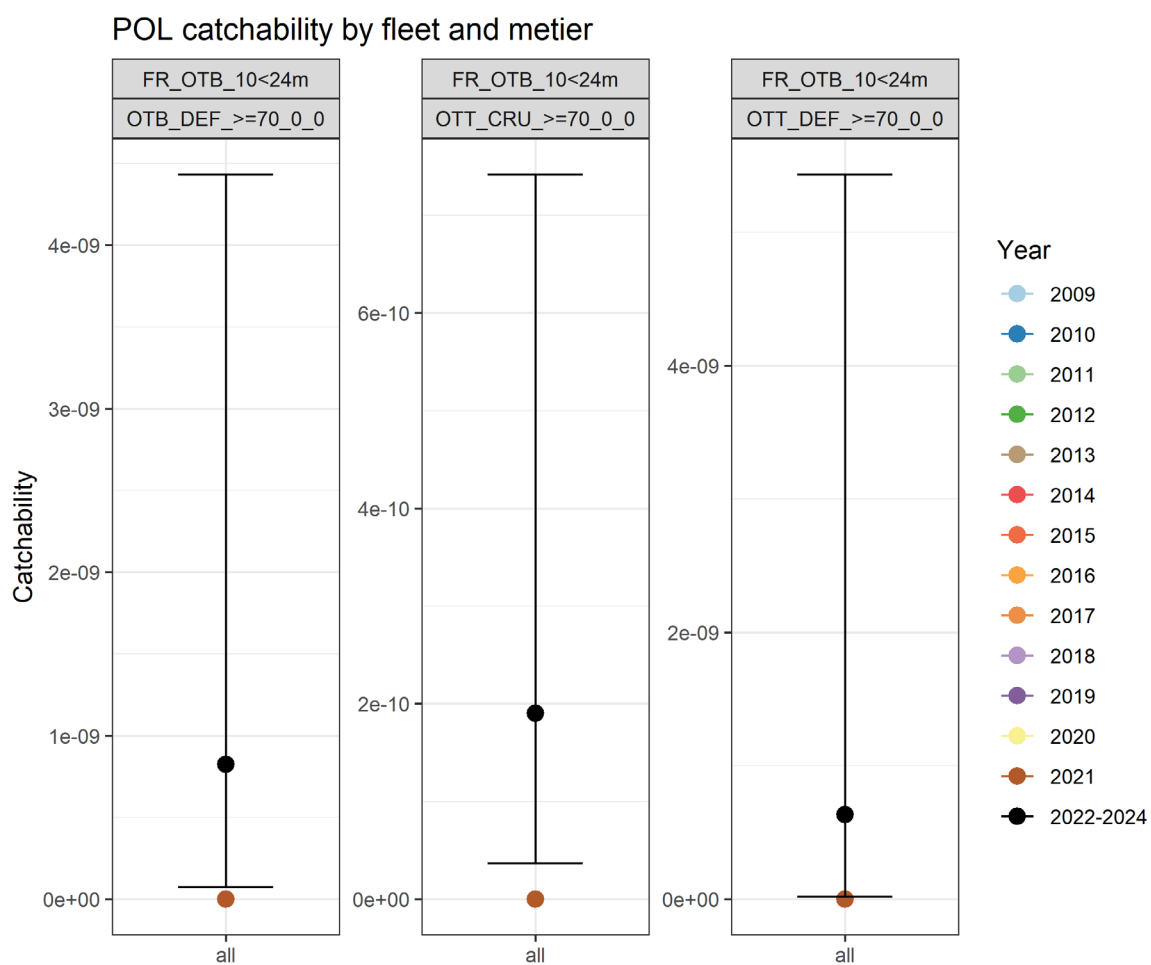


Figure 17: Pollack (POL) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

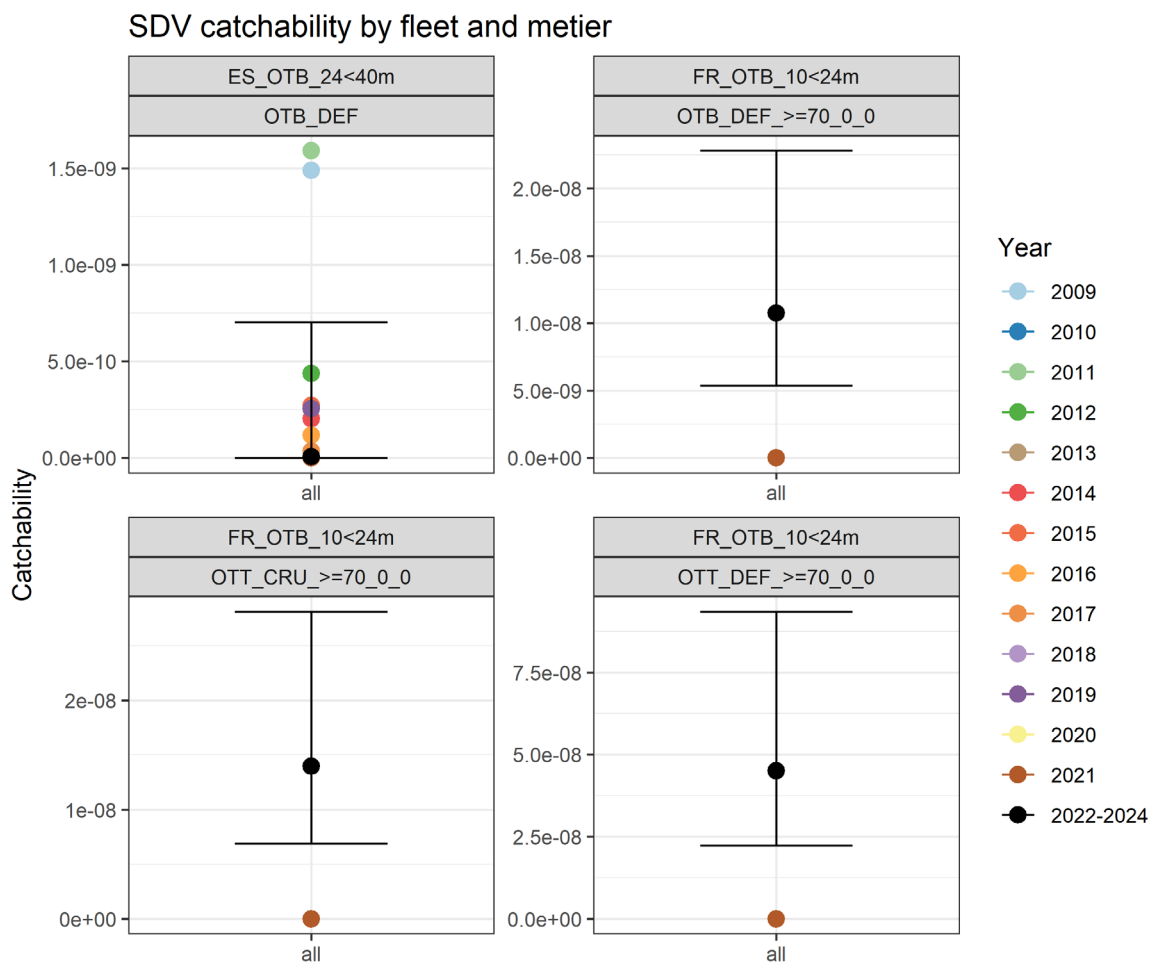


Figure 18: Smooth-hound (SDV) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

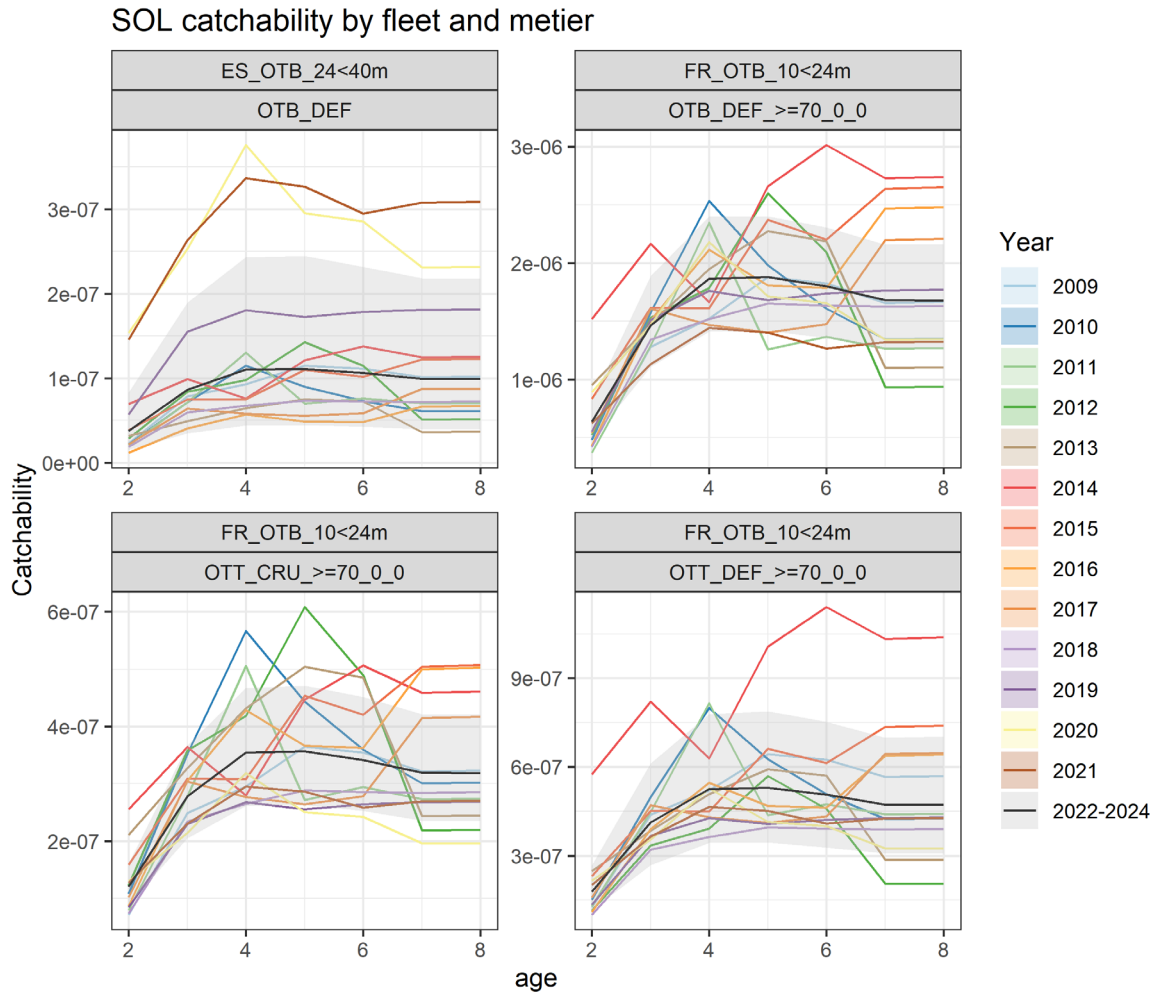


Figure 19: Sole (SOL) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

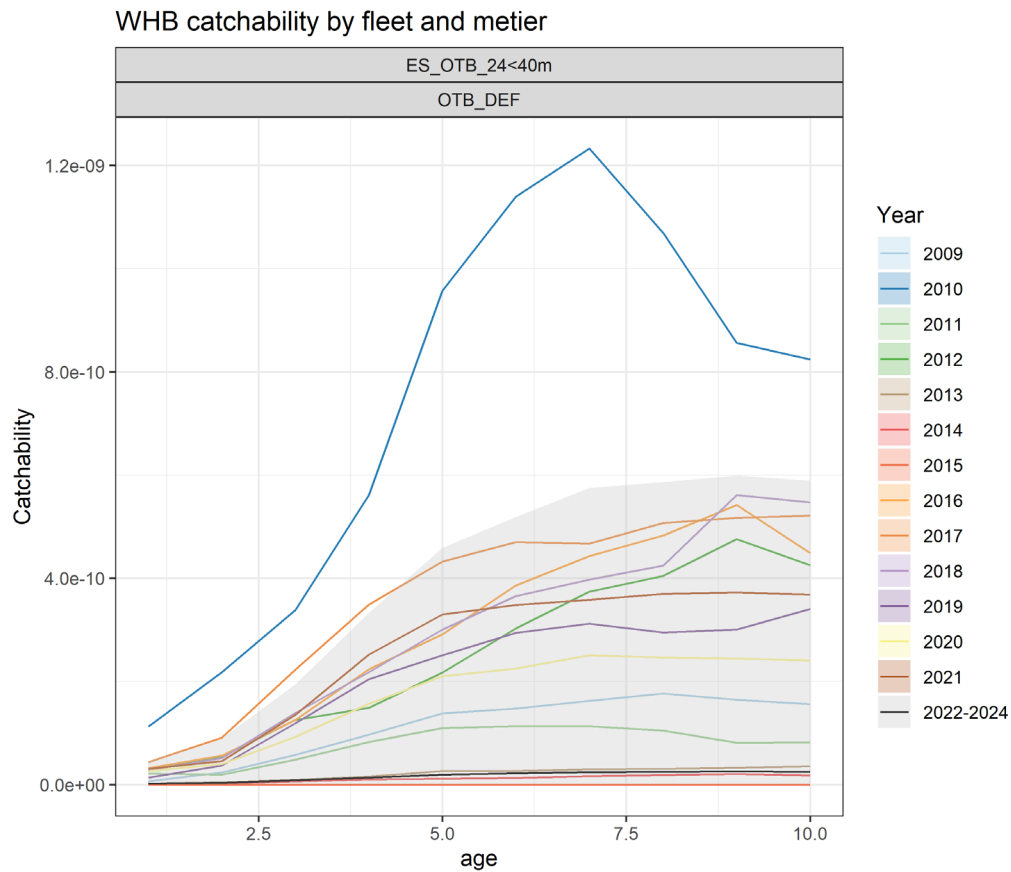


Figure 20: Blue whiting (WHB) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

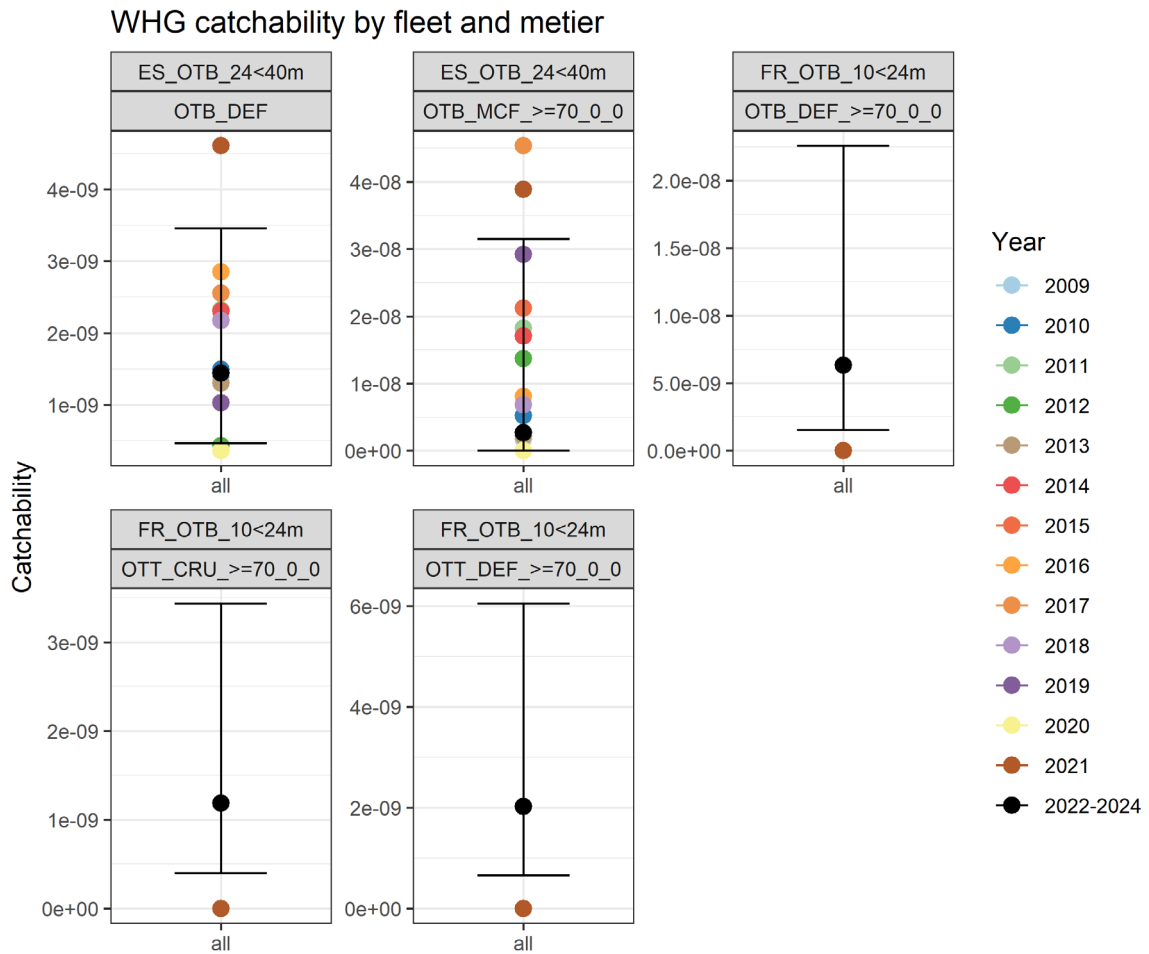


Figure 21: Whiting (WHG) catchability by métier. Each year data is represented by a different colour. Solid colour lines represent historical observed values (2009-2021) and black lines to median estimates in the projection period (2022-2024), with the grey area representing the 90 % confidence intervals.

5.1.2 Effort proportion

Figure 22 shows simulated effort proportions by métier for the two main target fleets of the study, simulated values are based on the observed effort proportions in the period 2009-2021.

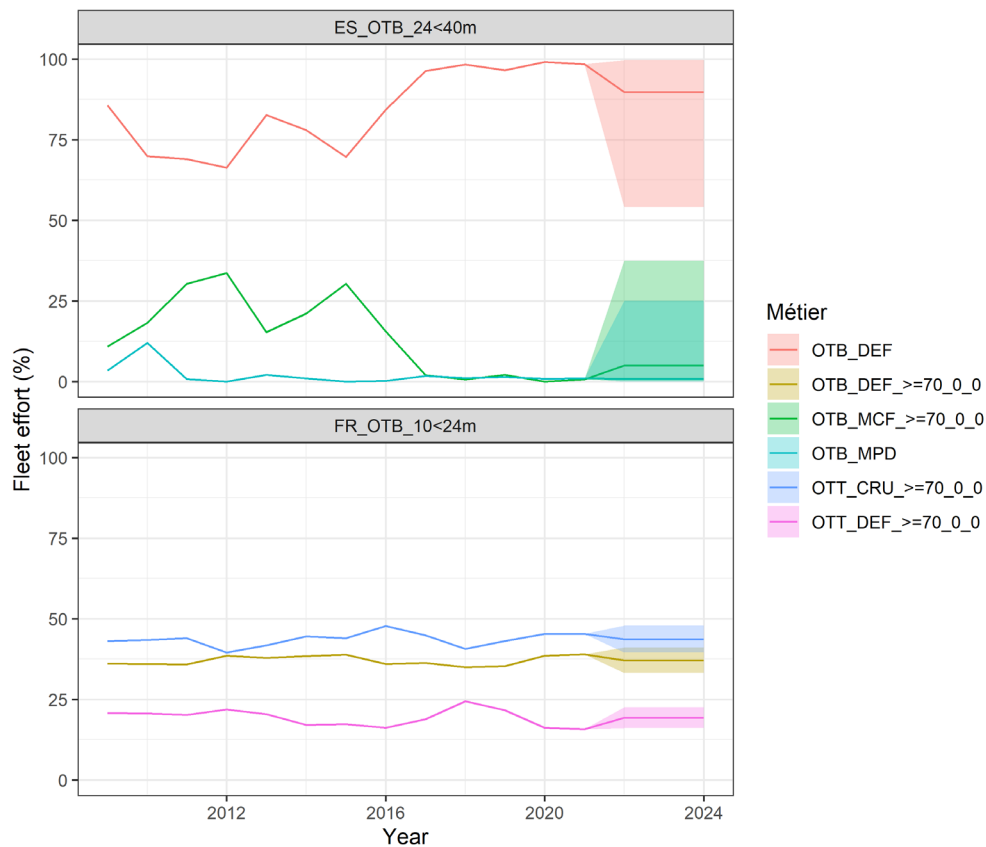


Figure 22: Effort proportion by métier for the French bottom otter trawlers 10 to 24 m in length (FR_OTB_10<24m) and the Spanish 24 to 40 m bottom trawlers (ES_OTB_24<40m). Each métier is represented by a different colour. Solid lines represent historical observed values (2009-2021) and median estimates in the projection period (2022-2024) and the coloured area represents the 90 % confidence intervals.

5.1.3 Quota share

Figure 23 shows simulated quota shares for the stocks targeted by the analysed fleets. Simulated values are based on historical quota shares and their variability (since 2009).

Study to assess the robustness of mixed fisheries scenario assumptions

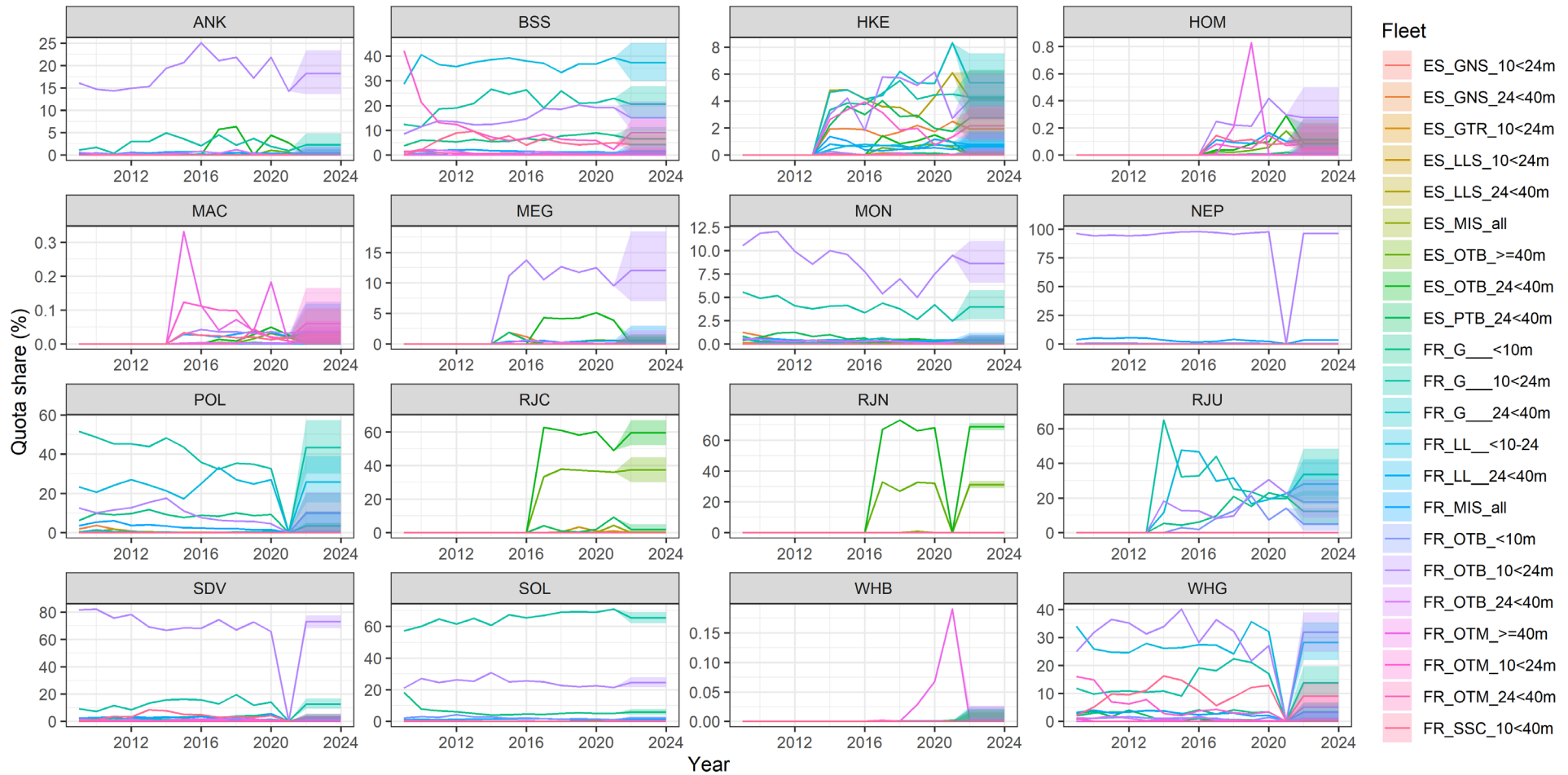


Figure 23: Quota share for the French bottom otter trawlers 10 to 24 m in length (FR_OTB_10<24m). Each stock is represented by a different colour. Solid lines represent historical observed values (2015-2021) and median estimates in the projection period (2022-2024) and the coloured area represents the 90 % confidence intervals. Stocks' codes correspond to black-bellied anglerfish (ANK), seabass (BSS), hake (HKE), horse mackerel (HOM), mackerel (MAC), megrim (MEG), white anglerfish (MON), Norway lobster (NEP), pollack (POL), thornback ray (RJC), cuckoo ray (RJN), undulate ray (RJU), smooth-hound (SDV), sole (SOL), blue whiting (WHB), and whiting (WHG).

5.2 Uncertainty analysis

5.2.1 French bottom otter trawlers (FR_OTB_10<24m)

The impact of fleet parameter uncertainty on model outputs varied depending on the effort scenarios considered (Figure 24 and Figure 25). The larger variation was observed in the 'max' scenario, both in terms of expected effort and forecasted landings.

Extremely large efforts simulated in the 'max' scenario (Figure 24) compared to status quo effort were due to cases with very low simulated catchabilities for some stocks, mainly hake and megrim.

Regarding forecasted landings, very little variation was observed in most of the scenarios, except for the 'max' scenario where very larger variation was observed (but still much lower than variation observed for effort in this scenario). This variation in forecasted landings was probably coming from the uncertainty in catchability coupled with the technical interactions among different stocks.

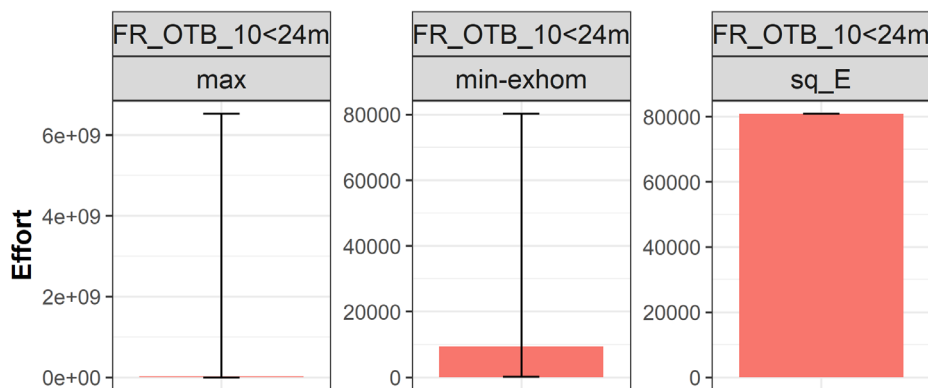


Figure 24: Variation in effort for the French bottom otter trawlers 10 to 24 m in length (FR_OTB_10<24m), given uncertainty in stocks' catchability, effort proportion by métier and quota shares by fleet and stock under alternative mixed fisheries scenarios. Bars represent median estimates and vertical lines the 90 % confidence intervals. Different scales are used due to the big differences observed between scenarios.

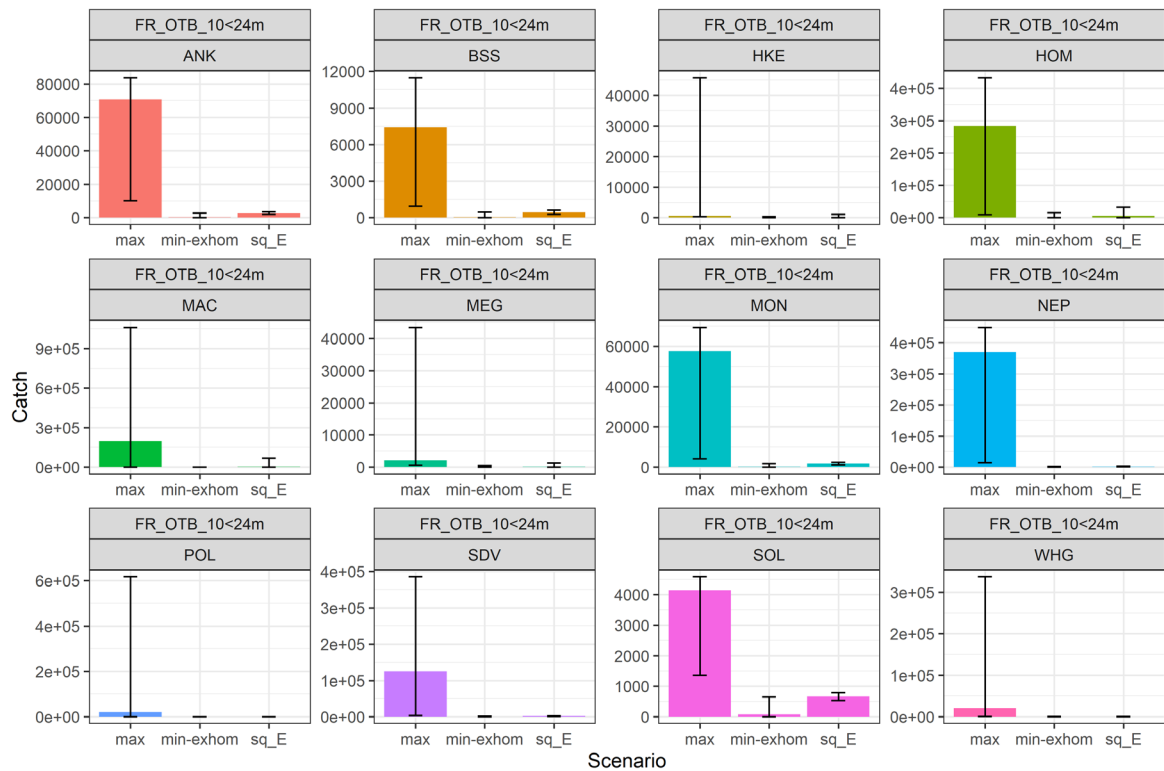


Figure 25: Variation in catches by stock for the French bottom otter trawlers 10 to 24 m in length (FR_OTB_10<24m), given uncertainty in stocks' catchability, effort proportion by métier and quota shares by fleet and stock under alternative mixed fisheries scenarios Bars represent median estimates and vertical lines the 90 % confidence intervals. Stocks' codes correspond to black-bellied anglerfish (ANK), seabass (BSS), hake (HKE), horse mackerel (HOM), mackerel (MAC), megrim (MEG), white anglerfish (MON), Norway lobster (NEP), pollack (POL), smooth-hound (SDV), sole (SOL), and whiting (WHG).

Mackerel was identified as the main choke species (with 73 % probability, Figure 26) followed by pollack, sole and seabass (with 10 %, 9 % and 6 % probabilities, respectively).

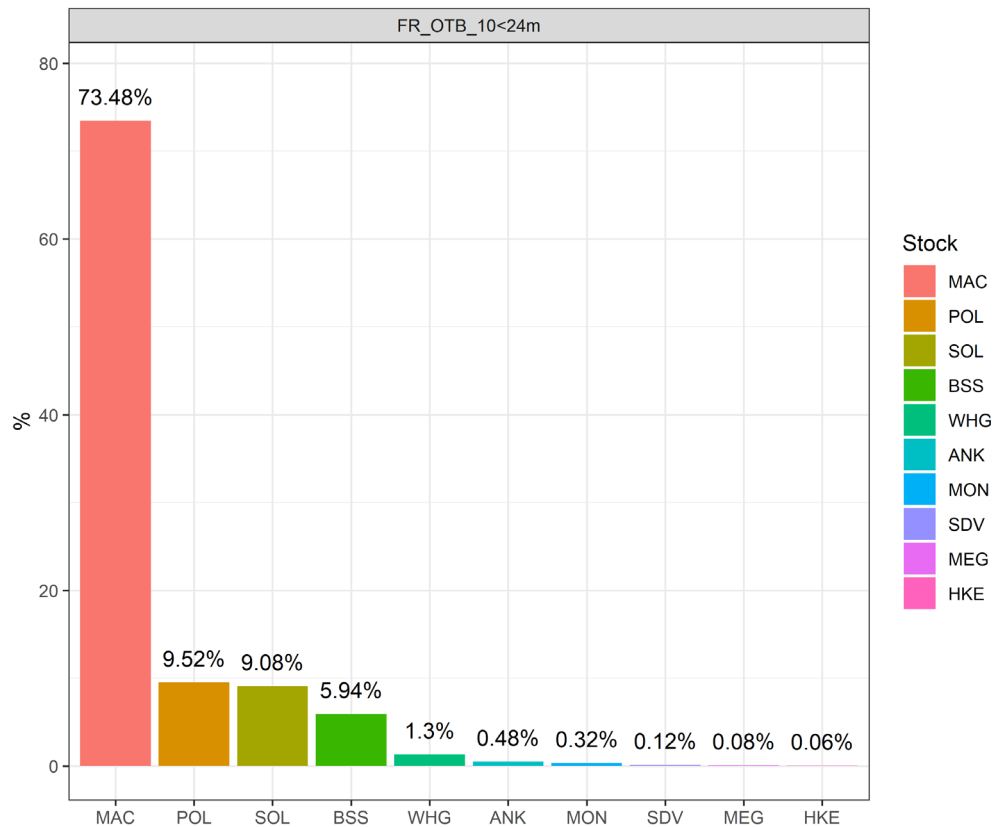


Figure 26: Frequency of choking effect by stock for the French bottom otter trawlers 10 to 24 m in length (FR_OTB_10<24m). Each stock is represented by a different colour. Stocks' codes correspond to mackerel (MAC), pollack (POL), sole (SOL), seabass (BSS), whiting (WHG), black-bellied anglerfish (ANK), white anglerfish (MON), smooth-hound (SDV), megrim (MEG), and hake (HKE).

5.2.2 Spanish bottom trawlers (ES_OTB_24<40m)

The impact of fleet parameter uncertainty on model outputs varied depending on the effort scenarios considered (Figure 27 and Figure 28). The larger variation was observed in the 'max' scenario, both in terms of expected effort and forecasted landings.

Extremely large efforts obtained in the 'max' scenario (Figure 27) compared to status quo effort were due to cases with very low simulated catchabilities for some stocks, mainly for blue whiting, but also for smooth-hound and white anglerfish. These high variations in the 'max' scenario were also obtained in the forecasted landings. This variation in forecasted landings was probably coming from the uncertainty in catchability coupled with the technical interactions among different stocks, as occurred for the French bottom otter trawlers.

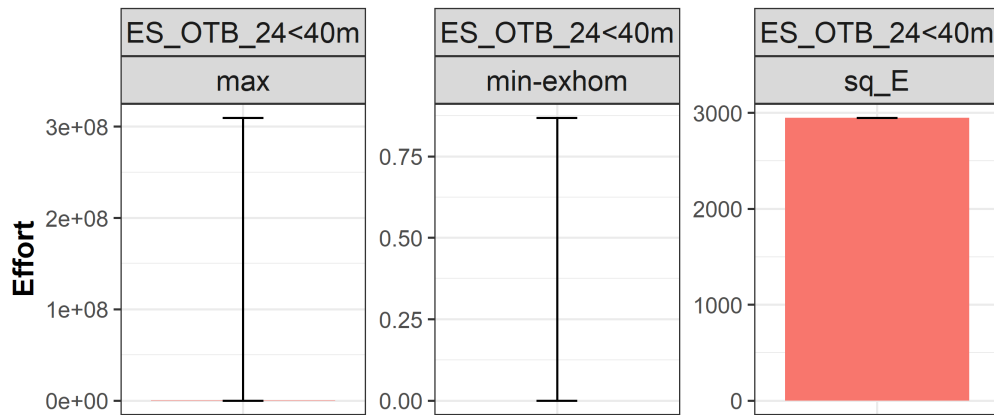


Figure 27: Variation in effort for the Spanish 24 to 40 m bottom trawlers (ES_OTB_24<40m), given uncertainty in stocks' catchability, effort proportion by métier and quota shares by fleet and stock under alternative mixed fisheries scenarios Bars represent median estimates and vertical lines the 90 % confidence intervals. Different scales are used due to the big differences observed between scenarios.

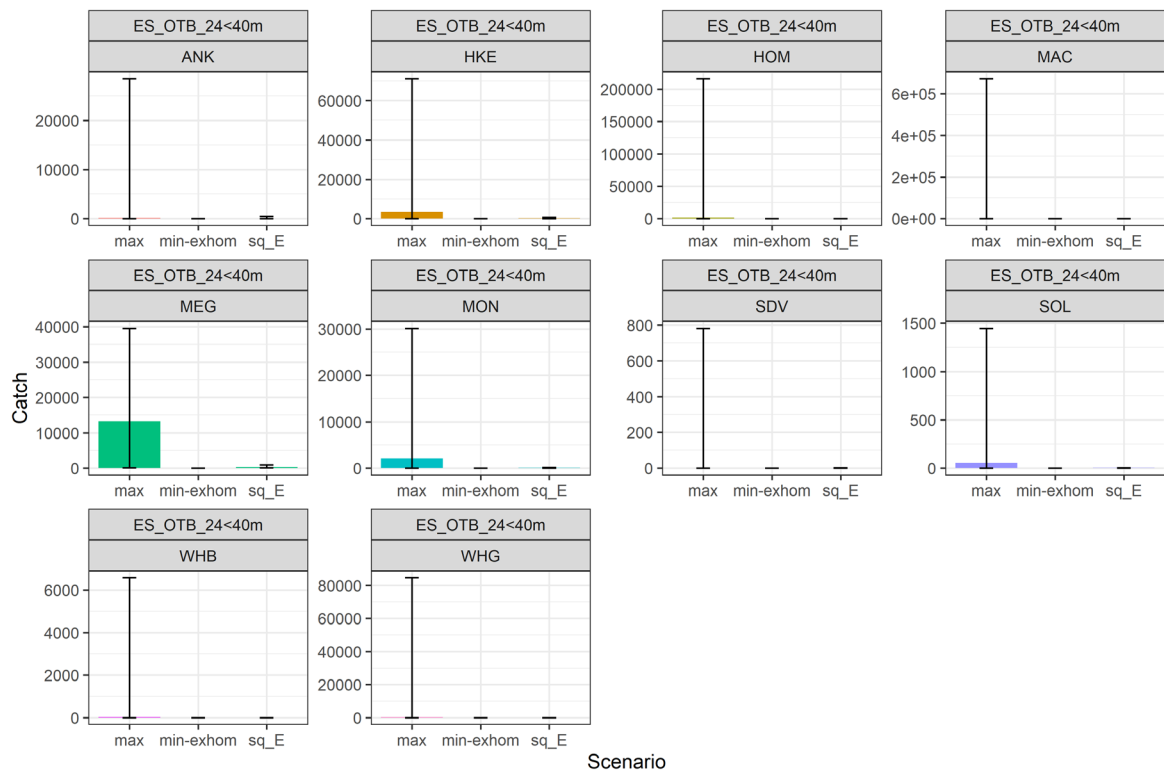


Figure 28: Variation in catches by stock for the Spanish 24 to 40 m bottom trawlers (ES_OTB_24<40m), given uncertainty in stocks' catchability, effort proportion by métier and quota shares by fleet and stock under alternative mixed fisheries scenarios Bars represent median estimates and vertical lines the 90 % confidence intervals. Stocks' codes correspond to black-bellied anglerfish (ANK), hake (HKE), horse mackerel (HOM), mackerel (MAC), megrim (MEG), white anglerfish (MON), smooth-hound (SDV), sole (SOL), blue whiting (WHB), and whiting (WHG).

Blue-whiting, smooth-hound and black-bellied anglerfish were identified as the main choke species (with probabilities between 20 % and 16 %, Figure 29) followed by megrim, hake and mackerel (with probabilities lower than 5 %)

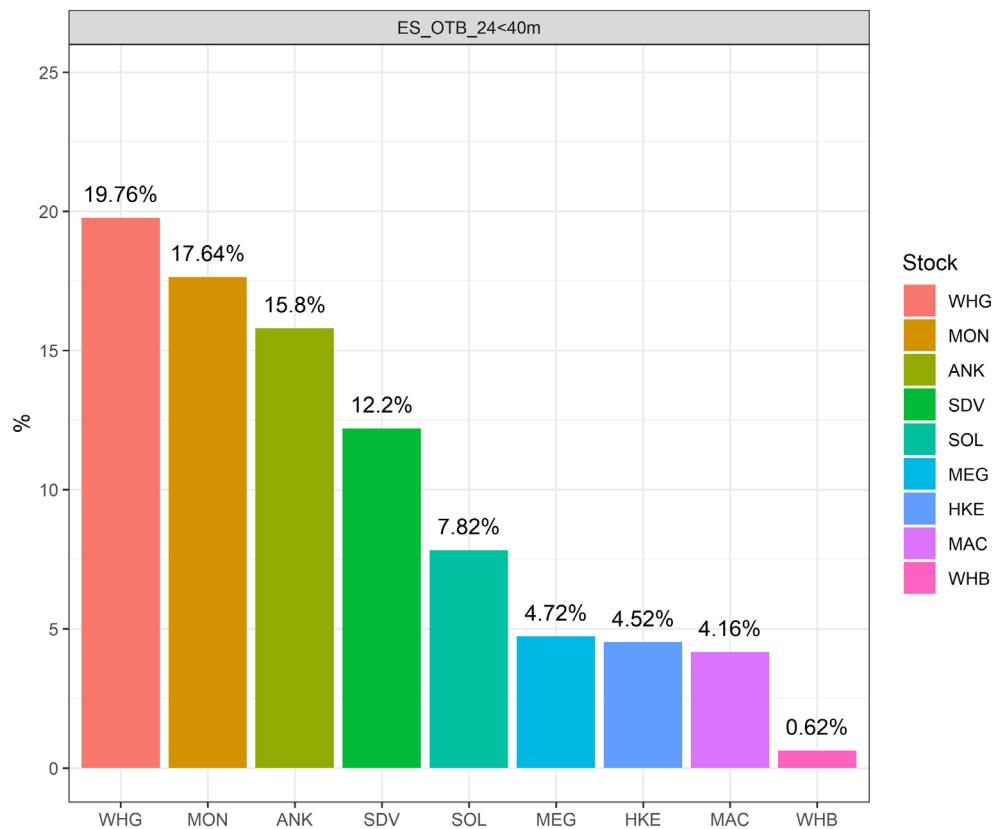


Figure 29: Frequency of choking effect by stock for the Spanish 24 to 40 m bottom trawlers (ES_OTB_24<40m). Each stock is represented by a different colour. Stocks' codes correspond to whiting (WHG), white anglerfish (MON), black-bellied anglerfish (ANK), smooth-hound (SDV), sole (SOL), megrim (MEG), hake (HKE), mackerel (MAC), and blue whiting (WHB).

5.3 Global Sensitivity Analysis

5.3.1 Spanish bottom trawlers (ES_OTB_24<40m)

The total effort in the max scenario depended mostly on the intensity exerted by the fleet in each of the métiers (Figure 30). Furthermore, the variance was mainly explained by the interaction between input factors. The quota-share of some stocks in isolation explained some of the output variance. This happened because these stocks were the less restrictive stocks for the fleet in some cases. In the 'min' scenario the most important input factor was the intensity in the 'DEF' métier (the one targeting demersal fishes) that is the most important métier for the fleet. In this case, most of the variance was explained by the input factor in isolation. In this scenario the quota shares had higher impact and the impact was similar for all the stock except for black-bellied anglerfish. For horse mackerel the impact was almost zero because it never limited the effort of the fleet.

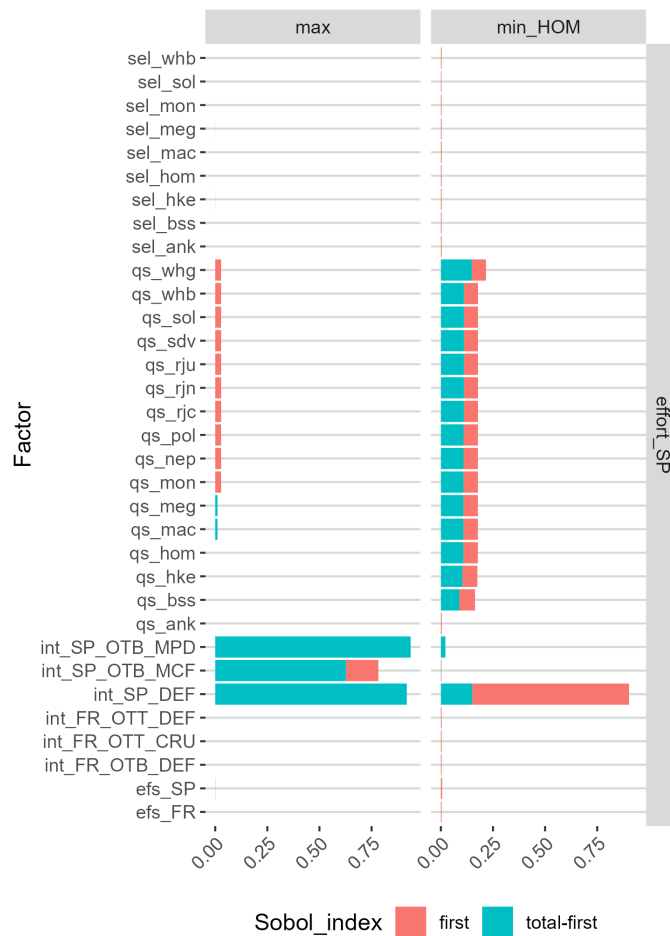


Figure 30: Global sensitivity indicators for the Spanish trawling fleet: effort under 'max' and 'min_HOM' scenarios. Red bar corresponds with the first order index and the whole bar (red plus blue) with the total index.

In the scenario where the effort was fixed 'fixEff' and the 'max' scenario (scenario where the fleets continue fishing until the last quota is exhausted) the only input factor that had a significant impact in the output variance of the stock catches was the intensity with which the stocks were caught (Figure 31 and Figure 32). The rest of the factors had some marginal impact, especially quota share. The main difference between scenarios was that while in the 'fixEff' scenario the variance was explained almost exclusively by the input factors in isolation, in the 'max' scenario most of the variance was explained in interaction among factors. In the 'fixEff' scenario, the effort level (the variable that is directly related to the catch level) was fixed as an input parameter and hence the interaction between the input factors was low.

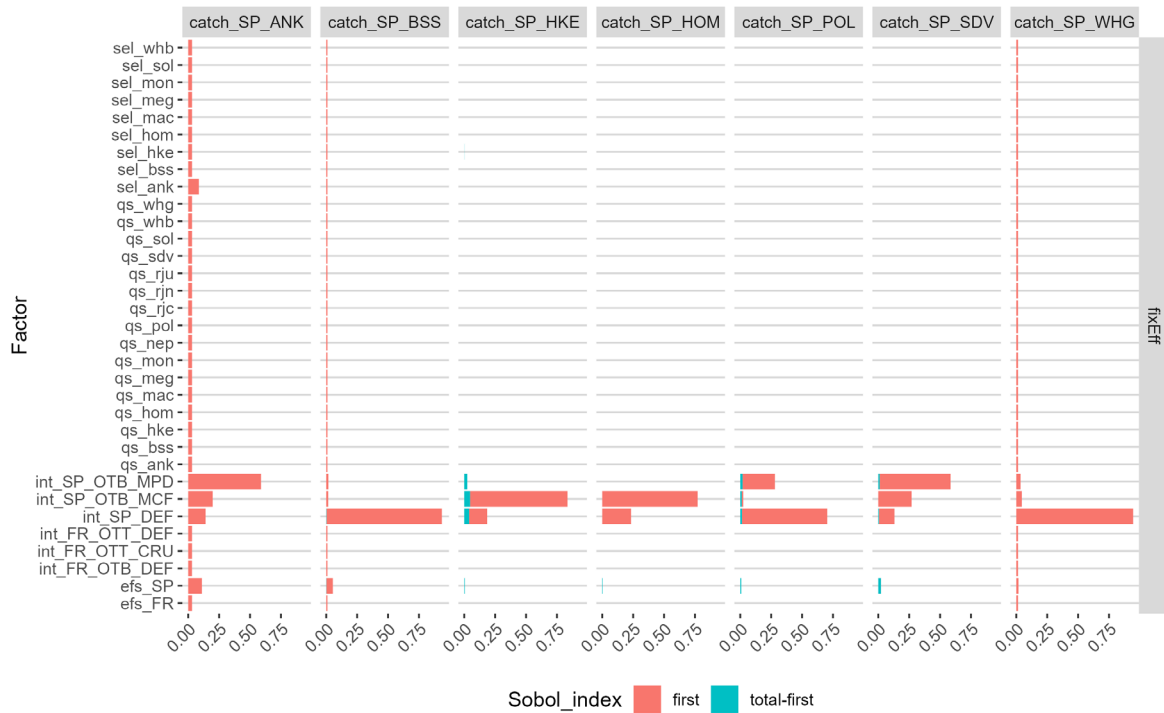


Figure 31: Global sensitivity indicators for the Spanish trawling fleet: catch under 'fixEff' scenario. Red bar corresponds with the first order index and the whole bar (red plus blue) with the total index.



Figure 32: Global sensitivity indicators for the Spanish trawling fleet: catch under 'max' scenario. Red bar corresponds with the first order index and the whole bar (red plus blue) with the total index.

In the 'min_HOM' scenario the variable with the highest impact was the intensity exerted in the most important métier, the Spanish otter trawlers targeting demersal fish, (int_SP_DEF, Figure 33). Furthermore, in most of the cases, most of the variance was explained by the input factor in isolation. In this case, the quota shares of all the stocks, except horse mackerel (HOM), had a significant impact in the output variance. The amount of variance explained by the input factor in isolation and in interaction with other factors depended on the stock.



Figure 33: Global sensitivity indicators for the Spanish trawling fleet: catch under 'min' scenario. Red bar corresponds with the first order index and the whole bar (red plus blue) with the total index.

The probability of being a choke stock was the variable that was affected by more input factors (Figure 34). As expected, in this case the quota share explained a significant proportion of the variance. The selectivity, that had little impact in catch and effort variables, had some impact in this case and the impact was almost always of first order (i.e. the interaction of selectivity with other input factors did not have almost any impact in the output variance). The effort proportion among métiers also had a significant impact in this case, especially for white anglerfish, hake and smooth-hound. The values around 0.25 and 0.15 for anglerfish, smooth-hound and withering are likely related to a convergence issue and do not indicate a real impact in the choking effect.



Figure 34: Global sensitivity indicators for the Spanish trawling fleet: probability of being a choke stock under 'min' scenario. Red bar corresponds with the first order index and the whole bar, red plus blue, with the total index

5.3.2 French bottom otter trawlers (FR_OTB_10<24m)

The total effort in the max scenario depended mostly on the intensity exerted by the fleet in the OTB_DEF métier (i.e. the otter trawlers targeting demersal fish) and the quota share of whiting (WHG), blue whiting (WHB), smooth-hound (SDV) and two of the rays (RJU and RJN) (Figure 35). In the 'min_HOM' scenario, all the quota-shares contributed significantly to the variance, the stocks which contributed the less were the horse mackerel, hake, seabass and anglerfish. The contribution of the rest of the input factors was similar. The variance in both scenarios was fully explained by the interaction between input factors.

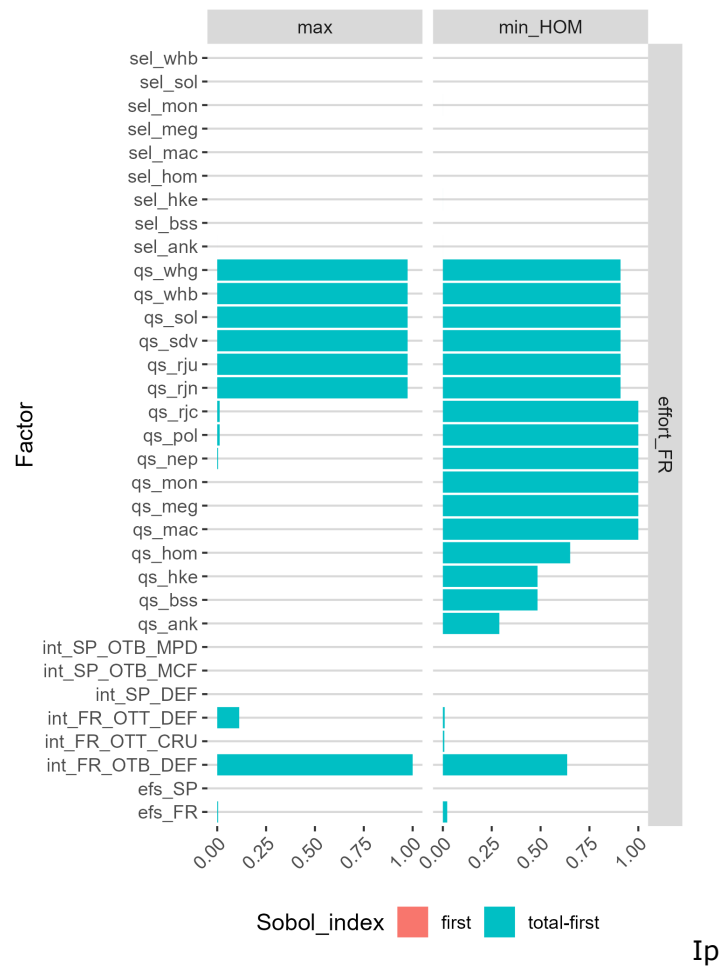


Figure 35: Global sensitivity indicators for the French trawling fleet effort under 'max' and 'min' scenarios. Red bar corresponds with the first order index and the whole bar (red plus blue) with the total index.

In the scenario where the effort was fixed, 'fixEff', the intensity on the 'OTB_DEF' métier and the effort proportion among métiers were the only factors with a significant impact in the results (Figure 36). For some stocks (horse mackerel, mackerel and one of the rays) the value of the first order index for the rest of the input factors was positive and had a very similar value which is attributed to a convergence problem and not to a real effect. The variance was explained by both the factors alone and in interaction with each other.

In the 'max' scenario the intensity in the OTB_DEF métier and the quota-share of some of the stocks, bycatch stock specially, were the input factors with the highest impact on the output variance (Figure 37). The variance was partially explained by factors in isolation and partially in interaction among themselves.

In the 'min' scenario, all the quota shares had a significant impact on the output variance of catches (Figure 38). Apart from that, the intensity in the OTB_DEF métier and other métiers in particular cases, and the effort proportion among métiers also had significant impact. In the case of the white anglerfish, except the intensity, all the other factors had an impact of first order. In the case of intensity, the impact was in interaction with other factors.

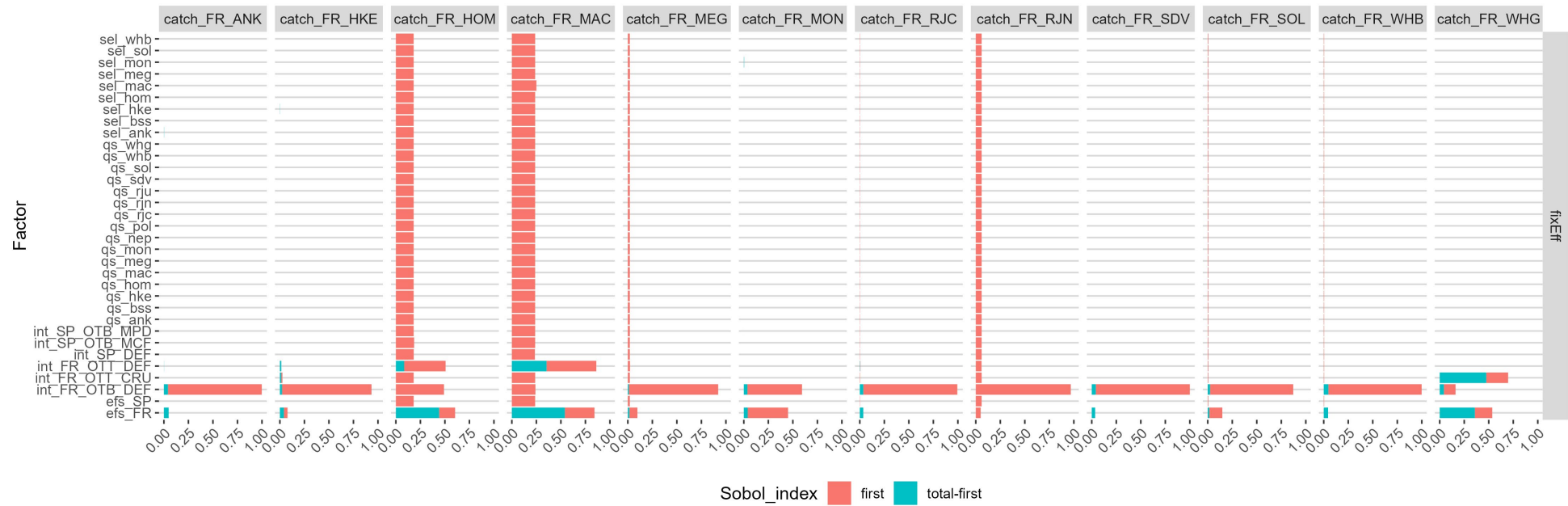


Figure 36: Global sensitivity indicators for the French trawling fleet catch under 'fixEff' scenario. Red bar corresponds with the first order index and the whole bar (red plus blue) with the total index.

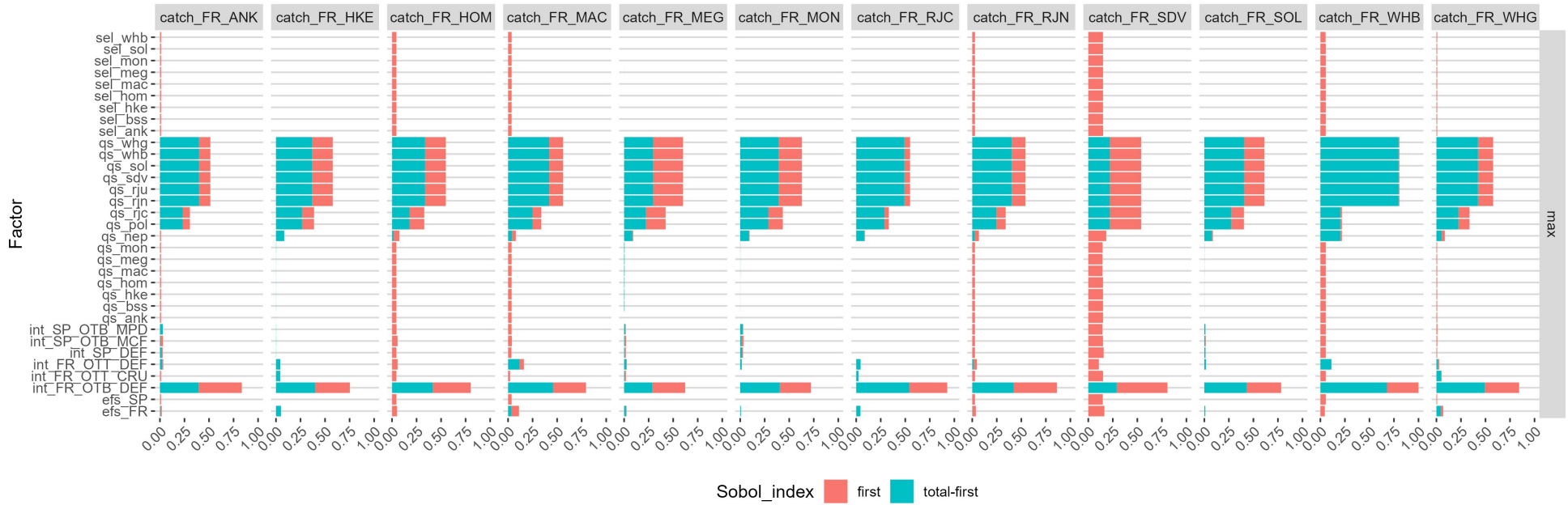


Figure 38: Global sensitivity indicators for the French trawling fleet: catch under 'min_HOM' scenario. Red bar corresponds with the first order index and the whole bar (red plus blue) with the total index.

Study to assess the robustness of mixed-fisheries scenario assumptions

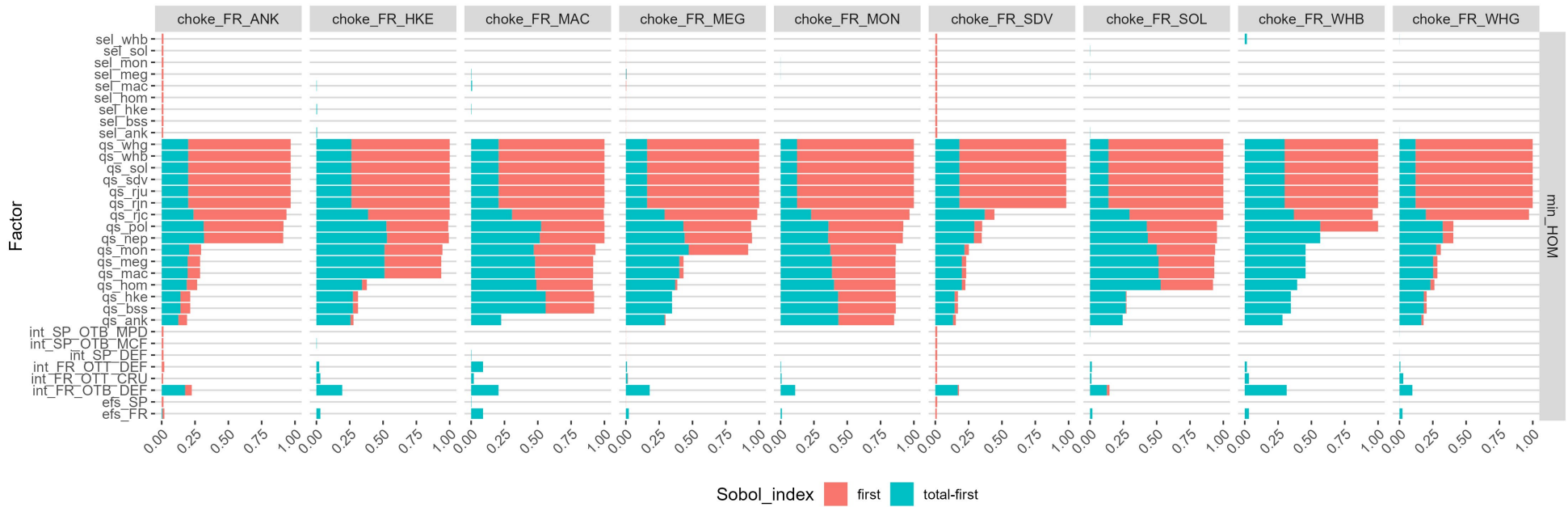


Figure 39: Global sensitivity indicators for the Spanish trawling fleet: probability of being a choke stock under 'min_HOM' scenario. Red bar corresponds with the first order index and the whole bar (red plus blue) with the total index.

The probability of being a choke stock was mainly driven by the quota-shares in the case of France (Figure 39). The intensity in the OTB_DEF métier in interaction with other factors also explained a significant part of the variance, but less than the quota shares. The quota shares of the stocks with a constant CPUE approach, together with sole and blue whiting, had the highest impact in the probability of being a choke stocks. The impact was mainly in isolation but the interaction between input factors was also significant.

6 CONCLUSIONS

Propagation of fleet parameter uncertainty in mixed fisheries forecasts was carried out through a study, which introduced Monte Carlo simulations to stochastically sample input parameter values from historical data. These have been developed as a set of generic methods that could be applied to the conditioning of any mixed fishery model. The impact of fleet parameter uncertainty on model outputs varied depending on the stock and the effort scenarios considered and could be greatly impacted by technical interactions. Variations in forecasted landings were observed under different effort scenarios, underscoring the necessity for more precise data in specific areas of mixed fisheries forecasting.

Parameter uncertainties in forecasting were examined for the Bay of Biscay main fleets, and output uncertainty quantified to be able to identify most influential parameters. The intention was to understand how uncertainties in historical data and input parameters affect model projections.

The mixed fisheries models involve numerous input parameters, including catchability, effort distribution, and quota allocations. These models rely on historical data, which may be error-prone, for parameter conditioning. Sensitivity analysis is crucial for understanding the relationship between input uncertainties and output variations. GSA efficiently characterizes this relationship but can be computationally demanding. Within the Bay of Biscay case study GSA was implemented to assess the sensitivity of catchability, quota-share, and effort proportion.

The Bay of Biscay case study focused on conducting an uncertainty analysis and GSA for demersal mixed fisheries in the region, with a particular focus on French and Spanish fleets as proof of concept. The uncertainty conditioning approach used estimates of the uncertainties in selectivity and intensity separately, extracting first the intensity and modelling the selectivity afterwards. In the future, both intensity and selectivity could be estimated simultaneously instead of doing it in two steps. The key problem would be to propose an appropriate model that accounts for the correlation among different species intensities. As a further step, intensities could be modelled using a time series-oriented approach (e.g., AR1 or random walks) so that predictions in one year depend on the predictions in the year before.

Introduction of uncertainty provided a better representation of plausible future situations. In a deterministic approach, a single stock is identified as the choke stock for each fleet in the landing obligation scenario, however there were several stocks that had similar probability of choking the fishery but were hidden in the deterministic approach.

The intensity with which the stocks are caught in each métier were the input factors that had the highest impact in almost all the output variables analysed. The variance in the intensity input factors was high, in fact, the confidence intervals were limited not to greatly exceed the historical observations. The high uncertainty in the intensity could have conditioned the results, giving prominence to this variable to the detriment of the rest.

The selectivity had little impact in output variables analysed. The role of selectivity in the model is to give age structure to the catches, but does not impact the volume. Thus, in the short term, where catch structure and biomass are not analysed, it makes sense not to have any impact. However, in long term simulations when there is a feedback loop between the stock biomass and exploitation pattern its impact could be significant. If the output variables explained included some type of structure related with the age, the impact would be higher too.

Quota-share explained a significant part of the output variance for some variables, especially in the event of strict compliance with the landing obligation ('min_HOM' scenario), but the amount explained was low in general. The low observed variability in the input data and the high variability in the intensity input factor could have downplayed the importance of this input factor. Quota-share was conditioned based on the historical catches instead of in real quotas and including the uncertainty in the process of quota trading could be interesting.

Garcia et al. (2021) conducted a GSA in the Iberian Waters mixed fisheries demersal system and found that effort-share was the most important input factor. However, in this case study effort proportion among métiers had very limited impact. Garcia et al. (2021) applied the same variability to all the input factors, which likely over-estimated the variance in this variable and as a result its relevance was over-estimated. This contradiction highlights the importance of conditioning the uncertainty properly.

7 RECOMMENDATIONS

- Correlation among stocks' catchability arises at haul level, however mixed fisheries models are conditioned at métier level, and the correlation between the catchability (intensity) was derived at this more aggregated level. It could be interesting to calculate correlation among stock catchabilities at haul level and compare them with the correlations obtained in this analysis to check if they are similar. Alternatively, it could be interesting to analyse options for using existing data at the haul level to improve conditioning at the métier level.
- There were several NA-s in the catchability data that were replaced by a low number. This had a big impact in the conditioning in some cases which in turn impacted in the results. Alternative conditioning should be tested and, if possible, data time series completed.
- The GSA results are very sensitivity to the uncertainty conditioning. In this case the variance in the intensity was limited because the model used produced too wide confidence intervals that extended beyond the historical observations. This behaviour could be related to the lack of long enough time series data and the selected model itself. Further research is needed to extend the time series data and improve the models used in the uncertainty conditioning.
- Due to time constraint, convergence of the indices has not been analysed. However, Garcia et al. (2021) used 10,000 base interactions with a more complex model and observed that the sensitivity indices were fairly stable from 2,000 iterations forward. However, in that analysis they used Sobol sequences to speed up the convergence (Renardy et al., 2021). The work here attempted to use Sobol sequences in this analysis, however, it was not possible to transform Sobol sequences to constrained sampling of intensity. The sensitivity indices showed little variability in some cases (quota share indices for example), the reason for such pattern could be related to convergence issues and should be investigated in further analysis.
- Sobol sequences are usually used in GSA to reduce the computational cost of the analysis. These sequences are sequences of pseudo random numbers that ensure an optimum coverage of the unit hypercube. Using random numbers, the coverage of high

dimensional spaces becomes very inefficient. In this case we couldn't use these sequences because it was not possible to transform from Sobol sequences to truncated log-normal multivariate distributed numbers. It is recommended to quantify the save in computational cost in Sobol sequences to know if it is worth to use them and avoid using truncated distributions in the conditioning if relevant.

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ANNEX 14: TRIP-BASED VISUALISATIONS HIGHLIGHTING VARIABILITY IN TARGET BEHAVIOUR AND CATCH COMPOSITION

This annex provides additional trip visualisations of variability in target behaviour and catch composition between individual fishing trips.

Landing proportions at the trip level were calculated. From the landing proportions, trips were classified according to the dominant species in terms of landing composition. This classification enables trips to be grouped according to the 'target' behaviour (i.e. the species with the highest share in the landings). It also enables visualisation of how variable targeting is between trips.

For each trip the catch composition is calculated and assigned a colour to indicate the proportion of the species in the landings (where black indicates high proportions and yellow indicates low proportions) at trip level. As such, the graphs show the variability in catch composition of trips with a certain targeting behaviour, as well as the relative number of other species caught alongside 'target' species. To aid visualisation, trips targeting species that contribute less than 0.5% to the total number of trips are excluded from the figure, and rare species are grouped in an OTH category.

Irish pelagic trawling trips (Figure 1) have higher targeting capability than Irish bottom trawl trips: black is dominant in every trip group and trips usually catch between one and four species.

For the Belgian fleets the beam trawl fishery with mesh size ≥ 120 mm (Figure 2) shows a clear targeting for plaice. However, cod also appears in most of the trips in relatively high proportions – around 25 % – followed by anglerfish, lemon sole and haddock. This fishery frequently catches other demersal species too, although in lower proportions.

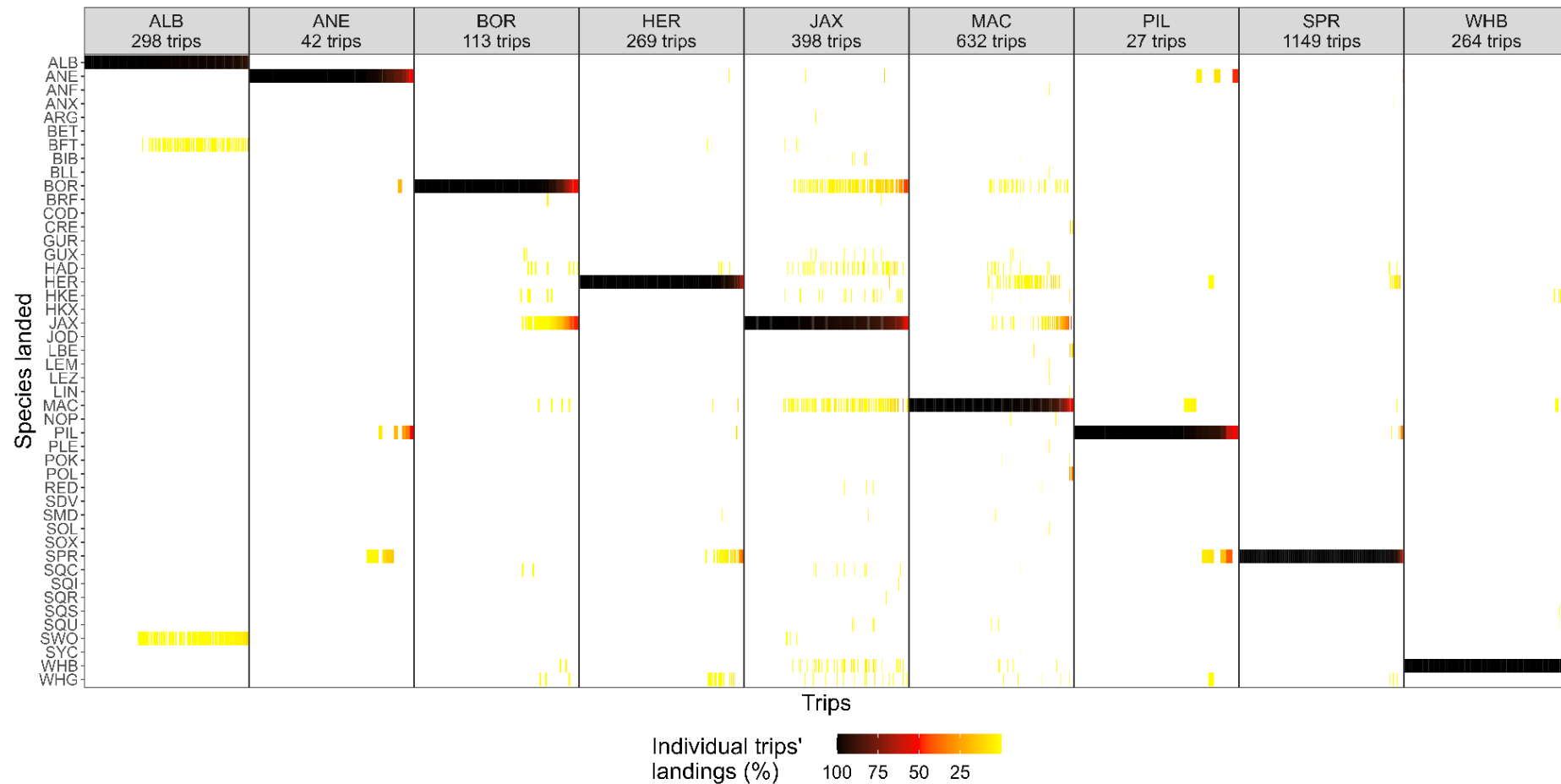


Figure 1: Targeting behaviour and catch composition by trip ordered by targeting by Irish midwater pair trawls (PTM) across all areas. Species abbreviations: ALB = albacore tuna; ANE = European anchovy; ANX = anchovies; ARG = Argentines; BET = Bigeye tuna; BFT = bluefin tuna; BIB = bib; BLL = brill; BOR = boarfish; BRF = blackbelly rosefish; COD = cod; CRE = edible crab; GUR = red gurnard; GUX = gurnards; HAD = haddock; HER = herring; HKE = European hake; HKX = hakes; JAX = Jack and horse mackerels; JOD = John dory; LBE = European lobster; LEM = lemon sole; LEZ = megrim; LIN = ling; MAC = mackerel; NOP = Norway pout; PIL = European pilchard; PLE = plaice; POK = saithe; POL = pollack; RED = redfishes; SDV = smooth-hounds; SMD = smooth-hound; SOL = common sole; SOX = soles; SPR = sprat; SQC = common squid; SQI = northern shortfin squid; SQR = European squid; SOS = sevenstar flying squid; SQU = squids; SWO = swordfish; SYC = small-spotted catshark; WHB = blue whiting; WHG = whiting

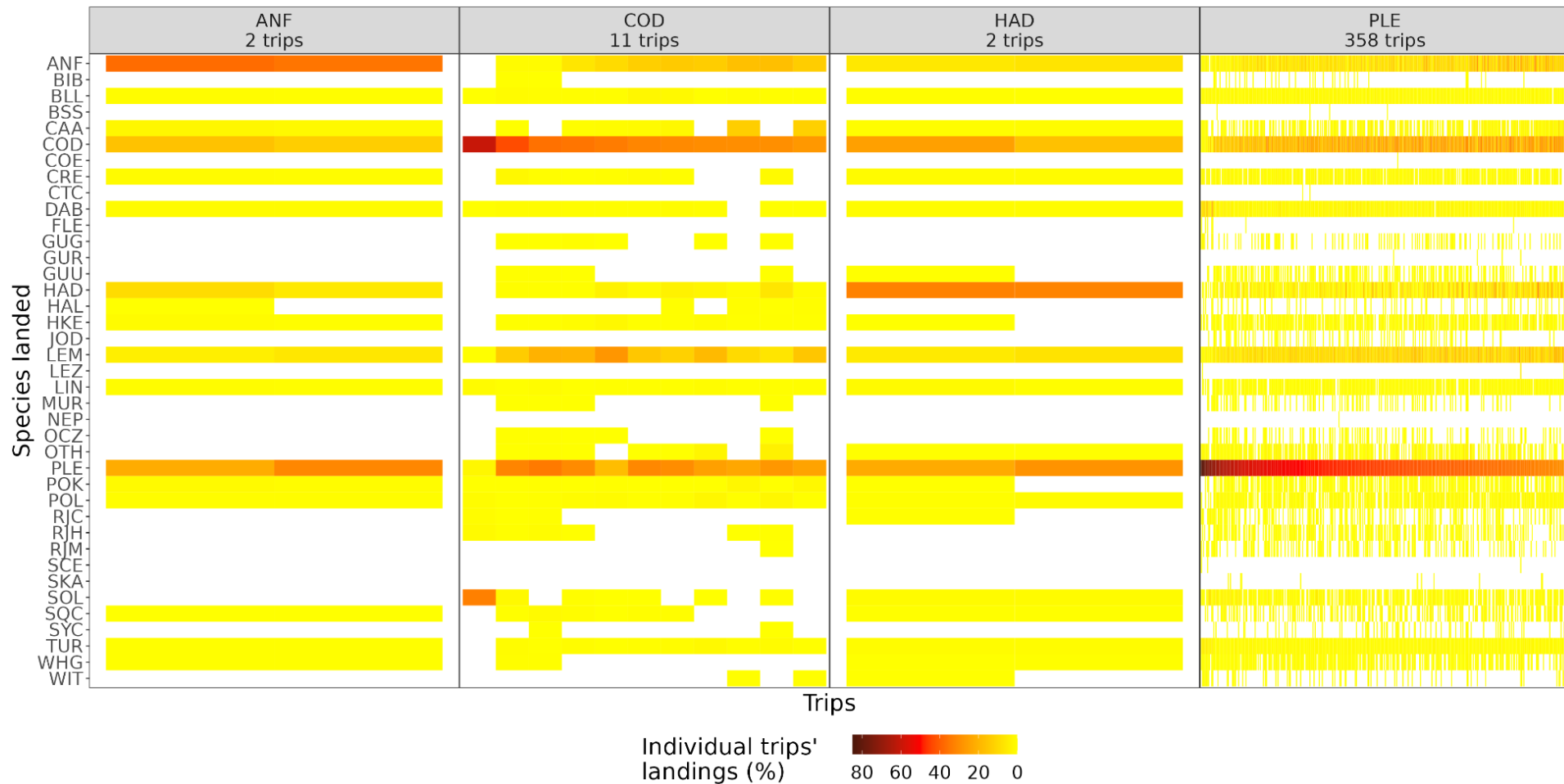


Figure 2: Targeting behaviour and catch composition by trip ordered by targeting Belgian beam trawls targeting demersal species with mesh sizes no less than 120 mm (TBB_DEF_>=120 m tier) in the North Sea. Species abbreviations: ANF = anglerfish; BIB = bib; BLL = brill; BSS = seabass; CAA = wolffish; COD = cod; COE = conger eel; CRE = edible crab; CTC = common cuttlefish; DAB = dab; FLE = flounder; GUG = grey gurnard; GUR = red gurnard; GUU = tub gurnard; HAD = haddock; HAL = halibut; HKE = hake; JOD = John dory; LEM = lemon sole; LEZ = megrim; LIN = ling; MUR = Surmullet; NEP = *Nephrops*; OCZ = octopus; OTH = 'other'; PLE = plaice; POK = saithe; POL = pollack; RJC = thornback ray; RJH = blond ray; RJM = spotted ray; SCE = king scallop; SKA = skates and rays; SOL = common sole; SOC = sockeye salmon; SYC = small-spotted catshark; TUR = turbot; WHG = whiting; WIT = witch flounder

ANNEX 15: FIGURES PRESENTING TECHNICAL INTERACTIONS BETWEEN MÉTIERS AND STOCKS

These figures aim to present technical interactions between métiers and stocks across the Celtic Sea and North Sea case study ecoregions. Each visualisation allows identification of the important stocks within an ecoregion and which métiers are landing them. The plot depicts the proportion of each stock landed within an ecoregion by métier, whereby columns sum to the total proportion of a stock landed in that ecoregion, totalling 1 if the ecoregion is the same, or larger than the stock area.

The métiers shown within the ecoregion are limited to those accounting for a proportion of at least 0.01 of stock landings within the area. This removes those métiers with very minor contributions from the visualisation to prevent overwhelming the plot with métiers of little impact within the area. The darker the colour of the cell, the greater the proportion of landings reported for a stock occur within a métier. Figure 1 presents the full figure of the Bay of Biscay example presented within the main report.

In the Celtic Sea, Figure 2, OTB_DEF_100-119 is the most important métier in terms of the proportions of stocks the métier lands. In contrast, GNS_CRU_0 (indicating unknown mesh range) is the least important métier, with low proportions of few stocks being landed as a result of this métier. In relation to whiting nearly all landings are landed by the OTB_DEF_>=120 métier as depicted by the dark red colour. A very small proportion is landed by 1 other métier, depicted by the light blue colour, this was SSC_DEF_100-119.

In the North Sea ecoregion, Figure 3, there are a large number of both stocks and métiers depicted. As such the figure has been trimmed to allow easier viewing. In this case the most important métiers (OTB_DEF_>=120 and OTB_CRU_70-99, TBB_DEF_70-99) within the region have very diverse catch compositions, and contribute to the main part of a number of stocks, depicted by the stocks having dark coloured squares associated with these métiers. Interestingly, some Nephrops stocks are primarily targeted by >=120 mm mesh gear, others by the more traditional 70-99 mm mesh sizes. The third most important métier in the area, TBB_DEF_70-99, has high proportions of sole but lower proportions of plaice.

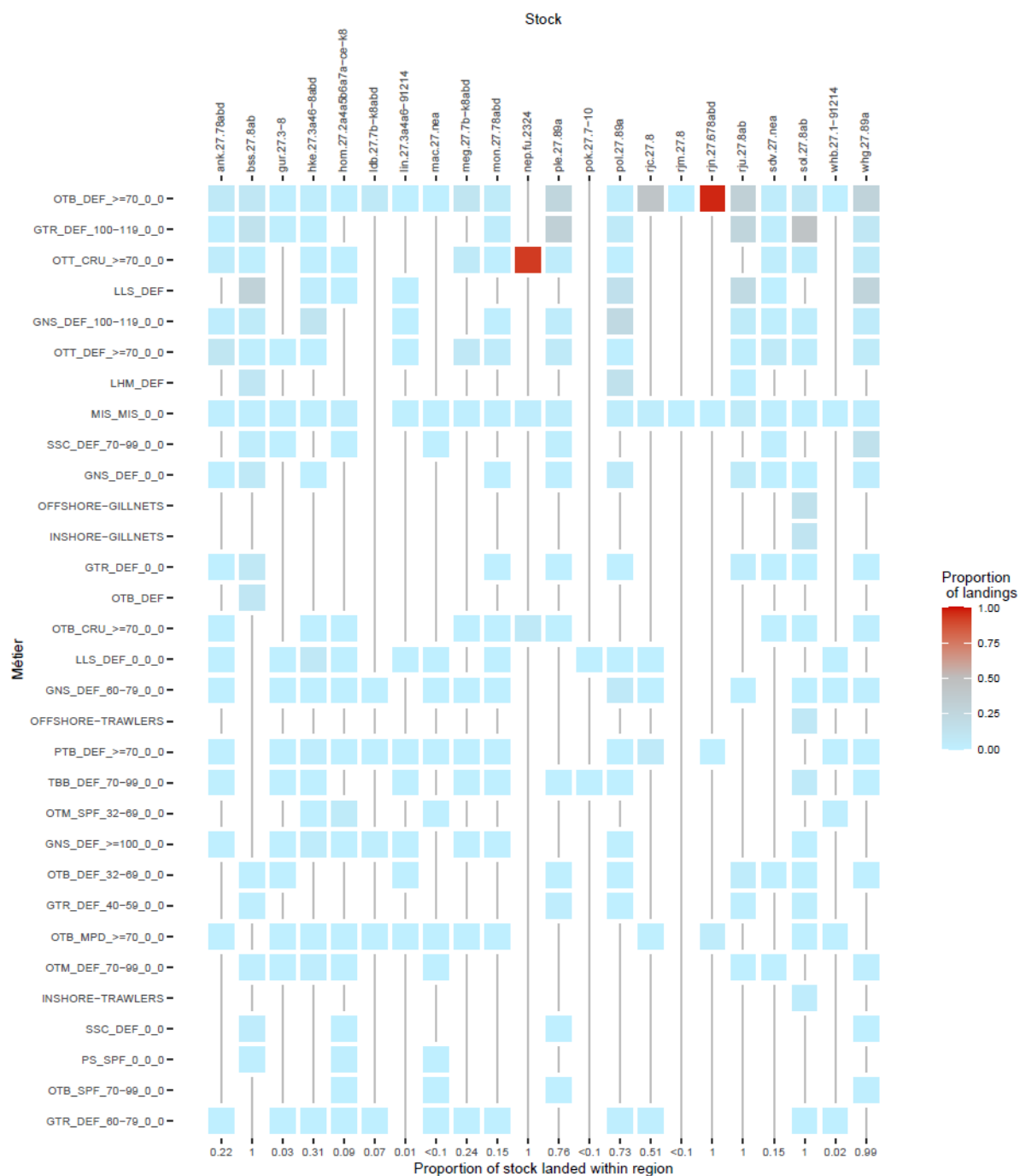


Figure 1: Technical interactions between stocks and métiers within the Bay of Biscay in 2021

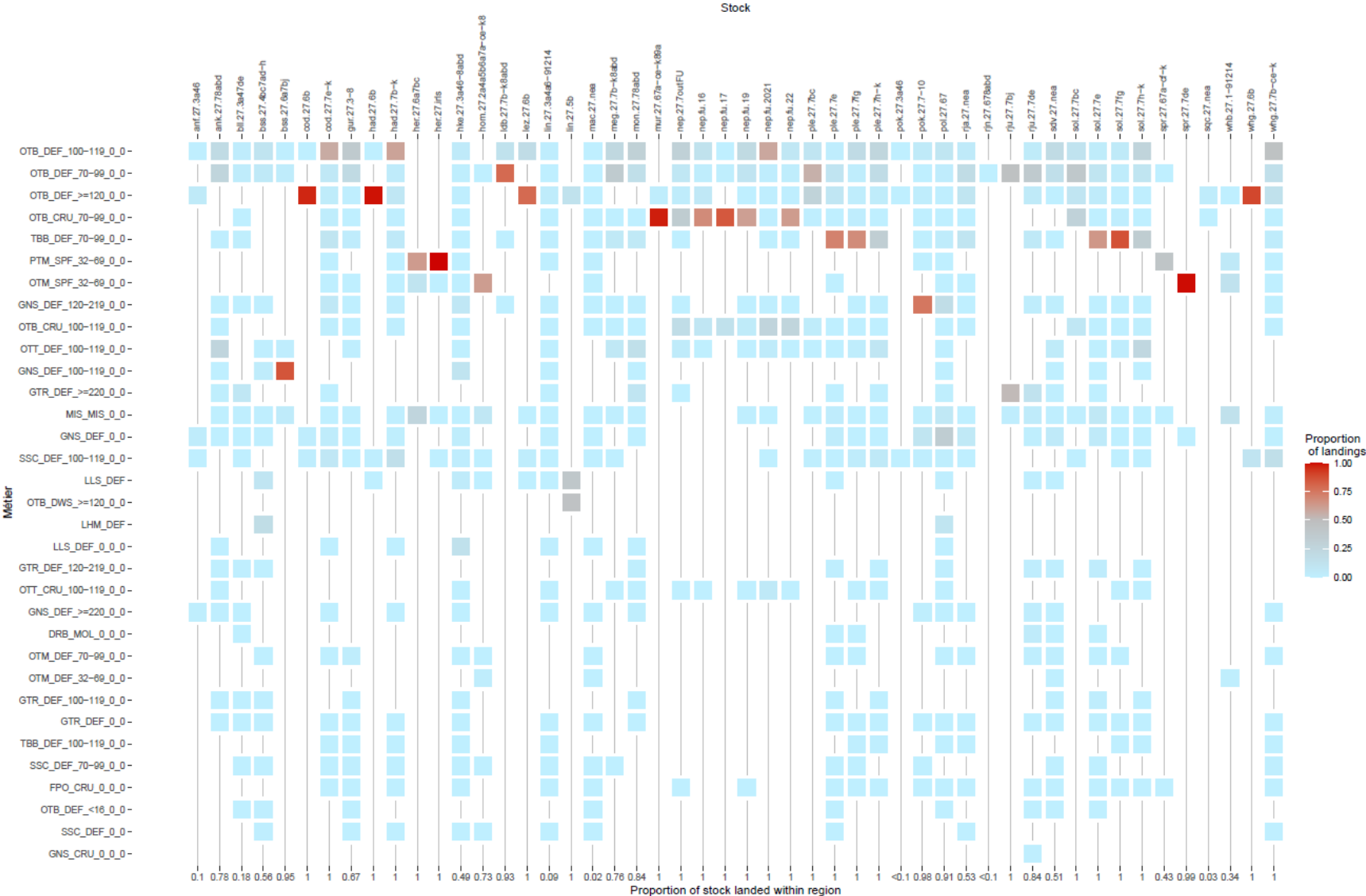


Figure 1: Technical interactions between stocks and métiers within the Celtic Sea ecoregion in 2021

ANNEX 16: FIGURES IDENTIFYING HIGH CHOKING RISKS

This annex provides a North Sea case study of the figures prepared to identify high choking risks within an ecoregion presented in section 5. Combining the degree of technical interactions (the number of strata that species y is caught together with species x, divided by the number of strata where species x is caught) and the ratio of the catch to the advice. Each panel of the figure shows a stock and the proportion of stocks caught together with this stock. The height of the bars shows how frequent a stock appears in strata of the stock shown in the title of each panel, while the colour of the bar indicates the ratio between the catch and advice of a stock. Stock in red indicate stocks with a zero advice.

In the Celtic Sea for example (Figure 1), in around 45 % of the strata where sole 7.e is caught, Celtic Sea hake and whiting are also caught, but the percentage of the scientific advice caught is very different in each of them (40 % and 140 % respectively), making only whiting a potential choke species for sole; additionally, around 40 % of sole 7.e is caught together with Celtic Sea cod, where the red colour of the bar indicates that Celtic Sea cod has a zero-catch advice.

In approximately 90 % of the strata (Figure 2) where North Sea sole (sol.27.4) is caught, North Sea plaice is also caught (ple.27.420). However, the light blue colouring of the bar means that North Sea plaice catches are no more than 50% of the advice. This indicates that there is little choking of North Sea sole by the North Sea plaice stock. In contrast, in about 80% of the turbot catches (tur.27.4), cod (cod.27.47d20) is also caught. The orange bar of cod indicates that the catch is higher than the advice, and cod can thus be seen as a species with a potential choke risk for turbot.

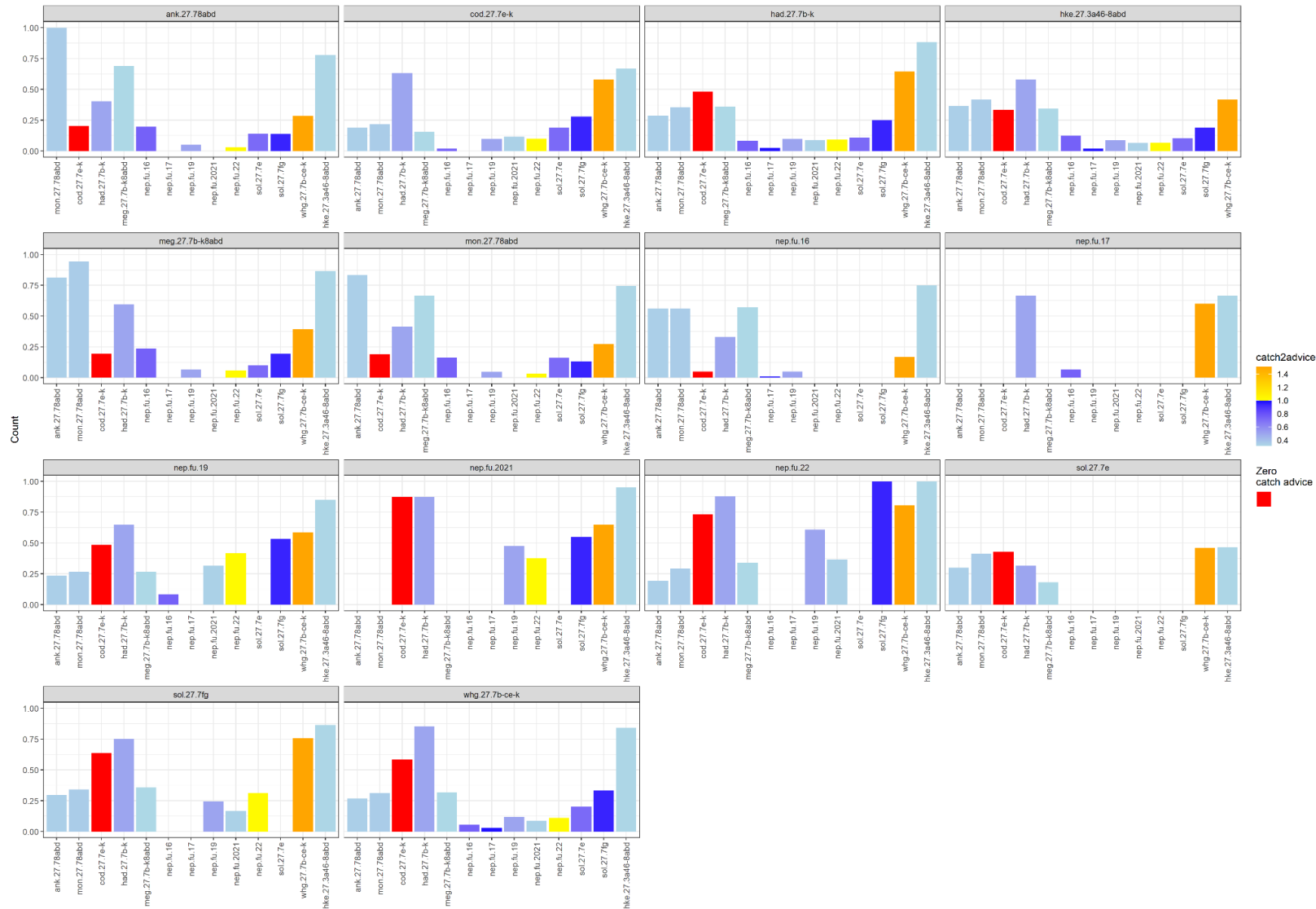


Figure 1: Technical interactions between stocks and choking risk (catch uptake versus advice) for a selection of demersal fish stocks in the Celtic Sea for 2021.

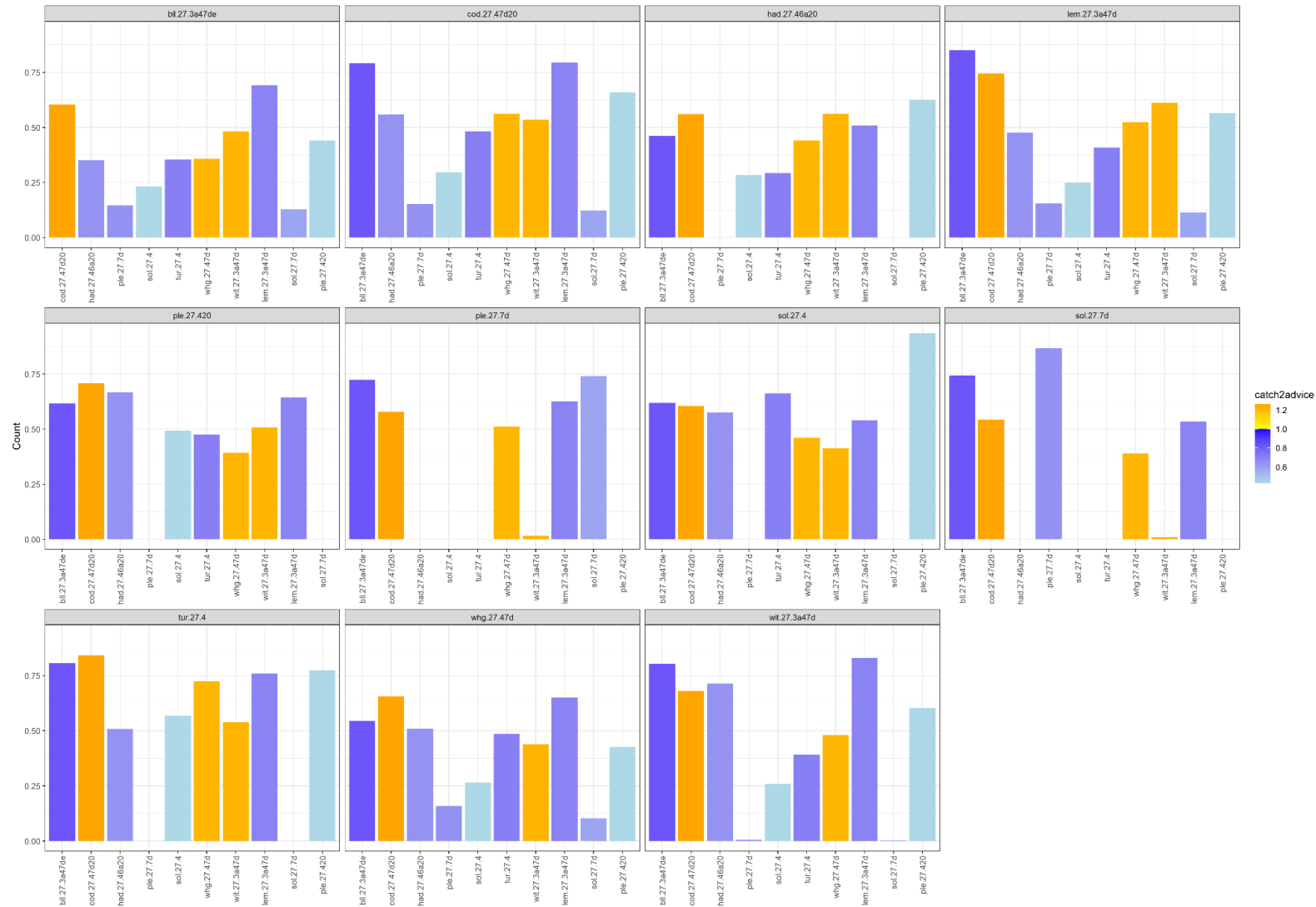


Figure 2: Technical interactions between stocks and choking risk (catch uptake versus advice) for a selection of demersal fish stocks in the North Sea for 2021.

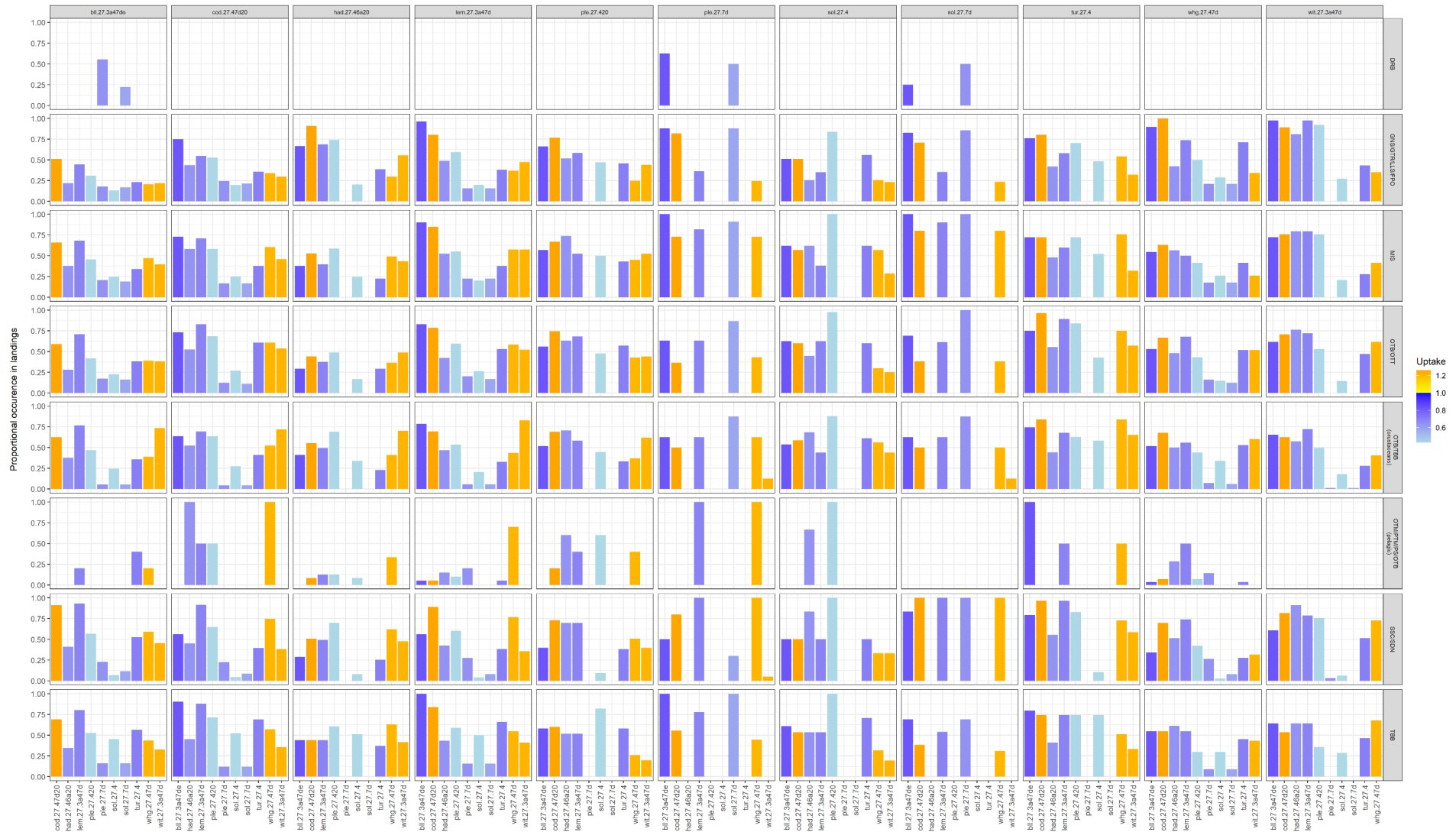


Figure 3: Technical interactions between stocks and choking risk (catch uptake versus advice) for a selection of demersal fish stocks in the North Sea by gear category for 2021.

ANNEX 17: DEVELOPMENTS NEEDS TO EVALUATE REBUILDING OF STOCKS IN THE LONG TERM

Currently, mixed-fisheries considerations are based on a two-year forecast of stock assessment model-output and catch-and-effort data at métier level. This is because, in single-stock short-term forecasting, everything is considered constant in the projection period. Although this assumption is considered valid in the short term, to evaluate stock rebuilding in the long term it is necessary to introduce dynamism and uncertainty to the projection.

The FLBEIA model (Garcia et al., 2017) used in most of the mixed-fisheries case studies was built for long-term simulations and has all the elements needed to run long-term mixed-fisheries simulations. In fact, it has already been used to analyse the performance of management strategies in a mixed-fisheries framework (see Garcia et al., 2019; Garcia et al., 2021). In comparison, the Fcube model was built to run short-term projections, but it is possible to extend it to run long-term projections in specific cases.

The steps required to extend both models to produce mixed-fisheries considerations in order to analyse stock rebuilding in the long term are shown in Figure 1 below. The first step is to define the dynamics of the processes that form the system. The system can be divided in three main components: the stocks, the fleets and the catch-advice components. In the next section we identify the processes that should be modelled in each of these components to run long-term simulations, and where and how uncertainty should be introduced.

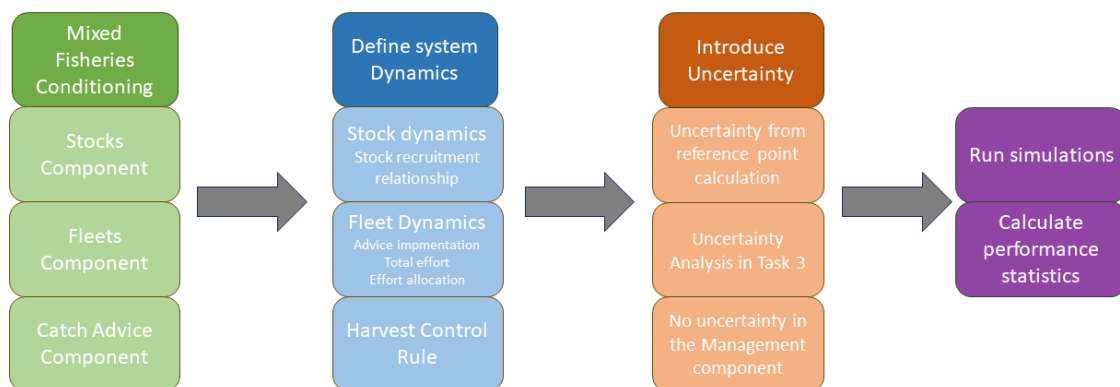


Figure 1: Conceptual diagram with the steps required to run long-term simulations from mixed-fisheries model conditioning

1 SYSTEM DYNAMICS

When conducting a short-term forecast (e.g. two years ahead) to produce the ICES mixed-fisheries considerations, simple assumptions are made for the dynamics of the system in the forecasted years. This period is generally considered acceptable because the parameters that are based on assumptions normally have a low contribution to the outcome of forecast. For example, assumptions on future recruitment often represent a small proportion of the catches in the considerations year produced by the short-term forecast. In addition, over a short forecast period, the system is unlikely to undergo large changes, and the value of a number of parameters can be assumed to be similar to those in most recent years.

However, when carrying out long-term simulations, particularly when testing for rebuilding of stocks, it can be expected that the whole system will change considerably through time. Instead of simple assumptions, a conditioning that reflects the dynamic nature of the stocks and their fisheries must be used.

If the model is to adequately represent the dynamics of the system and its natural variability, a number of changes to the model components are required. These changes are reviewed below.

1.1 Biological operating model

Stocks with analytical assessment

Recruitment dynamics

The main approach for recruitment dynamics in MSE is to use a stock-recruitment model. There are a number of key considerations when deciding on a recruitment model and these are reviewed below.

The choice of the functional relationship (Beverton and Holt, Ricker, segmented regression or other) to be used should be dictated by the historical estimates of recruitment and SSB. However, very often there is no clear support for a specific stock-recruitment model. An approach to account for this uncertainty in MSEs (but that is also at the basis of EqSim¹, the ICES software to estimate MSY) consists of using a composite stock-recruitment model: in each iteration (i.e. stock replicate) and for each stock the stock-recruitment relationship can have its own functional form, with the proportion of the iterations in the operating model (OM) having each functional form reflecting the likelihood of each of them (Simmonds et al., 2011).

In some instances, when there is no clear indication that a specific stock-recruitment model formulation is more appropriate than any other, the approach has also been to use the simplest model, i.e. a segmented regression model.

Finally, in some cases the stock-assessment model used for the assessment includes a stock-recruitment model, and the functional form of the stock-recruitment model in the MSE should be the one used in the stock-assessment model.

Biological parameters

Variability in biological parameters (weight, maturity), generally has less impact on stock dynamics than recruitment. Different approaches can be implemented: from constant values, to resampling from a set of recent values, or modelled as random processes (with means and variances based on past values).

In some instances, when key biological processes have been found to influence these biological parameters (e.g. density dependent growth), such processes can be explicitly modelled in the OM, and incorporated in the MSE.

Stocks assessed with surplus-production model

The mixed-fisheries models currently used at ICES also include stocks for which the biomass is modelled (i.e. stock for which the assessment is done using a surplus-production model), not abundances-at-age. The OM in this case could also be a biomass-based model, with parameters taken from the stock-assessment model. For this stock, all the biological processes are modelled together. Hence, simulation of recruitment and other biological parameters is not required. FLBEIA already includes the possibility of simulating biomass dynamic models.

¹ A stochastic equilibrium software that may be used to explore Maximum Sustainable Yield reference points

Data limited stocks

For stocks without an assessment, a number of approaches can be used to configure a population dynamics model with an appropriate representation of the key population dynamics parameters and of the state of the stock at the start of the simulations.

An age-structured OM can be developed based on life-history information (growth, maturation, natural mortality) and assumed distributions for some of the key population dynamics parameters (e.g. carrying capacity or recruitment at pristine stock size, steepness of the stock-recruitment model or stock depletion in the present year). Historical data (catches or landings in weight, biomass indices from surveys) available for the stocks can be used to calibrate those models (i.e. obtain posterior definition for these parameters). Such approaches have been implemented to conduct MSE on data-limited stocks. Examples can be found for data on short-lived species (Sánchez-Maróño et al., 2021), in Dutch freshwater lakes (Tien et al., 2020, using a feasible trajectories approach, Bentley and Langley, 2012), or Indian Ocean albacore tuna (Hillary and Mosqueira, 2023, using Approximate Bayesian computation).

These approaches to develop an OM in data-poor situations rely on population-dynamics formulations that are similar to those in age-structured stock-assessment models. However, the amount and the level of detail in the data used required is much lower than for a stock assessment. Such OMs should be considered as tools that present plausible population dynamic parameters, and therefore suitable for conducting simulations. The OMs should not be considered as providing stock-assessments of stock status estimates.

In some cases, such OMs have been developed without using historical data on the history of the stock, but purely based on life-history parameters. In this case, values for key population-dynamics parameters (e.g. carrying capacity or recruitment at pristine stock size) and on stock status at the start of the simulations are chosen arbitrarily. In practice, this approach is more often used to produce scenarios for simulation testing than in a formal MSE context (e.g. Fisher et al., 2021).

Data-poor stocks

Finally, stocks for which the above-mentioned approaches cannot be implemented can only be modelled assuming constant biomass combined with a constant CPUE approach to describe their exploitation. The mixed-fisheries considerations already includes stocks for which a constant CPUE approach is used. For those stocks, recent catchabilities, calculated based on catches and effort, are used in the forecast years to produce catch forecasts, based on the efforts of the fleets corresponding to each mixed-fisheries scenario. This approach to incorporate data-poor stocks in long-term simulations can be useful to give some idea of future trends in catches and possible choke effects but with the strong limitation that their biomass would be considered constant.

1.2 Fleet operating model

To produce the mixed-fisheries considerations, a number of parameters related to fleet characteristics (such a catchabilities, effort allocation per métier) are assumed to be constant in a short-term forecast. As for biology, these parameters are likely to change over time when considering a longer-term time frame.

A simple approach to generate future values for these parameters, as done for biological parameters such as weight-at-age or proportion mature-at-age, would be to assume that they vary randomly – where randomness should be based on the historical behaviour of the parameters (see next section for further details on uncertainty conditioning). However, this type of simple approach ignores the dynamics of the system, i.e. how some parameters would have evolved as a consequence of other changes in the system. A number of modelling approaches have been proposed to provide a more realistic view of the dynamics of the future fleets' characteristics.

- For effort-allocation to different métiers for each fleet, several approaches are possible, such as random utility models (Andersen et al., 2010), profit maximisation (which is already implemented in FLBEIA), or allocations based on landing-per-unit-effort or value-per-unit-effort and tradition (Marchal et al., 2013).
- Total effort per fleet, under the mixed-fisheries scenarios used at ICES, is defined by the most- (or least-) limiting quotas for the fleet. Other more dynamic approaches could involve setting future effort based on profit maximisation. Restrictions to effort changes can also be implemented as well as maximum effort values to represent situations with limitations in fishing capacity.
- It is important to include capital dynamics (i.e. entry-exit of units in the fleets) in long-term simulations: however, it is usually overlooked. FLBEIA includes a model to describe the entry and exit into the fishery based on economic indicators (Salz et al., 2011). However, model conditioning for this functionality has proved difficult, which has limited its application.
- There are fewer approaches to model catchability, and this parameter could be simulated based on random walks or assuming a given value for technological creep (i.e. a linear increase over time).

Management procedure

No management procedure is implemented in the model used to provide mixed-fisheries considerations. Management decision is an input variable (i.e. the ICES single-stock advice). To conduct long-term simulations, a management-procedure component needs to be added to the models to mimic the process that will be followed to define single-stock advice in future years. There are two main parts to a management procedure: estimator and advice rule. Both are described below.

Estimator

The estimator is the quantity that reflects stock status. For most stocks included in the ICES mixed-fisheries models, a stock assessment is run that provides estimates of stock abundances and fishing mortality at the start of the current year, and using a short-term forecast procedure, over to the considerations year. In MSEs, this procedure can be replicated entirely, with input data for the assessment model generated with observation error from the OM, and an assessment model run for each replicate of the stock, each year in the simulation period. An alternative to this computer-intensive approach involves a priori characterisation of the assessment error(s) (i.e. variance and potential correlations on the errors in the estimates produce by the stock assessment) and applying these to the OM to generate a stock perceived with errors.

For data-limited stocks, most of the estimators used at ICES (biomass indices from surveys) can be derived from the OMs by applying observation errors to the quantities of interest. However, the current models from WGMIXFISH are not using fish length, and therefore cannot produce length-based indicators (e.g. length-based proxy for F/F_{msy}) that are used in some data-limited advice rules at ICES. Including length information (e.g. mean length or age-length keys) for those stocks to generate length-based indicators would require some new developments in FLBEIA, the modelling framework currently used. Alternatively, a 'short-cut' approach could be taken by using OM-based information on F/F_{msy} with an additional term to represent a measure of errors.

Advice rule

Based on the estimators for the different stocks, the same advice rules as used at ICES (depending on stock categories; ICES, 2016) can be implemented to produce a catch advice. Many advice rules are already implemented in FLBEIA, and new ones could be implemented.

2 UNCERTAINTY CONDITIONING

A key component in long-term simulations is the uncertainty conditioning of the model. Knowledge of dynamics of the processes included in the model and about the parameters

that govern such processes is always incomplete. Furthermore, many processes, such as stock recruitment, are subject to natural variability. Thus, this uncertainty needs to be captured by the model if there is to be a realistic representation of the system dynamics. Moreover, the performance of management strategies is usually measured in terms of risk, and the accuracy of risk-related performance indicators is directly related to how well the existing uncertainty has been captured by the model. Based on existing literature Francis and Shotton (1997) categorised uncertainty in fisheries modelling into six types, listed below.

- Process uncertainty is related to the natural variability in the process, such as the natural variability in recruitment.
- Observation uncertainty arises in the process of data collection through measurement and sampling error.
- Model uncertainty refers to the incapacity of models to describe natural processes perfectly. Model uncertainty is formed by structural uncertainty, related to the adequacy of the mathematical equations used in the model, parametric uncertainty, related to the difference between real parameters and parameters used in the model and the structure of the error used to describe variability in the model.
- Estimation uncertainty relates to the process of parameter estimation.
- Implementation uncertainty refers to the difference between the management policies and how they are implemented in practice.
- Institutional uncertainty arises in the interaction of scientists, managers and stakeholders. The lack of well-defined operational objectives is a good example for this type of uncertainty.

2.1 Biological operating model

Uncertainty in biological OM is related to the first four categories described above. In the calculation of single-stock reference points, uncertainty is introduced in the stock-recruitment process and biological parameters based on existing data. Thus, the conditioning of base-case scenarios to analyse stock rebuilding in a mixed-fisheries framework should be based on the conditioning used to calculate single-stock reference points. Additional scenarios could also be conditioned and tested.

For the stock-recruitment relationship, several functional forms are considered (structural uncertainty). This includes parametric uncertainty and uncertainty around the stock-recruitment model. The stock-recruitment component within an FLBEIA model allows the introduction of parametric uncertainty and uncertainty around the stock-recruitment model. Structural uncertainty can be introduced by running stock-recruitment specific scenarios or iterations.

Weight, maturity and natural mortality-at-age are often considered constant in the analyses to calculate reference points. However, sometimes, historical values are used though resampling to introduce uncertainty in the future. In FLBEIA all the input parameters can incorporate uncertainty. Thus, resampled values or other probability distributions for the parameters obtained from other approaches can be used easily in FLBEIA to condition the mixed-fisheries models.

2.2 Fleet operating model

Uncertainty in fleet dynamics parameters is usually overlooked, especially in single-stock approaches, for example in the calculation of reference points. However, as shown in this study, they can have a significant impact on the results. The main parameters in the fleet component of the mixed-fisheries OM are catchability (separated further into selectivity and intensity in this study), quota share, and effort proportion.

In this study a simple approach was adopted to condition uncertainty in these parameters. We have seen that there is an important intra-métier correlation between stock intensities. This is a key aspect in mixed-fisheries models as the intensities govern the choking effect in mixed-fisheries.

In simple-effort dynamic approaches, effort proportion is considered an input parameter, and it would be necessary to condition uncertainty. However, in more complex approaches (see for example Andersen et al., 2010; Marchal et al., 2013 or Garcia et al., 2017). Effort proportion could be a dynamic parameter, and uncertainty should be introduced in the relevant model parameters.

2.2.1.1 Management procedure

The management procedure is divided into three components: the observation model, the assessment model and the advice model.

- Observation model: In the observation model, uncertainty should be introduced. Observation uncertainty should not be overlooked, as is often the case, and should be considered in all data that is used routinely to provide advice, surveys, catch data and biological data. The uncertainty in these data should be quantified in collaboration with the experts working in data collection. Normally, this uncertainty is not considered in the calculation of reference points and is only present in more complex single-stock MSE models.
- Assessment model and advice model: For these models, there is no need to introduce any uncertainty because their output comes directly from the selected assessment model or harvest control rule (HCR). Should the case-assessment model be replaced by a short-cut approach, the model error should be characterised and introduced as random variation (see previous section).

3 PROJECTION

3.1 Simulations

Mixed-fisheries models are complex models that require a large amount of computational time. While mixed-fisheries considerations are calculated deterministically with a two-year projection, stock rebuilding should be done stochastically and for several years, no less than one life span of the most long-lived stocks. Thus, analysing stock rebuilding with mixed-fisheries models would require a high-performance computing system such as a cluster with various nodes.

3.2 Performance statistics

Performance statistics for mixed-fisheries models need to focus on the performance of the fleets, and differ from traditional single-stock performance statistics such as probability of SSB being below B_{lim} , variability in the catch or fishing mortality level compared to the target. As there are no specific objectives at fleet level, it is not possible to define performance statistics that measure the achievement of the target. However, there are useful performance statistics that could be calculated at both the stock and fleet level.

- Probability of being a choke stock.
- Implementation error in catches at stock and fleet level. Implementation error arises naturally in mixed-fisheries models as reaching all the catch quotas simultaneously is impossible. The difference between the catch quotas and the real catches provides an idea of the use of fishing opportunities at fleet level.
- Total yield.
- Variation in total effort.

ANNEX 18: BEST PRACTICE AND PROCESSES TO ADD NEW STOCKS IN MIXED FISHERIES MODELS

The inclusion of new stocks in ICES mixed-fisheries considerations products is not a static process. As single-species stock assessments evolve to better describe the dynamic of the stock, so too must the mixed-fishery assessments evolve to adapt to the new forms of information provided. This process of adaptation requires continuous development in forums such as WGMIXFISH, and continuous communication with stock assessors, model developers, and single-species working groups. The aim of this work is to develop the WGMIXFISH best practice guidelines and outline a framework by which new stocks are selected and added to a mixed-fisheries case study. This framework will review the existing methods by which new stocks are included in Fcube and FLBEIA, highlight the data requirements and discuss the potential limitations and research needs.

1 CURRENT PRACTICE

The current best practice guidelines (under development, pers coms. ICES), state that the following points should be considered when deciding which stocks to include in the assessment models

- Priority should be given to stocks of commercial importance (i.e. target stocks, managed by TAC). However, bycatch of non-target stocks may also be of interest in a mixed-fisheries context.
- Stocks that are not thought to have a high degree of mixed-fisheries interactions due to their ecology or fisheries can be excluded (e.g. pelagic stocks).
- Specific pelagic stocks should be considered if they account for a significant proportion of the demersal fleet catches (for example, 50 % of demersal fleet catch consists of pelagic species in the Iberian Waters model).
- The number of stocks included in the model also needs to be manageable both computationally and because of the time involved in data processing and model conditioning.

Stock assessment results and the forecast settings used to produce the single-stock advice are obtained directly from the stock assessor, advice sheet or working-group report. Where relevant, information on the raising procedures for discards and the allocation of age compositions should also be collected. This ensures that the starting point of the mixed-fisheries scenarios is the same as for the single-stock advice.

The ICES WGMIXFISH guide to best practices, which outlines a summary of the different options to consider when incorporating stocks, can be found in Table 1 (under development, pers coms. ICES). This summary demonstrates the possibilities and limitations to consider when trying to implement a new stock within a mixed-fisheries case study.

Table 11: Factors to consider when considering a stock to include in a mixed-fisheries model

Options	Stocks with full age-based assessments and forecast	Also include stocks with biomass-dynamics methods	Includes all TAC stocks	Include all stocks
Description	Only those stocks that have a full category 1 assessment with age-based or size-based population dynamics or an absolute abundance estimate (e.g., <i>Nephrops</i>) are included.	Includes stocks that have biomass-dynamic models for future population dynamics.	Includes all TAC managed stocks, including those without population models, which are included on a 'constant CPUE' basis where no assessment exists.	Includes all stocks, even non-quota stocks, caught by the fleets and fisheries are explicitly included within the model, on a 'constant CPUE basis' where no assessment exists.
Strengths	Technical interactions modelled reflect changing stock abundance. The conditioning of the model is based on well-stabilised, robust, quantitative stock assessments. Differences in selectivity by fleet/métier can be introduced and evaluations of changes in selectivity can be evaluated.	Technical interactions modelled reflect abundance changes. It could improve the description/modelling of fishing activity or fleet dynamics.	Encompasses a greater number of potential choke stocks. It could improve the description/modelling of fishing activity or fleet dynamics.	Encompasses all the target stocks so may better reflect fishing effort expected; revenue can be modelled better. Can be used to forecast bycatch of sensitive species that are not in the TAC and quota system but are relevant to other management frameworks/directives. It could improve the description/modelling of fishing activity or fleet dynamics.
Limitations	Does not include all stocks caught by fishery, and possibly not all target stocks. May not include the choke stock. The definition of métiers could be wrong because other relevant species are not considered.	Does not include all stocks., May not have a way of projecting future stock size.	Choke effects may be unrealistic because of increases or decreases in abundance. Assumption of constant biomass may only be reasonable for short-term projections.	Non-quota stocks cannot choke fisheries. Difficult to communicate. May involve too many stocks to accurately evaluate. Potential missing data on stocks.

Study to assess the robustness of mixed-fisheries scenario assumptions

Options	Stocks with full age-based assessments and forecast	Also include stocks with biomass-dynamics methods	Includes all TAC stocks	Include all stocks
				Assumption of constant biomass may only be reasonable for short-term projections.
Examples	Current Fcube model for the Celtic Sea.	Long-term scenarios of the North Sea FLBEIA model in external projects (ProByFish, EASME, 2021). Current FLBEIA model for the Iberian Waters (one cat.2 stock ank.27.8c9a).	Current FLBEIA model for the Bay of Biscay, and <i>Nephrops</i> stocks in other regions.	Long-term scenarios of the North Sea and Bay of Biscay FLBEIA models in external projects (ProByFish, EASME, 2021) included some bycatch stock.

Most of the stocks currently in the ICES mixed-fisheries models are category 1 stocks (ICES, 2016; i.e. Table 2), which are defined as stocks with quantitative assessments; this includes stocks with full analytical assessments and forecasts that are either age-/length-structured or based on production models (ICES, 2022d). However, this is not the only limitation of the inclusion of new stocks. Often the inclusion of new stocks depends strongly on the technical difficulty, data quality and ability to communicate with the stock assessor and/or the single-species working group.

Stocks with analytical assessments can easily be incorporated in either Fcube or FLBEIA models from the moment that the assessment output is provided as an age-structured FLR object. All assumptions used by the stock-assessment working group to condition the short-term forecast need to be provided to configure the mixed-fisheries model, as well as the reference points for the stock. The ICES mixed-fisheries working group routinely quality controls the catch single species advice obtained from the original framework used for assessment and single species advice is reproducible after migration to the mixed-fisheries model.

For some stocks for which the assessments are length-structured, converting the assessment output to an FLR age-structured object has proven challenging. Discrepancies have been observed in some of the input vectors (such as weight-at-age for the hake stock in the Bay of Biscay case study) and some quantities (e.g. fishing mortality) are not directly comparable. However, the development of dedicated tools could help streamline this process, such as the R package *ss3om* (Mosqueira, 2020) to load Stock Synthesis (SS3) models into FLR.

Table 2 2: Stocks and their ICES data category currently included in two ICES mixed-fisheries case studies (ICES, 2022c)

Mixed-fisheries case study	Stock	ICES data category
Celtic Sea	cod.27.7e-k	1
	had.27.7b-k	1
	whg.27.7b-ce-k	1
	Nep (FUs 16, 17, 19, 20–21, 22, and 27.7 outside FUs)	1
	sol.27.7e	1
	sol.27.7fg	1
	mon.27.78abd	1
	ank.27.78abd	1
	meg.27.7b-k8abd	1
	hke.27.3a46-8abd	1
North Sea	cod.27.47d20	1
	had.27.46a20	1
	ple.27.420	1
	ple.27.7d	1
	pok.27.3a46	1
	sol.27.4	1
	sol.27.7d	1
	tur.27.4	1
	whg.27.47d	1
	wit.27.3a47d	1
	Nep (FUs 5–10, 32, 33, 34, and Subarea 4 outside FUs)	1

Several sources of data are required for each individual stock within an ICES mixed-fisheries model. These data sources are outlined in a Celtic Sea example from WGMIXFISH-

Methods 2022 (ICES, 2022b), where how each data source feeds into the code and process can be seen (Figure 1). Each data source should be assessed for quality and consistency with other sources, i.e. the total landings should be comparable across all data sources. In cases when sources are not consistent, differences should be well documented, explained, and clarified with stock assessor and data submitters. Unresolved inconsistencies are resolved when all sources are merged to create the fleet data (landings, discards, effort, and age data, at the level of the fleet and métier). Any assumptions made during this process to fill in gaps in data should be fully documented and approved by group.

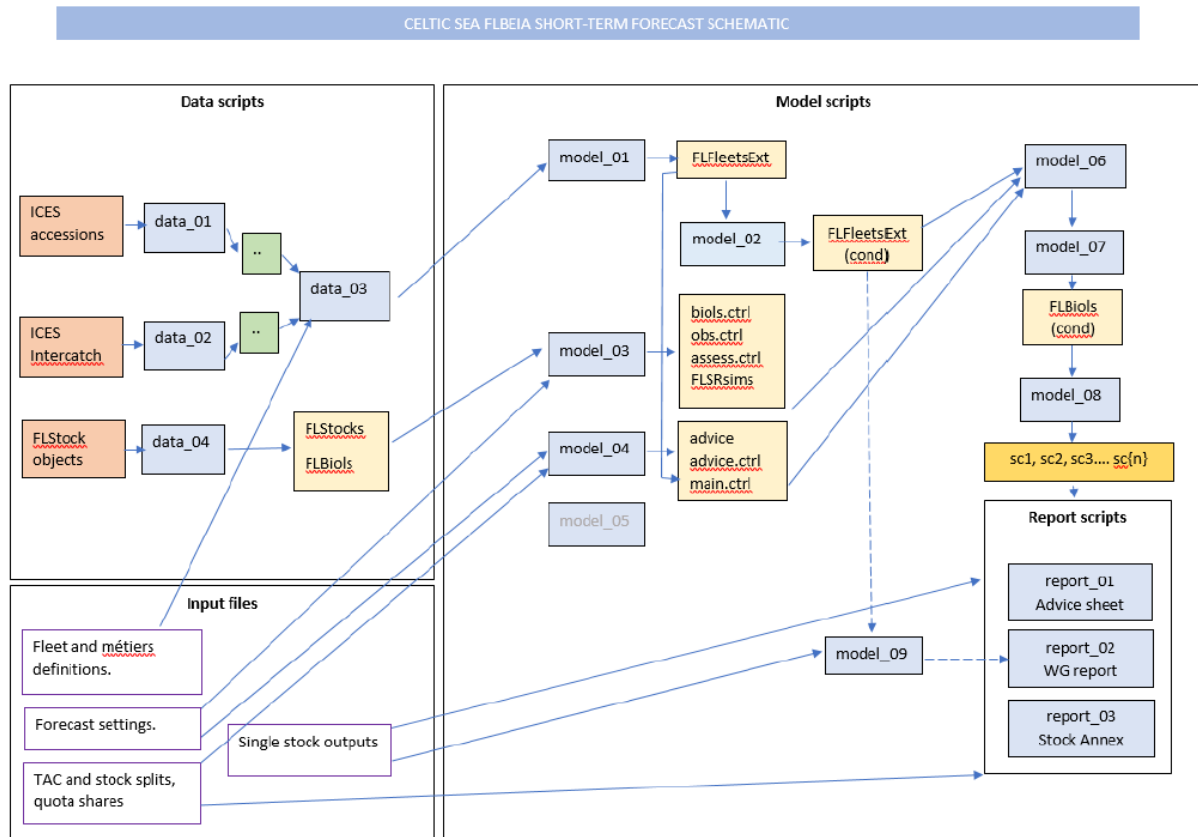


Figure 1: Schematic of Celtic Sea code to process data inputs, and model to produce short-term forecasts, taken from ICES, 2022b

2 WGMIXFISH ADVANCES TO INCLUDED NEW STOCKS

To address the growing and diverse need of mixed-fisheries considerations products, WGMIXIFSH has developed several additional methodologies/tools to include ensure the group's ability to include different stocks.

2.1 Inclusion of new stocks assessed with surplus-production models

A growing number of biomass dynamics models are being used in ICES, these stocks are considered category 2 stocks (ICES, 2016). The inclusion of these stocks in Fcube and FLBEIA to incorporate stocks assessed with a surplus-production model were achieved during the DRuMFISH project (EASME, 2018). During this study, the main surplus-production model used was SPiCT. In Fcube, incorporated stocks with SPiCT assessment were achieved by configuring the stock and corresponding fleet data in terms of exploitable biomass so that the stock can be included in the calculation of the efforts per stock and fleet. Then, using the fishing mortality resulting from the implementation of the mixed-fisheries scenarios, the SPiCT model was run to produce short-term prediction of the catches and stock size for these stocks. Running SPiCT inside Fcube considerably increased the running time, which proved to be a major issue when conducting long-term simulations

but was acceptable for producing the short-term forecast as used in the mixed-fisheries considerations.

Incorporation of stocks with a biomass model in FLBEIA (including SPiCT or JABBA; Winker et al., 2018) is easy because the framework enables modelling of either age-structured or biomass population dynamics. The stock assessment output (biomass, catches, harvest rate) simply need to be passed to FLBEIA as FLStock objects, and the model parameters related to population dynamics need to be used in the configuration of the FLBEIA model. For example, long-term scenarios of the North Sea FLBEIA model in the ProByFish project (EASME, 2021). A current example from an ICES mixed-fisheries considerations product is the Iberian Waters advice sheet, where a category 2 stock, black-bellied anglerfish (*Lophius budegassa*) (ank.27.8c9a) in divisions 8.c and 9.a, is incorporated in the mixed-fisheries assessment (ICES, 2022e).

2.2 Inclusion of new stocks with no available assessment

The species are often selected for inclusion based on data availability, management needs and expertise in the room. However, recent studies (Altuna-Etxabe, 2019) have shown that the absences of data-poor species could result in missed management goals. Therefore, to produce useful management tools, all relevant stocks should be captured by a model, and not just those most readily available.

The quality-control basis for all WGMIXFISH considerations products is to be able to reproduce the single-species advice forecast. This means that in absence of an analytical stock assessment and forecast there is currently no defined basis to include data-poor stocks (category 3–6), or stocks with no advice.

A possible approach to include such stock comprises assuming a constant catch rate (constant CPUE). The option of constant CPUE can be used for short-term forecasts when it can be assumed that the biomass next year would not be significantly different from the one this year. The ICES WGMIXFISH uses this approach to estimate the impact of the mixed-fisheries scenarios on bycatch species (e.g. whiting, rays and skates, and pollack in the Bay of Biscay model) and such an assumption also forms the basis of the ICES advice for *Nephrops* stocks. However, because of the necessary assumption of constant biomass, these stocks are included in the models for 'illustrative' purposes only, meaning that they are not used in the computation of the effort per fleet, and cannot become choke species.

Approaches to include such stocks in a dynamic manner in long-term simulation are discussed in the section relating to rebuilding stocks (Annex 10).

2.3 Stocks that extend outside the case study area

The geographical boundaries of stocks do not always line up neatly with the mixed-fisheries definitions of mixed-fisheries ecoregions. This manifests in the form of missing catches when a stock is widely distributed, and a significant portion of a stock's catch occurs outside of ecoregion, for example hake in Bay of Biscay. According to the WGMIXFISH best practice guidelines (under development, pers. Coms. ICES) the magnitude of the missing catches per stock should be estimated and is obtained by comparing the total catches from the fleet data to the total catches from the stock assessment. The approach taken to account for differences in the total catches is to allocate these catches to a pseudo fleet (details given in Table 3).

There are several areas to be improved for best practice:

- implementation of a consistent approach for 'missing' catches (e.g. out-of-area catches) across all ecoregions;
- scaling down of procedure (implement use of estimated values in stock objects and develop a (scaling) procedure to unifying estimated values with observed values (e.g. InterCatch/Accessions data) used in conditioning fleets).

Table 3: How missing catches are accounted for in ICES mixed-fishery assessment model fleet data

Case study	Out-of-area catches
North Sea	Added to OTH_OTH fleet.
Celtic Sea	Put in a stock-specific OTH fleet (pseudo fleet).
Bay of Biscay	Put in a stock-specific OTH fleet (pseudo fleet).
Iberian Waters	Put in a stock-specific OTH fleet (pseudo fleet).
Irish Sea	Not applicable

An additional issue is stocks that appear in more than one mixed-fisheries case study, such as including anglerfish and megrims in the Celtic Sea and Bay of Biscay advice. As published in the WGMIXFISH methods report in 2021 (ICES, 2021a) Figure 2 shows several examples where stocks are incorporated independently in the Celtic Sea case study (orange ellipses) and Bay of Biscay case study (blue ellipses). In these cases, the stock area is much larger than the individual mixed-fisheries considerations area. At present, an assumption is made that catches of the stock from outside the individual mixed-fisheries ecoregion area are included in an OTH fleet with a constant effort. For example, in the Celtic Sea model, catches of anglerfish from the Bay of Biscay are assumed to be based on constant effort in the other area across all modelled scenarios and vice versa. Different assumptions could also be made, such as constant catch, constant proportion of catch or full TAC uptake. The current approach creates an inconsistency, in that there are different catches in the 'max' scenario in the Celtic Sea considerations (where there was a large projected overshoot) and the Bay of Biscay considerations (where there was a smaller projected overshoot) for this stock (Figure 3). The level of bias this introduces is dependent on the relative level of catches in each area (Table 4). This makes interpreting the mixed-fisheries considerations across the two case studies impossible. The solutions discussed include the following:

- continue as at present;
- present only catches for the region of the mixed-fisheries considerations not the stock level (though F_s , SSBs etc. would still need to be presented at stock level);
- coordinate mixed-fisheries models so that one model informs the catch in the others fleet for the OTH model (technically challenging);
- combine the models to run consistent scenarios across both areas, splitting results out for the mixed-fisheries considerations product.

After some discussion, it was considered that the fourth solution was the most promising option as it results in the fewest compromises and consistent considerations. It is also facilitated using FLBEIA, where most objects are stored as lists that can be combined once the data has been compiled in each respective region. It was agreed to test this approach either as part of the IBPMIXFISH (ICES, 2021b) or ahead of this year's ICES WGMIXFISH-ADVICE meeting. It was considered that combining the models but presenting the results separately would be the best way to ensure consistency and easier to do in the FLBEIA framework. However, this data has not been implemented because the Celtic Sea ecoregion and Bay of Biscay are using different mixed-fisheries models. In future, when both are using FLBEIA, it may be possible to implement this strategy.

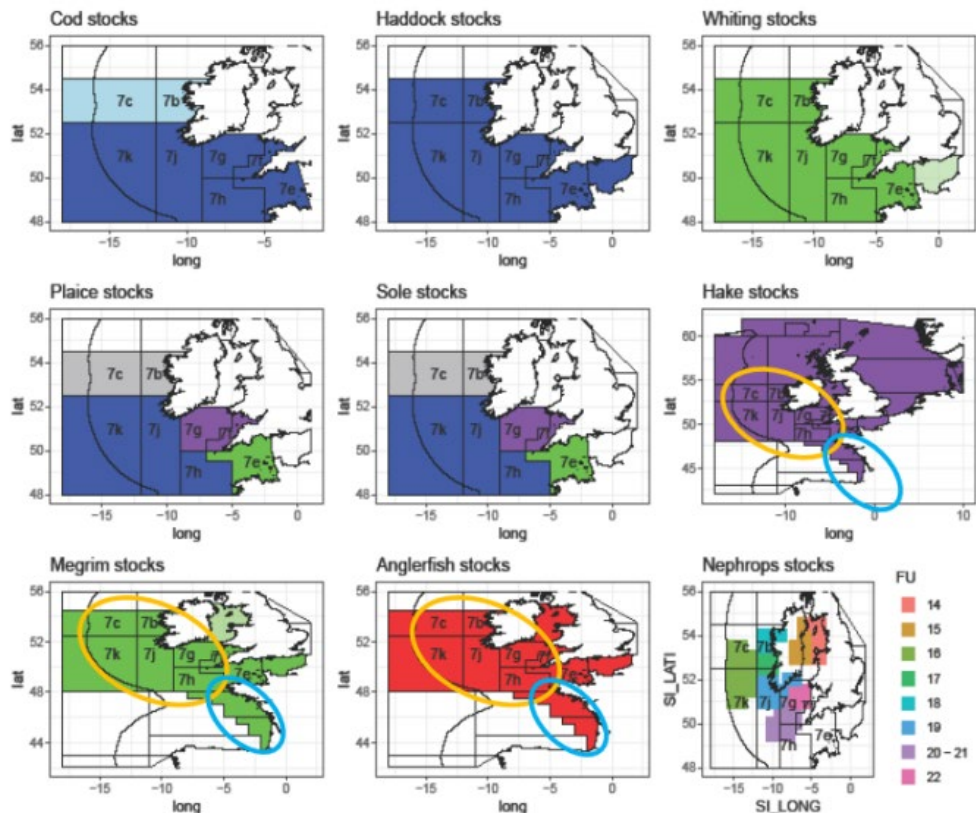


Figure 1: Overlap of stocks with different ICES areas and stock boundaries. The Celtic Sea model area is indicated by the named ICES subdivisions, while the stock boundaries are shown as different colours for each species and the management units outside stock boundaries are indicated by a lighter shaded area. Ellipses illustrate the Celtic Sea (orange) and Bay of Biscay (blue) mixed-fisheries model boundaries in relation to some of the shared stocks. Reproduced from ICES, 2021a

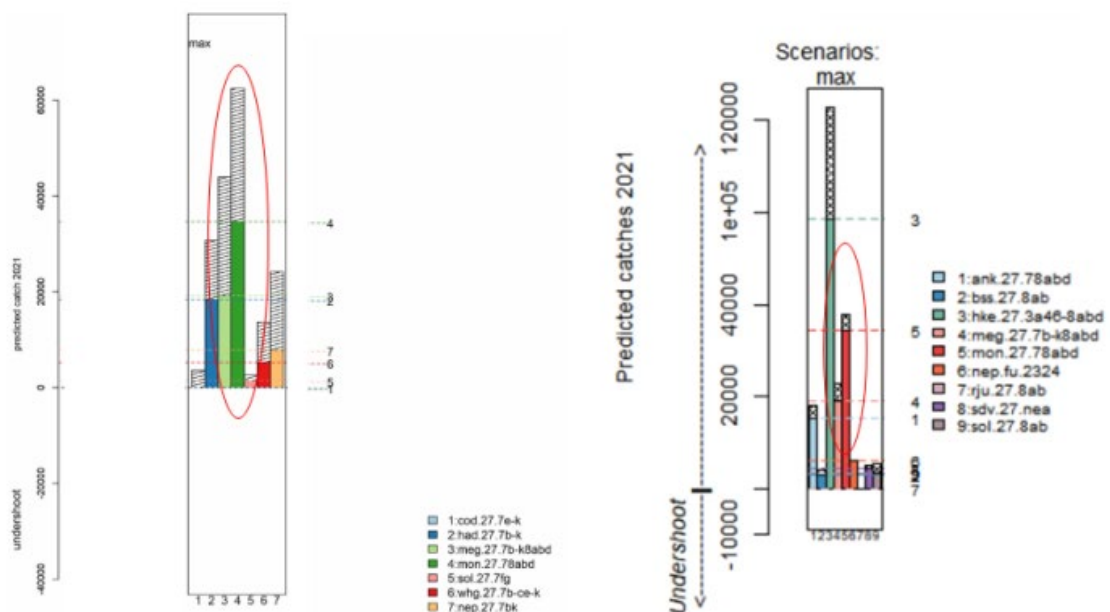


Figure 2: Differences in catch of mon.27.8abd in the 2020 Celtic Sea mixed-fisheries considerations (left) and the Bay of Biscay considerations (right), reproduced from ICES, 2021a

Table 4: Landings and TAC shares for anglerfish and hake across ICES area 7 and ICES area 8, reproduced from ICES, 2021a

Stock	Area 7	Area 8
White anglerfish (<i>Lophius piscatorius</i>) in Sub-area 7 and in divisions 8.a-b and 8.d	Landings (2020): 18 226 t (90 %)	Landings (2020): 1 852 t (9 %)
Black-bellied anglerfish (<i>Lophius budegassa</i>) in Sub-area 7 and in divisions 8.a-b and 8.d	Landings (2020): 6 502 t (75 %)	Landings (2020): 2 174 t (25 %)
	Landings (joint 2020): 24 782 t (86 %)	Landings (joint 2020): 4 026 t (14 %)
	TAC (joint 2020): 35 299 t (80 %)	TAC (joint 2020): 9 008 t (20 %)
Hake (<i>Merluccius merluccius</i>) in sub-areas 4, 6, and 7, and in divisions 3.a, 8.a-b, and 8.d	Landings (2020): 35 100 t (48 %)	Landings (2020): 19 700 t (27 %)
	TAC (2020): 63 325 t (56 %)	TAC (2020): 42 235 t (37 %)

3 CHALLENGES FOR THE FUTURE

As highlighted by WGMIXFISH methods 2023 (ICES, 2023b) a future challenge will be the integration of ensemble models which can better account for the complexity that drives the dynamics of fish stock. However, incorporating this into a mixed-fisheries model will be challenging. An example of this is the integration of newly benchmarked North Sea cod into the mixed-fisheries model.

As described in the same report, North Sea cod underwent a benchmark in 2023, resulting in the stock being split into three sub-stocks (ICES, 2023b). The integration of these stocks in the mixed-fisheries model is hampered by the fact that spatially-explicit data do not currently exist at the métier level and the sub-stocks mix during the year, thus hindering the assigning of a cod catch to a specific métier/sub-stock interaction. The group discussed in detail the best way forward for the integration of cod in the model. Two possibilities were retained: either inclusion as a merged-stock object, with some loss of consistency with the single-stock advice forecasts, or complete removal.

The concern with the inclusion of a merged-stock object is the loss of sub-stock advice considerations based on differing biological status (e.g. SSB either above or below MSY $B_{trigger}$). This disparity could lead to potentially different choke situations that would not be captured by a merged-stock object in the mixed-fisheries forecasts. This could affect the credibility of our projections as it is inconsistent with the cod advice based on independent sub-stocks. Despite this drawback, the WGMIXFISH group felt it necessary to evaluate the technical feasibility of merging the three sub-stocks into a single stock. The results of this merging test are intended to be presented in the WGMIXFISH-ADVICE 2023 report (ICES, 2023b).

However, the results of the merging test will not resolve the issue that a merged object would fail to detect differences in choking behaviour among the sub-stocks. Nevertheless, given that cod is the stock that motivated the development of the mixed-fisheries model in the North Sea, there was a general feeling that its exclusion might diminish the relevance and utility of the mixed-fisheries considerations. Until future data allows for the direct integration of sub-stocks and differentiation among fleet catches, a feasible compromise for the present would be to proceed with a merged cod stock object and to add clarifying text explaining the deviation from the stock single species advice and the possible consequences for the mixed-fisheries considerations. The group also discussed the possibility of treating the cod stock differently to the other stocks in the model (e.g. exclude

it from the list of restrictive stocks), or running an additional more restrictive considerations scenario using the smallest catch single species advice of the three sub-stocks. The inclusion of these possible extra scenarios will be further evaluated during the 2023 WGMIXFISH-ADVICE meeting.

4 CONCLUSIONS AND RECOMMENDATIONS

Although the majority of stocks represented in current mixed-fisheries considerations products are category 1 stocks with full analytical stock assessments, using FLBEIA there are methods and examples of how to include all types of stocks. The process of including new stock requires good communication between WGMIXFISH and the stock assessor, collection of all current data, quality-control reviews, and clear definitions of limitations and assumptions. This is time-consuming, and work cannot always be completed in one year. Incorporation of new stocks takes intersessional research and development, along with development at WGMIXFISH-METHODS before it can be approved for use in the production of mixed-fishery considerations. The inclusion of each new stock also changes the structure and dynamics of the fleet and model, and may also require the development of specific scenarios, and time to be spent by WGMIXFISH-METHODS and WGMIXFISH-ADVICE in reviewing the revised products to ensure that the outcomes of the scenarios are logical and meaningful. There is no one-size-fits-all in terms of assessment model or considerations product. Time and manpower are currently the key factors for being able to incorporate additional stocks.

ANNEX 19: CONSIDERATIONS AND DECISIONS CURRENTLY MADE WITHIN THE NEW AREA MIXED-FISHERY ASSESSMENT DEVELOPMENT PROCESS

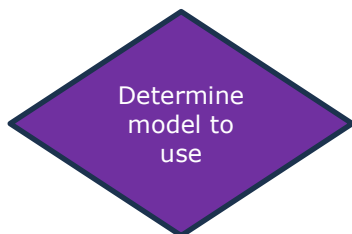
This annex provides a summary of the considerations and decisions currently made within the mixed-fishery assessment development process, expanding on the decision boxes from the flow diagram depicted in Figure 39. This information is adapted from a mixed-fisheries assessment best practice guidance document currently being developed by WGMIXFISH (under development, Pers. Coms. ICES).



Experts consider a range of factors when deciding which species to include in a mixed-fishery assessment.

The decision-making process involves consideration of:

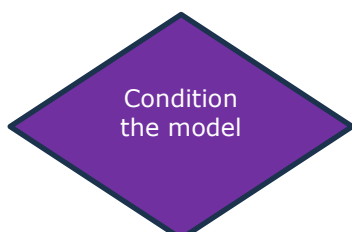
- technical interactions from a fishing perspective within the area;
- stock interactions of commercial species, and or vulnerable species;
- computational and processing requirements / conditioning demand;
- stock data available, from:
 - only those stocks with full age-based assessments and forecast methods or an absolute abundance estimate;
 - stocks with biomass-dynamics methods;
 - TAC stocks, even where no analytical population model is available;
 - all stocks, even non-quota.



Two models are used for mixed-fishery assessments within ICES: Fcube and FLBEIA.

- FLBEIA uses age-disaggregated catch information at the fleet and métier level, and allows for differences in selectivity among fleets/métiers. Additionally, FLBEIA offers more flexibility for future changes to methodology.
- Fcube is used when age-disaggregated data are unreliable or where the dynamics are driven primarily by discarding, this is because the way discards are projected in FLBEIA is not considered suitable in extreme fishing situations (e.g. zero TAC advice) (IBPMIXFISH; ICES, 2021b).

Over time, the intention is to progress all ecoregions to use FLBEIA. However, more development work is required for data-poor stocks before this will be feasible.



This is time consuming, and deals with the variety of settings within the model – from forecast settings (to replicate those for each single-stock advice), through future recruitment (dependent on single-stock approach), to define fleets/métiers, determine minimum thresholds, how to account for missing catches, and fleet behaviour.

Define fleets/métiers: There are currently three method choices for determining fleets/métiers:

- fleet-based;
- fishery-based;
- fleet and métier based: the recommended method, currently used by all ecoregions.

However, there is currently no standardised way to define the fleets and métiers, and each ecoregion has developed its own approach. To do so, the following should be considered:

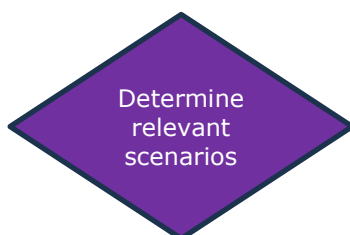
- matching DCF métiers with definitions used in the cod long-term management plan (e.g. North Sea);
- whether separation of fleets over vessel length is necessary;
- combining across gear groupings that have similar catch profiles;
- combining countries that only account for a small proportion of the catch (e.g. Bay of Biscay – countries other than Spain and France are grouped together);
- combining métiers across ICES divisions that are often combined for sampling, management and advice purposes (e.g. Celtic Sea);
- conducting a clustering analysis (or similar) to characterise the fishery and ascertain whether fleets/métiers with similar data/interactions can be merged;
- compatibility with other datasets (e.g. STECF for economic data) or with regulations/technical measures;
- the expert opinion of ecoregion fisheries experts.

Determine minimum thresholds: To maintain a manageable level of complexity resulting from large numbers of fleet/métier units with small contributions to catches of each stock included within the model, it is necessary to determine a minimum threshold below which units can be amalgamated into an 'other' or 'miscellaneous' category. Currently, these minimum thresholds vary across the ecoregions. Best practice within WGMIXFISH is to carry out a sensitivity analysis to determine the most appropriate threshold level.

Fleet behaviour: Fleet behaviour in the mixed-fisheries model is assumed to be similar to the recent past as observed in the fleet data. This is intended to ensure the fleet behaviour is relevant. Best practice has this set to the last three years, but the North Sea is the exception to this as it uses the last data year. Fleet behaviour encompasses a number of parameters, for which different modelling approaches could be used:

- effort allocation per métier within a fleet;
- catchability (catch efficiency) per métier and species;
- gear selectivity per métier and species (age-based models only);
- quota share per fleet (typically based on historic landings share).

The TAC used for the intermediate year and advice year in the forecast are taken from the last single-species advice issued for each stock. The TACs are shared between the fleets using the assumption made on the quota share per fleet. TACs for *Nephrops* need separate treatment to align functional units and the larger TAC areas.



There are several scenarios that are current best practice to be included within the models. These are reproduced in Table 1 from the developing ICES mixed-fishery assessment guidance document.

The single-stock scenario method in Table 1 can be applied to all stocks included in the mixed-fisheries assessment model. There is also scope to develop scenarios to meet the requirements of the ecoregion, and the particular scenarios presented in subsequent ICES considerations sheets will consider stock protection and / or management interests, e.g.

in some ecoregions an economic supplementary scenario has been provided where value was used to maximise value of catches.

The WGMIXFISH group considers an earlier 'range' scenario (that used the FMSY ranges of the single-species assessments to provide an optimised scenario) as no longer appropriate because of misinterpretation of mixed-fisheries considerations sheets and is developing an alternative scenario.

Table 1: Best practice scenario descriptions included within all ecoregion assessments, reproduced from the developing ICES mixed-fishery assessment guidance document

Scenario	Description	Aim
Maximum ('max')	For each fleet, fishing in the advice year stops when all stock shares of that fleet have been caught.	This scenario highlights the least-restrictive stocks and results in overshoot of the advised catch for most stocks.
Minimum ('min')	For each fleet, fishing in the advice year stops when the first stock share of that fleet has been caught.	This scenario is the most precautionary option and can highlight some potential 'choke species' issues. This option results in the under-utilisation of the single-stock advice possibilities of most stocks.
Status quo effort ('Sq_E')	The effort of each fleet in the advice year is set equal to the effort in the most recent historical period (average of last three years) for which landings and discard data are available.	This scenario indicates the likely level of catch if there is no change to the fishing effort exerted by each fleet.
Single stock ('stock')	The effort of each fleet in the advice year corresponds to the effort needed to take their stock share of the specified 'stock', regardless of other catches. If a fleet does not have any fishing opportunities for the specified stock, status quo effort is used.	This scenario indicates the likely level of catch for other stocks if the single stock advice for the stock of interest is fully taken.

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The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

