INTER-BENCHMARK PROCESS TO EVALUATE A CHANGE IN OPERATING MODEL FOR MIXED FISHERY CONSIDERATIONS IN THE CELTIC SEA AND NORTH SEA (IBPMIXFISH)

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i Executive summary

The objective of the inter-benchmark working group was to evaluate whether FLBEIA (Garcia *et al.*, 2017) can be used to generate advice on mixed fisheries considerations in Celtic Sea and Greater North Sea ecoregions. The working group should implement an adequate conditioning of the model and investigate the ability of the model to reproduce single species advice and provide meaningful mixed fisheries advice.

The validity of the FLBEIA model implementation in both ecoregions was assessed comparing the parameterisation and forecasted indicators in mixed fisheries scenarios against those obtained by the stock assessment working groups and Fcube model. In both case studies the model was implemented using fleet and métier dependent catch-at-age, and discards and landings weight-at-age. In general, in both case studies, the fishing mortality at age and catch-at-age resulting from aggregating the fleet and métier dependent catch-at-age showed a good match with those calculated and estimated by the assessment working groups in the last assessment year. There were significant differences in some cases attributed to the procedure used to raise the data in the stock assessment working groups and the assumptions of the assessment models used.

Regarding FLBEIA model results, in Celtic Sea several problems were encountered in reproducing the advice and forecast of mixed fisheries scenarios. Those were mainly attributed to the use of Cobb-Douglass model at high levels of fishing mortality and the impact of discards weight-at-age in the forecast of discards. In the North Sea the reproduction of single stock advice was adequate, and the results of the forecast of mixed fisheries scenarios obtained with FCube and FLBEIA were similar.

The group concluded that FLBEIA implementation of mixed fisheries in the Celtic Sea was not ready for provision of advice in 2021. However, for North Sea it was concluded that the FLBEIA implementation with métier dependent catch-at-age structure provides meaningful results to provide advice in mixed fisheries considerations.

The working group recommended continuing working in 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. Furthermore, it also recommended to organize a dedicated workshop to address some of these issues and others identified during the meeting.

ii Expert group information

Expert group name	Inter-Benchmark Process to evaluate a change in operating model for mixed fishery considerations in the Celtic Sea and North Sea (IBPMIXFISH))
Expert group cycle	Annual
Year cycle started	2021
Reporting year in cycle	1/1
Chair(s)	Dorleta Garcia, Spain
Meeting venue(s) and dates	20-22 September 2021, by correspondence (11 participants)

1 Objective

The main objective of the inter-benchmark working group was to evaluate whether FLBEIA (Garcia *et al.,* 2017) can be used to generate mixed fisheries considerations in Celtic Sea and North Sea case studies. The objective achievement of the objective was evaluated through three terms of reference:

a) **Evaluate the proposed change in operating model** for mixed fishery considerations in the Celtic Sea and North Sea from FCube (Ulrich *et al.,* 2011) to FLBEIA, and its appropriateness for providing advice.

b) **Review parametrization** of the new FLBEIA models for each ecoregion. Parameters that need checked include e.g. fleet-aggregated catches vs. single stock advice objects.

c) Check the ability of the FLBEIA model to incorporate the **single species advice** and its capacity to produce scenarios that provide **meaningful mixed fisheries advice**. Forecast behaviour should be evaluated in terms of the consistency of historical, intermediate and advice year values by stock (e.g. catches, fishing mortality and SSB), and catches and choking behaviour by fleet/stock for forecast scenarios.

2 Methodological approach

2.1 Generation of mixed fisheries considerations

In the generation of mixed fisheries considerations stock dynamics estimates, from stock assessment working groups, and catch and effort data by fleet and métier, from Intercatch or provided in accessions by the countries, are used to populate multi-stock and multi-fleet models. Then, a set of scenarios with different assumptions about the effort exerted by the fleets in the advice year are run to forecast the total landings and discards produced for each effort level given the catch advice of the stocks. The two models used nowadays in ICES to do the forecast are FCube (Ulrich *et al.*, 2011) and FLBEIA (Garcia *et al.*, 2017).

The workflow in the generation of mixed fisheries considerations is given in Figure 1.1. In brief:

1. The data is obtained from stock assessment working groups, Intercatch, and effort and catch data provided by the countries in accessions. The effort and catch data provided by the countries are more detailed than that provided by Intercatch and it includes the size of the vessels. Before moving to the second step, a quality check of the data is carried out to ensure consistency among datasets.
2. Data are then used to build the FLR (Kell *et al.*, 2007) objects needed to feed the forecast models. In both models the main input data object is the FLFleets object that stores all the data related with the fishing activity at fleet, métier and stock level. The data related with the stock dynamics are stored in an FLBiol object in the case of FLBEIA and FLStock object in the case of Fcube.
3. Before running the scenarios and producing mixed fisheries considerations the short-term forecast used to generate stock advice in stock assessment working groups is replicated using the same procedure used in the forecast of the mixed fisheries assessment models (using a single fleet that account for all the catch). The objective is to ensure that the forecast procedure used in stock assessment working groups and that used in mixed fisheries is consistent. If the match between both procedures is accurate, we can ensure that differences in effort scenarios are a consequence of the fleet dynamics and technical interaction between stocks.
4. Once the single stock advice is accurately reproduced the mixed fisheries models are used to forecast the landings and discards by fleet and métier for each stock under different effort level assumptions.
5. Mixed fisheries considerations that present the consequences of single stock advice in a mixed fishery framework are produced using the output of these scenarios.

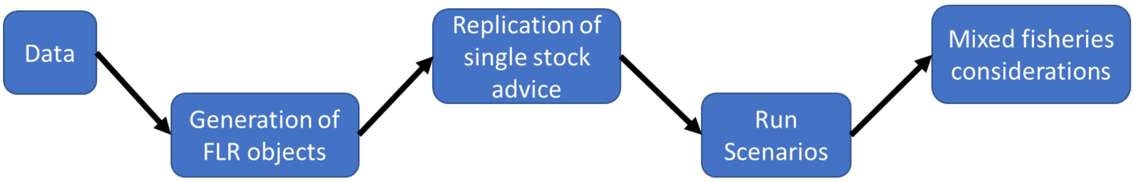

Figure 1.1 Main steps in the generation of mixed fisheries considerations.

Currently two mixed fisheries simulation models are available to do the forecast in Step 4 and produce mixed fisheries considerations in Step 5, Fcube (Ulrich *et al.*, 2011) and FLBEIA (Garcia *et al.*, 2017). Fcube was the first model used to produce mixed fisheries advice in ICES for the North Sea in 2009 (ICES, 2009). Since then, production of mixed fisheries considerations has been extended over ICES areas and currently WGMIXFISH produces advice for Celtic Sea, Bay of

Biscay (North), Iberian Waters, and North Sea. For Celtic Sea the advice is produced using Fcube and for Bay of Biscay and Iberian Waters FLBEIA is used since 2020 and 2018 respectively.

The data needed to condition both models are the same. However, the conditioning of FLR objects is different due to the structural differences between both models (see section 2.2), and FLBEIA needs more FLR objects because of its greater generality.

2.2 Comparison between Fcube and FLBEIA models

Table 2.1 lists some of the key structural differences between FCube and FLBEIA. The first aspect is regarding fleet/métier catches and catchabilities. FLBEIA allows for a higher degree of age-based catchability specification among fleet/métiers than FCube. Historically, users of FCube have used the selectivity patterns of the single stock assessments (SSA) to define a common relative age compositions in landings and discards among fleets/métiers, although the overall landings and discards are based on age-aggregated values. Each fleet/métier has its own. Each fleet/métier has its own overall catchabilities by stock as calculated from the share of the catch by fleet and métier as a proportion of the overall share multiplied by the stock level fishing mortality at the stock Fbar range and divided their specific effort (Equations 1 and 2), but the relative catchabilities at age were identical for each fleet/métier (i.e. they have the same selection patterns).

$$F(\mathrm{Fl}, m, \mathrm{St}, Y) = F(\mathrm{St}, Y)\frac{C(\mathrm{Fl}, m, \mathrm{St}, Y)}{\mathrm{Ctot}(\mathrm{St}, Y)},$$

Equation 1 (from Ulrich et al 2011)

$$q(\mathrm{Fl}, m, \mathrm{St}, Y) = \frac{F(\mathrm{Fl}, m, \mathrm{St}, Y)}{E(\mathrm{Fl}, m, Y)}.$$

Equation 2 (from Ulrich *et al*., 2011)

An age-disaggregated version of FCube (i.e. allowing for variable catchabilities for each fleet/métier/stock interaction) was developed but never applied in WGMIXFISH. FLBEIA explicitly allows for age-based differences, but this functionality has not yet been utilized in WGMIXFISH-ADVICE for the Iberian Waters and Bay of Biscay case studies. Rather, both studies still use an approach similar to FCube where the age-disaggregation of the catch for each fleet and métier is the same as the stock-level distribution. The North Sea and Celtic Sea FLBEIA models presented here have both been conditioned using age-disaggregated catch information at the fleet and métier level. The advantage of this approach is that it can explicitly consider differences in selectivity among fleets/métiers, which may have important consequences in terms of simulating catch dynamics and impacts to stocks; for example, fleets operating in nearshore waters may be more likely to catch younger ages than fleets operating in deeper areas.

Table 2.1. Known differences in model formulation between the currently used FCube model and the proposed FLBEIA model

Aspect	FCube	FLBEIA
Fleet/métier catches and selectivity	Age-aggregated catches. Uniform selectivity pattern among all fleet/métier/stock interactions consistent with the single-stock assessment. However, there exists an age-disaggregated version of FCube that has never been tested.	Age-disaggregated catches. Variable selectivity pattern among fleet/métier/stock interactions.

Aspect	FCube	FLBEIA
Stock dynamics	Age-based and fixed dynamics.	Age-based, biomass-based, and fixed dynamics. Biomass-based dynamics allows for the incorporation of stocks assessed with surplus production models (e.g. SPiCT)
Catch model	Baranov-type - Linear relationship between effort and fishing mortality (i.e. constant catchability, q) and non-linear relationship between effort and catch.	Cobb-Douglas-type – When alpha = beta = 1, linear relationship between catch and effort t and catch and biomass, but non-linear relationship between effort and fishing mortality.
Model development	Scripts not maintained	Maintained Package
Effort restriction	Based on partial fishing mortalities.	Based on catch restrictions.
MSE	Not developed in an MSE context	Developed for MSE

The second aspect listed in Table 2.1 is in regard to stock dynamics. In FCube, stock dynamics have been historically limited to age-based stocks. Fixed dynamics are used for *Nephrops* in the North Sea and Celtic Sea case studies, where the evaluation of choking effects from their quotas may be addressed without considering their impacts to future dynamics. FLBEIA allows for the definition of biomass-dynamics stocks, which are parameterized according to the generalized surplus production model of Pella and Tomlinson (1969). One of the more popular frameworks for fitting these types of models is via the R package SPiCT (A stochastic surplus production model in continuous time) (Pedersen and Berg, 2017). SPiCT models are not integrated directly in FLBEIA, but translating their fitted population dynamics parameters into FLBEIA has been documented (https://flr-project.org/doc/FLBEIA_Data_Poor_MSE.html). Integrating SPiCT directly into FCube forecasts has also been demonstrated in past WGMIXFISH-METH work, but this functionality was never adopted into advice. The lack of adoption had more to do with the limited number of data-limited, biomass-based stocks for which SPiCT assessments have been approved by ICES for providing single stock advice. Nevertheless, as time series continue to grow, the prospect of including additional biomass-based assessments in WGMIXFISH is likely to grow, and FLBEIA's established functionality in this regard would facilitate their inclusion in the future.

The third point relates to differences in the catch model; specifically, FCube uses the Baranov formulation, while FLBEIA uses a Cobb-Douglas formulation. The main difference is that the Baranov catch equation implies that fishing mortality (F) is treated a continuous rate over time, while the Cobb-Douglas equation assumes that catches occur instantaneously half-way through the time step, similar to the “cohort analysis” method of Pope (1972) (Figure 1.2).

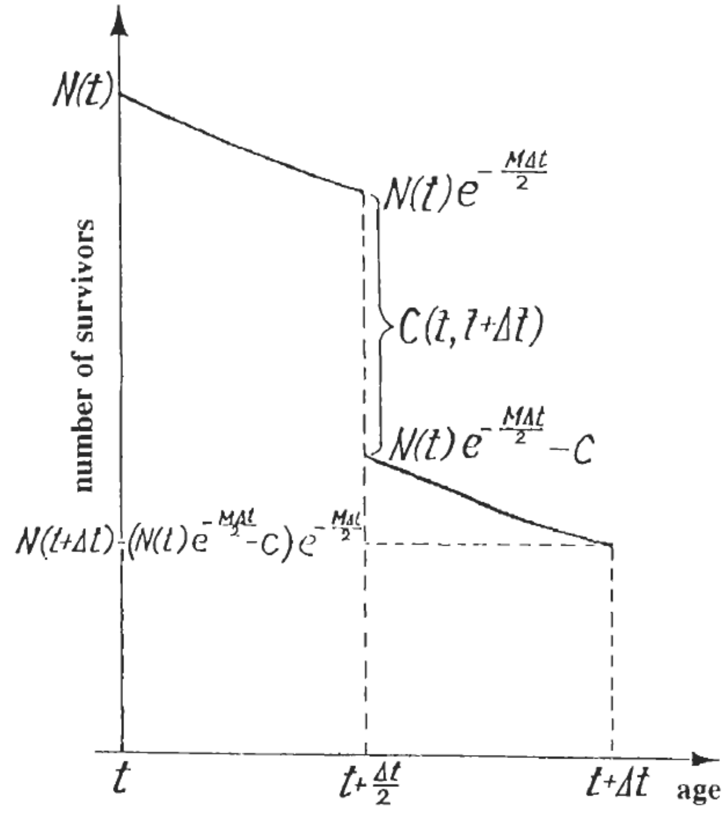

Figure 1.2. Pope's (1972) cohort analysis (graphic from Sparre and Venema, 1998).

Because of these differences, catchability (q) is defined differently for both models. In FCube, q is related to fishing mortality (F) and effort (E):

$$F = qE$$,

whereas in FLBEIA, q relates catches (C) to stock numbers (N) and effort (E):

$$C = NqE$$.

One consequence of this difference is that the Baranov equation assumes that simultaneous depletion by all fleets, and any relative changes in advised F are felt equally among the fleets (assuming that their "partial F", pF, is based on their fraction of the total catch for the stock). Thus, the fleet effort restrictions for a given stock are determined across for all fleets at once in FCube. Alternately, the instantaneous catch-based formulation used by FLBEIA allows for the estimation of effort restrictions independently for each fleet. Consequently, there will likely be differences among fleets in terms of their relative effort changes as compared to FCube, but these are generally quite small. Pope showed that when $F < 1.2$ and $M < 0.3$, differences to estimates of continuous depletion are small in terms of surviving numbers and realized F.

A key difference is that under a Baranov equation, as a continuous process, fishing mortality is linear with fishing effort, while catch (or catch per unit effort) declines due to the depletion of the stock. Conversely, under the Cobb-Douglas equation catch is linear with effort and thus the rate of fishing mortality (as calculated through the Baranov equation) increases more quickly at higher fishing efforts.

During the meeting several analysis were carried out to assess the differences between Baranov and Cobb-Douglass models in catch and fishing mortality for different effort levels (see Annex

2). For low and moderate levels of fishing mortality, the differences between both models were limited. However, the differences at high levels of fishing mortality were high.

2.3 Advantages and disadvantages of FLBEIA

The advantages and disadvantages of using FLBEIA listed below are in relation to Fcube model.

Advantages

1. **Full bio-economic MSE framework**: FLBEIA provides a full MSE framework. The model was designed to conduct bio-economic simulations in an MSE framework, as such, the operating model also includes an observation model and it has a management procedure component to use assessment models and harvest control rules to generate the catch advice dynamically. Futhermore, the operating model can also incorporate additional variables not included in the FLBiols and FLFLeets object, such as environmental or economic variables. This favours the use of the model in other areas such as research projects, which guarantees further development of the model itself and the case studies where it has been implemented.
2. **Modular and Extensible:** New models can be incorporated into FLBEIA to describe any of the processes that form the model, as far as the variables used by the model can be generated internally or given as input data.
3. **Documentation:** The model is very well documented, it has a detailed manual, a series of tutorials (https://flr-project.org/doc/), help pages within the R package and a research article (Garcia *et al.*, 2017)
4. **Maintainance**: The code is in GitHub and it is actively maintained by developers and collaborators.
5. **Population dynamics:** Apart of age structure populations it also includes a biomass based and fixed population dynamics.
6. **Effort restrictions based on quota-shares:** The effort in FLBEIA is restricted by catch quotas and not partial fishing mortalities. In Fcube the use of partial fishing mortality restriction causes that some stocks choke the fishing activity before their catch quota is fully consumed.
7. **Effort dynamics:** Effort dynamics in FLBEIA can be simulated using a Fcube like approach were effort share is provided as input data, or updated dynamically using a profit maximization appraoch, gravitiy models or others.

Dis-advantages

The main disadvantage of FLBEIA in comparison with Fcube is the use of Cobb-Douglass model to produce catch. Most stock assessment models used Baranov catch equation for catch production, as Fcube does. In general, Cobb-Douglas and Baranov give similar results but in extreme situations, like depleted stocks, the differences could be significant. There exists a Baranov model for catch production in FLBEIA but the performance is not fully correct. The calculation of effort is done independently by each fleet with causes mistmaches between the expected and real catches. In Fcube this problem is overcame using partial fishing mortalities as the restrictiors of effort instead of catch quota resctrictions. The same approach could be implemented in FLBEIA.

3 Case Studies

A detailed description of the work carried out in the case studies is presented in annex XX. The three ToRs of the working group were addresed in three steps:

1. Comparing the historical catch-at-age and fishing mortality-at-age resulting from aggregating the catch-at-age in the FLFleets object and calculating the corresponding fishing mortality-at-age. (ToR a, ToR b).
2. Using FLBEIA to reproduce the single stock advice using a single fleet and single métier FLFleet object, obtained through aggregation of the multi-fleet and multi-métier object. (ToR a, ToR C).
3. Using FLBEIA to forecast landings and discards by fleet in advice under different mixed fisheries scenarios (ToR a,ToR c)

A great effort was done in both case studies to produce catch-at-age, and discards and landings weight-at-age matrices by fleet, métier and stock that matched the matrices used in the stock asessment when they where aggregated. In general the match between catch-at-age and fishing mortality at age from the stock assessment model and that derived from aggregating the catch-at-age in the FLFLeets object was good. There were significant differences in some cases attributed to the procedure used to raise the data in the stock assessment working groups and the assumptions of the assessment models used (constant catchability in the older age classes or observation errors in the catch-at-age, for example). In Celtic Sea there were problems in the raising of the data of the stocks assessed by WGBIE (ICES, 2021). In the North Sea case study, there were some differences in plaice in the eastern channel related with assignation of plaice catches to different stocks that needs further investigation.

Regarding forecast in mixed fisheries scenario, Celtic Sea case study developed and implemented a fully age disaggregated FLBEIA model including the stocks that were part of mixed fisheries advice given in 2020. Several problems were encountered in reproducing the advice and forecast of mixed fisheries scenarios. Those were mainly attributed to the use of Cobb-Douglass model at high levels of fishing mortality and the impact of discards weight-at-age in the forecast of discards when there are big differences between the mean weight-at-age in the population and in the discards. The challenges with data, model conditioning and formulation led the group to conclude that the FLBEIA implementation of Celtic Sea mixed fisheries was not ready for provision of advice in 2021. However, it was agreed further work would be done to resolve the issue for advice in future years, subject to IBP approval. These efforts should focus on data for WGBIE stocks, implementing the Baranov catch production function in FLBEIA and reviewing the most appropriate way to project over-quota discards and discard weights.

In the North Sea the reproduction of the advice, using a single fleet, the differences between single stock forecast and FLBEIA forecast were within the +/-5% limit in most of the cases. The results obtained in the mixed fisheries forecast scenarios using FLBEIA and Fcube were also similar. Differences to FCube were due primarily to differences in the FLBEIA catch model (Baranov vs. Cobb Douglas), fishing activity restrictor (partial fishing mortality vs catch quotas) and fleet conditioning (métier dependent-age structure). The group unanimously agreed FLBEIA with métier dependent catch-at-age structure is the most realistic model configuration to provide advice in mixed fisheries considerations in the North Sea. FLBEIA, apart from métier dependent catchability at age (i.e. selectivity) it also provides a catch constrained forecast of fishing activity, that is more realistic for stocks managed through quotas. In this case study, the use of Cobb-Douglass production function did not seem to be problematic in the current situation and the gains from moving to FLBEIA outweigh this limitation (see section 2.3).

4 Recommendations

During the working group several problems were identified that need further discussion and investigation to improve the advice on mixed fisheries considerations. It was agreed that having a dedicated workshop should be the best way to address these problems. The workshop would have three objectives:

a) To define a set of guidelines or protocol to produce mixed fisheries considerations (conditioning of the models, reproduction of the advice and forecast of mixed fisheries scenarios) ;

b) To investigate and decide on the best way of conditioning the models when there are differences between the assumptions in single stock assessment models and mixed fisheries simulation models (e.g. differences between observed and estimated catch) ;

c) Improvement of mixed-fisheries models.

Issue	Objective
Analysis of trends in catchability and effort (total and effort share) to decide using mean of last N years or last year value (stock dependent for catchability and fleet dependent for the rest).	a)
Setting capacity limits to obtain more realistic scenarios (specially the 'max' one). This could lead to non-consumption of the full quota of the less limiting stocks.	a)
Starting point of the forecast, intermediate or advice year	a)
Conditioning catch-at-age by métier is easy when it is done in Intercatch by the stock coordinator, but it is done outside it is not straightforward. One of the main reasons for not doing it is Intercatch is using a length structure assessment model (hake, monkfish), in that case the age structure in the catch is an estimation and not a observed value.	
Definition of assumptions in the intermediate year	b)
Incorporation of discards, raising procedures and working groups	b)
Projection of discards weight-at-age when the differences with weight in the population are high or there are missing values.	c)
Incorporation of Baranov model into FLBEIA (catch quotas vs partial fishing mortalities)	c)

The group identified inconsistencies on how discards are raised in stock assessment working groups (allocations of discards are not done in WGBIE, they are in WGCSE following WKCELTIC procedures and a mean proportion is universally used in WGNSSK). During the working group it was decided to follow the procedure used by the assessment working groups as far as possible. However, it is considered an important issue to obtain for the quality of the stock assessments and mixed fisheries forecast. It is recommended that WGBIE revises the procedure on how discards are included in the assessments, for example looking at how it is done in WGCSE that has defined a procedure that has been per reviewed. As a first step forward and taking advantage of the benchmark workshops that will take place for hake, monkfish and megrim in 2022, the procedure used in WGCSE will be presented in the corresponding data workshops.

5 Conclusions

The working group recommended to:

- Continue working in the conditioning of Celtic Sea case study and improving the FLBEIA model before it can be used to provide advice for mixed fisheries considerations;
- Use FLBEIA with fleet and métier dependent catch-at-age structure to provide advice for mixed fisheries considerations in the North Sea.

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Annex 2: Background and case study specific information

Introduction

The over-arching goal of IBPMIXFISH is to evaluate whether a change in operating model from FCube (Ulrich *et al.*, 2011) to FLBEIA (García *et al.*, 2017) is appropriate for providing mixed fishery considerations in the Celtic Sea and North Sea. To achieve this goal, both case studies present an overview of the proposed model changes, conditioning, and their influence on mixed fishery model forecasts. For these comparisons we consider the data used in last year's WGMIXFISH-ADVICE, where FCube was used in both studies. However, as FLBEIA is age-based this model includes age-disaggregated landings and discards which are not used in the FCube framework currently used to provide advice, and so was processed for the IBP.

The rational for the model change stems from a desire to use a modelling framework that improves transparency and flexibility. While both FCube and FLBEIA models are based on similar assumptions and methodologies, FLBEIA has several advantages; including (but not exhaustive): a full Management Strategy Evaluation (MSE) framework allowing for additional explorations beyond the scope of short-term forecasts for advice; an actively maintained and documented package within the FLR (Fisheries Library in R) toolbox for quantitative fisheries science; and well-developed bioeconomic modules. There are some differences in model structure between FCube and FLBEIA which are features of the modelling frameworks, and the assumptions and consequences are set out within this document.

Historical perspective

The Working Group on Mixed Fisheries Advice for the North Sea (WGMIXFISH) was first formed in 2010 following the planning work of the Workshop on Mixed Fisheries Advice for the North Sea (WKMIXFISH) and the Ad hoc Group on Mixed Fisheries in the North Sea (AGMIXNS) in 2009. Since then, the working group has expanded to include other case studies and now takes place in two parts: working groups for methodological development (WGMIXFISH-METH) and advice (WGMIXFISH-ADVICE).

FCube was used as the simulation model for the initial model of the North Sea as well as for other case studies that were later added, including the Celtic Sea. In addition to these case studies, WGMIXFISH-ADVICE also currently provides advice for the Bay of Biscay and Iberian Waters, both of which are conducted using FLBEIA (Figure A.1).

FLBEIA was first developed around 2012 but was not used immediately in WGMIXFISH. FLBEIA models were developed in parallel to FCube in the Celtic Sea and North Sea since 2015 and 2018, respectively, but FCube has remained the operating model used for advice. However, FLBEIA has been adopted as the operating model for advice in both other case studies - Iberian Waters (since 2018) and the Bay of Biscay (since 2020).

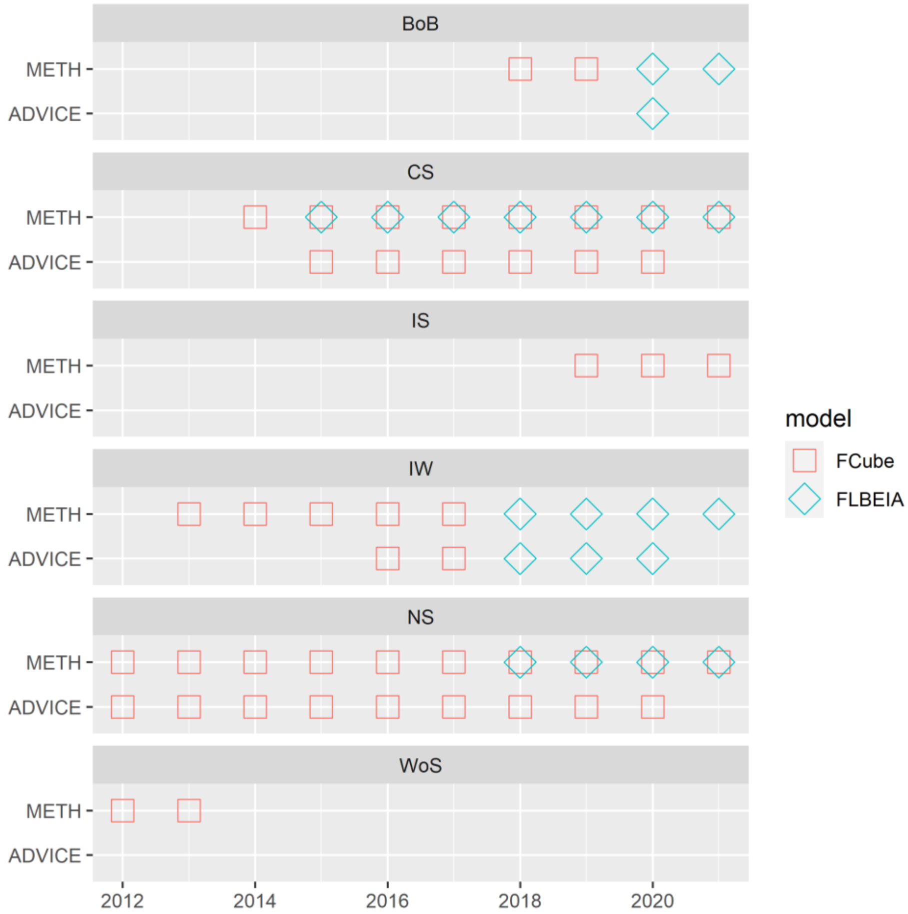


Figure A.1. History of case study inclusion in WGMIXFISH-METH and WGMIXFISH-ADVICE. Overlapping model symbols indicate parallel development during the Methods meeting. Case study abbreviations: BoB = Bay of Biscay, CS = Celtic Sea, IS = Irish Sea, IW = Iberian Waters, NS = North Sea, WoS = West of Scotland.

Format of the document

The following sections provide case study specific information on model structure, data conditioning and forecasting procedures, as well as proposed changes and consequences following a move to FLBEIA. Where the model change does not have specific consequences for future advice, such as more general information on data inputs and conditioning procedures, reference may be made to each case study's stock annex.

Celtic Sea case study

Summary

The Celtic Sea case study developed and implemented a fully age-disaggregated FLBEIA model including the stocks that were part of mixed fisheries advice given in 2020. There were significant challenges with data, model conditioning and formulation that led the group to conclude that it was not ready for provision of advice in 2021. However, it was agreed further work would be done to resolve the issue for advice in future years, subject to IBP approval. In particular, these efforts should focus on data for WGBIE stocks, implementing the Baranov catch production function in FLBEIA and reviewing the most appropriate way to project over-quota discards and discard weights.

Case Study

Fisheries in the Celtic Sea are highly mixed, targeting a range of species with a number of different gears. Otter trawl fisheries target mixed gadoids (cod, haddock, and whiting), *Nephrops*, hake, anglerfishes, megrims, rays as well as cephalopods (cuttlefish and squid). Beam trawl fisheries target flatfish (plaice, sole, turbot), anglerfishes, megrims, and cephalopods (cuttlefish and squid), while set-net fisheries target flatfish, hake, pollack, cod, anglerfishes as well as some crustacean species. Beam trawling occurs for flatfish (in 7.e and 7.fg) and rays (7.f). The fisheries are mainly prosecuted by French, Irish, and English vessels with additional Belgian beam trawl fisheries and Spanish trawl and net fisheries along the shelf edge (7.hjk). Mixed-fisheries considerations are produced by ICES annually and in 2020 this advice combined the single-species stock assessments with information on the average catch composition and fishing effort of the fleets catching cod, haddock, whiting, Norway lobster, sole, white anglerfish, and megrim in the Celtic Sea (ICES 2020a).

Previously mixed fisheries advice for the Celtic seas has been produced using the FCube model (Ulrich *et al.*, 2011). This model implemented for advice does not consider age-structure of the catch at the fleet and métier level (as described above) and is based on fleets efforts to achieve their share of fishing mortality targets (partial Fs). Please refer to section 1.1 above for details on the differences between FCube and FLBEIA. By moving the model to FLBEIA it will provide the group the ability to model age-based catches at the fleet and métier level. This will enable the group to consider a number of other measures down the line which have been previous identified as important by stakeholders such as the impact of technical measures (e.g. gear-based selectivity changes) on the management of a system (ICES, 2021b). This proposed change requires a change in model and a change in the data that is being used to parametrised this model.

Data

A principal difference between FCube and FLBEIA is the inclusion of fleet and métier level age data. The incorporation of this additional data source offered the opportunity to revise data processing methodologies and scripts used to quality control and merge data.

Data sources

Four types of data are required: catch (tonnes), value (euros), effort (kWdays), age structure by métier (numbers in thousands and mean weight-at-age in g), and single species stock assessment (inputs including biological parameters, outputs in terms of population numbers and forecast settings including future recruitment assumptions). The source of each data source is summarised in Table A.2.3.1, and can vary per stock, with varying levels resolution (métier or stock level), quality and reproducibility.

Table A.2.3.1 Summary of data sources used within the Celtic Sea FLBEIA case study.

Data type	Stocks	Source	Quality and Reproducibility
Effort (kWdays)	All	WGMIXFISH data call (aka 'Accessions')	Annual data call available at the level of métier level 6, vessel length, and country. Checked for quality and conforms to a known data call format
Landings (tonnes)	All	WGMIXFISH data call (aka 'Accessions')	Annual data call available at the level of métier level 6, vessel length, and country. Checked for quality and conforms to a known data call format. Generally consistent with country submissions to other sources such as InterCatch and official catch statistics
Discards (tonnes)	sol.27.7fg	InterCatch	Clear, standardised process, handling fleets in the same consistent manner.
	cod.27.7e-k	SharePoint	Clear, standardised process, handling fleets in the same consistent manner. Raised using common format developed during WKCLETIC (reference). Full reproducible and quality control plots supplied.
	had.27.7b-k		
	whg.27.7b-ce-k		
	hke.27.3a46-8abd	Stock Assessor &/TAF	Raised using individual scripts, supplied by stock assessors on request. Not fully transferable to the mixfish method, full fleet age structure not retained for discards and age/length structure. Questions raised around discard raising process.
	meg.27.7b-k8abd		
	mon.27.78abd		
	Nep stocks	SharePoint – datamined by WGMIXFISH expert from advice sheets	Clear, standardised process, handling fleets in the same consistent manner. Full reproducible
Fleet age structure (numbers and weights) Additional data (not previously required for FCube)	sol.27.7fg	InterCatch	Clear, standardised process, handling fleets in the same consistent manner.
	cod.27.7e-k	SharePoint	Clear, standardised process, handling fleets in the same consistent manner. Raised using common format developed during WKCLETIC (reference). Full reproducible and quality control plots supplied.
	had.27.7b-k		
	whg.27.7b-ce-k		
	hke.27.3a46-8abd	Stock Assessor &/TAF	Raised using individual scripts, supplied by stock assessors on request. Not fully transferable to the mixfish method, full fleet age structure not retained for discards and age/length structure. Questions raised around age allocation process.
	meg.27.7b-k8abd		
	mon.27.78abd		
	Nep stocks	Not applicable	Not applicable
Single species stock assessment inputs and forecast	sol.27.7fg	TAF	All assessments are fully transparent and reproducible through the ICES TAF framework or stockassessment.org. Easily accessed and run
	cod.27.7e-k	stockassessment.org	
	had.27.7b-k		

Data type	Stocks	Source	Quality and Reproducibility
	whg.27.7b-ce-k		
	hke.27.3a46-8abd	TAF	Fully reproducible
	meg.27.7b-k8abd		
	mon.27.78abd	Stock Assessor	Stock Assessor
	Nep stocks	Not applicable	Not applicable

All landings and effort data came from the same source, WGMIXFISH data call. However, the source of information on discard rates, age structure and assessment outputs varied depending on the stock and single species working group in question.

In the case of WGCSE stocks (cod.27.7e-k, had.27.7b-k, whg.27.7b-ce-k, sol.27.7fg, and *Nephrops* stocks) discard rates and age structure were easily assessable and raised in a transparent process was easily transferred to the fleet structure provided in WGMIXFISH data.

This was not the case for WGBIE stocks (hke.27.3a46-8abd, meg.27.7b-k8abd, mon.27.78abd, which are all raised outside of InterCatch. Although the IBP group does not question the validity of how age and discard data were raised for the single species stock assessment, a number of concerns were raised about the transferability of this key information to the fleet structure available in WGMIXFISH data. As a result, a number of assumptions had to be applied to the WGBIE age and discard data so that they could be merged with WGMIXFISH fleet structure. This is not ideal and has resulted in a number of inconsistencies between the WGBIE discard and age data and WGMXIFHS fleet structure.

Data merging

The above data sources are then combined to produce the “fleet object”. Within this object the fleets were defined by aggregating age, catch, and effort across country, gear group, and vessel length (where applicable). Details on the previous methods of data processing can be found in the stock annex (ICES 2020b). Métier were defined according to gear type, target assemblage and ICES subdivision or groups of subdivisions on the basis of previous analyses (Moore *et al.,* 2020).

The flow chart in Figure A.2.3.2.1 details the process by which these data are merged. Throughout the data merging process, the accessions data (aka WGMIXFISH data) landings and effort are considered the true landings and effort to which everything else is raised or compared. The métier and stock information available within the accessions data provide the structure around which the fleet object is built. Within each new step of the fleet construction additional data sources is partitioned across this fleet and stock structure, applying landings totals, age and weight structure (step 1), discard totals, age and weight structure (step 2), followed by effort (step 3).

If data were missing, a series of approaches are taken to fill in missing data (i.e. ages or discard rates). Ideally, age and discard data are partitioned across the fleet at the resolution of country*métier*ICES area. However, this resolution is not always available (e.g. due to limited sampling) so a hierarchy of “fill-in” options are applied to the data. These options include matching sample data at the level of métier or stock. Finally, this process is assessed for quality and consistency to ensure that the final mixed fisheries forecast is not affected by errors/artefacts in the primary input data. In cases where there are less landings present in the accessions data then the stock object from the assessment, these extra catches are allocated to a stock specific "others" fleet, e.g. "cod_27.7e-k_fleet". This is particularly important for stocks that have catches outside of the Celtic Sea, i.e. anglerfish and megrims. If there are more landings in the accessions data than the stock object, the accessions landings are retained. This can lead to more landings than from the assessment, though in general this is not the case (Table A.2.3.2.1).

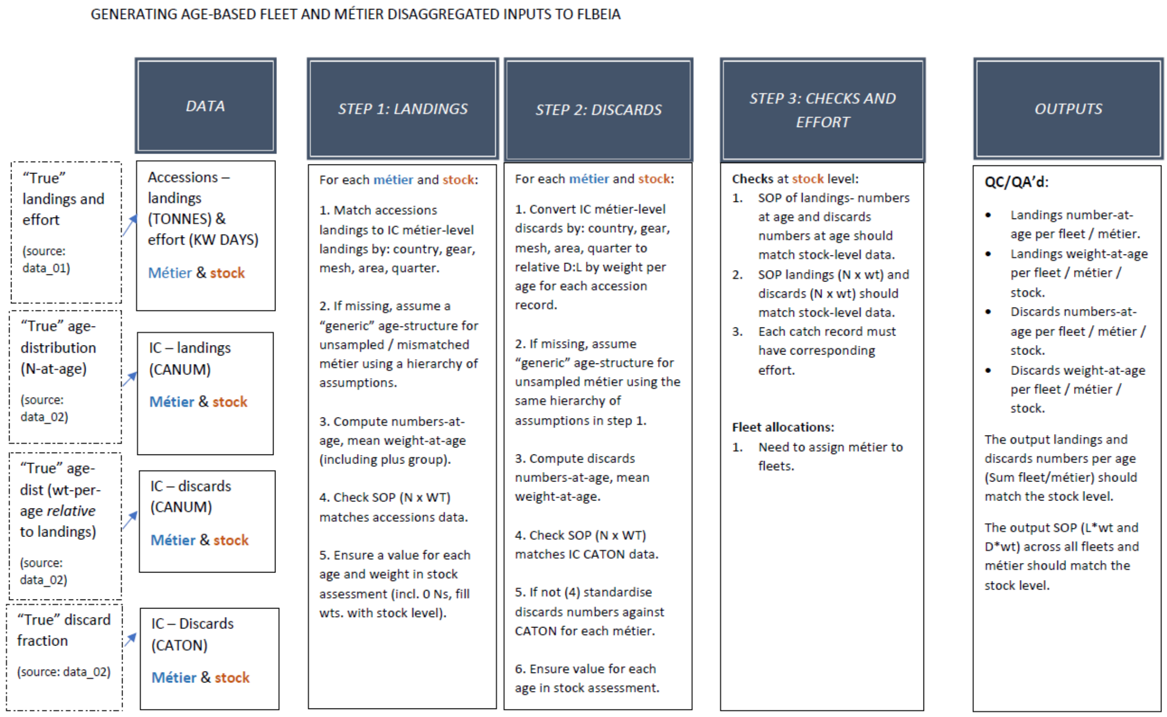


Figure A.2.3.2.1. Summary of data merging processes applied in the Celtic Seas case study to produce the fleet object. The final fleet object contains total catches, numbers and weight-at-age by fleet.

The final product of this data merging process is a fleet object which contains total landings, discards and effort per stock, fleet and ICES division. Quality of this fleet object is then assessed by comparing the totals in terms of tonnage and numbers to the single species stock assessment (FLStock object).

The total discards (tonnes) within the fleet object are summarised in Figure A.2.4.2.2, where the differences by stock between mixed fisheries fleet object (bars) and the single species stock object (black dot) are presented. This plot highlights the resolution at which the sample data (age, weight, and discards) were partitioned across the fleet structure: stock*country*métier*ICES area (red), stock*métier (green) or stock (blue). The quality control checks focused on the final three years (2017–2019) of the fleet object as these are used to condition the FLBIEA model.

Good consistency was found between the single species assessment stock object (black dot) and the fleets object (bars) in terms total discards (Figure A.2.3.2.2) and landings (Figure A.2.3.2.4), discard (Figure A.2.3.2.3) and landings (Figure A.2.3.2.5) numbers-at-age in the final three years (2017–2019) for all WGCSE stocks (cod.27.7e-k, had.27.7b-k ,whg.27.7b-ce-k , sol.27.7fg, nep stocks).

However, inconsistencies were found in totals available in the stock object and the fleet object for WGBIE (meg.27.7b-k8abd and mon.27.78abd). These differences were evident in terms of total discards (Figure A.2.4.2.2) and numbers (Figure A.2.4.2.3). In the case of mon.27.78abd there are more discards present the fleet object then the stock object. This may be driven by differences in the process of discard raising employed by the single species stock assessor and this mixed fisheries case study. Conversely, for meg.27.7b-k8abd the fleet object contained less discards then the stock object, which could be an artefact of species labelling in the baseline accessions data where megrims are grouped as LEZ by some counties.

Some minor differences are present for the total numbers of landings in the fleet and stock object whg.27.7b-ce-k (Figure A.2.3.2.2) in 2019. This was due to an error in the code used for the raising of age and discard data by the single species stock assessor and is currently being corrected as part of a separate IBP (reference).

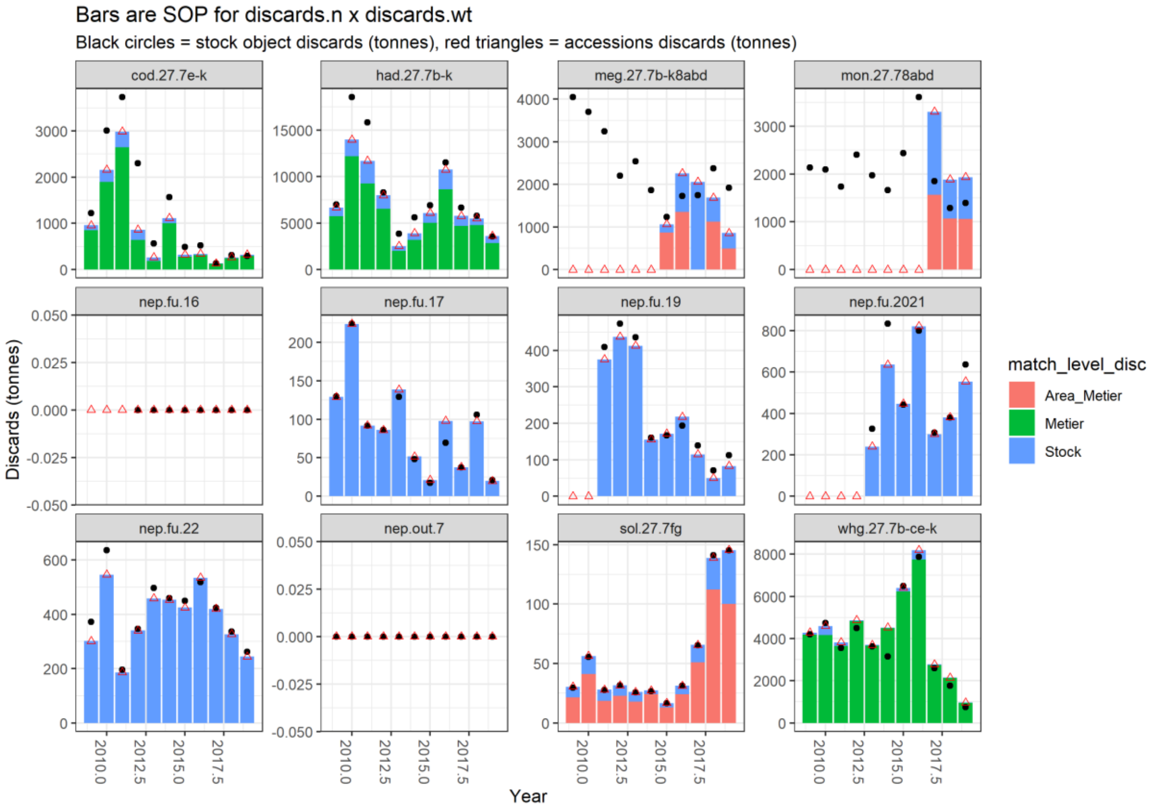


Figure A.2.3.2.2. Summary of the total discards in tonnes available in single species stock object (black dot) and the mixed fisheries fleet object (bars). The plots also highlight the resolution at which the sample data (age, weight and discards) were partitioned across the fleet structure: country*métier*ICES area (red), métier (green) or stock (blue).

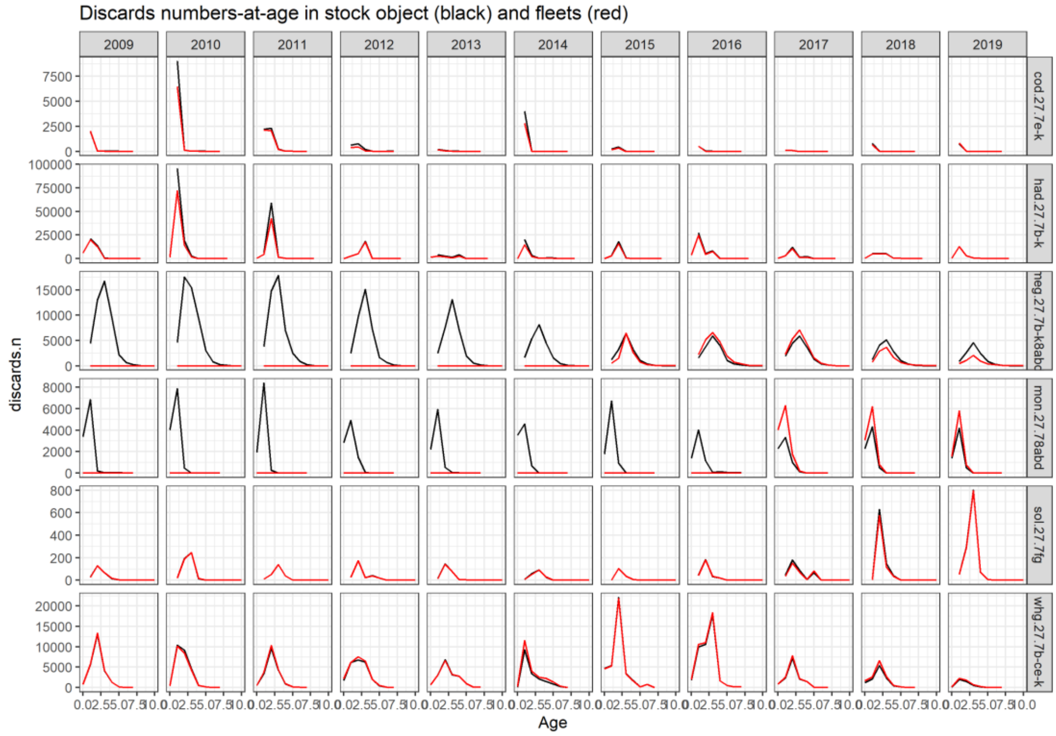


Figure A.2.3.2.3. Summary of the discard numbers of age (thousands) available in the single species stock object (black) and the mixed fisheries fleet object (red) after the merging process has been completed.

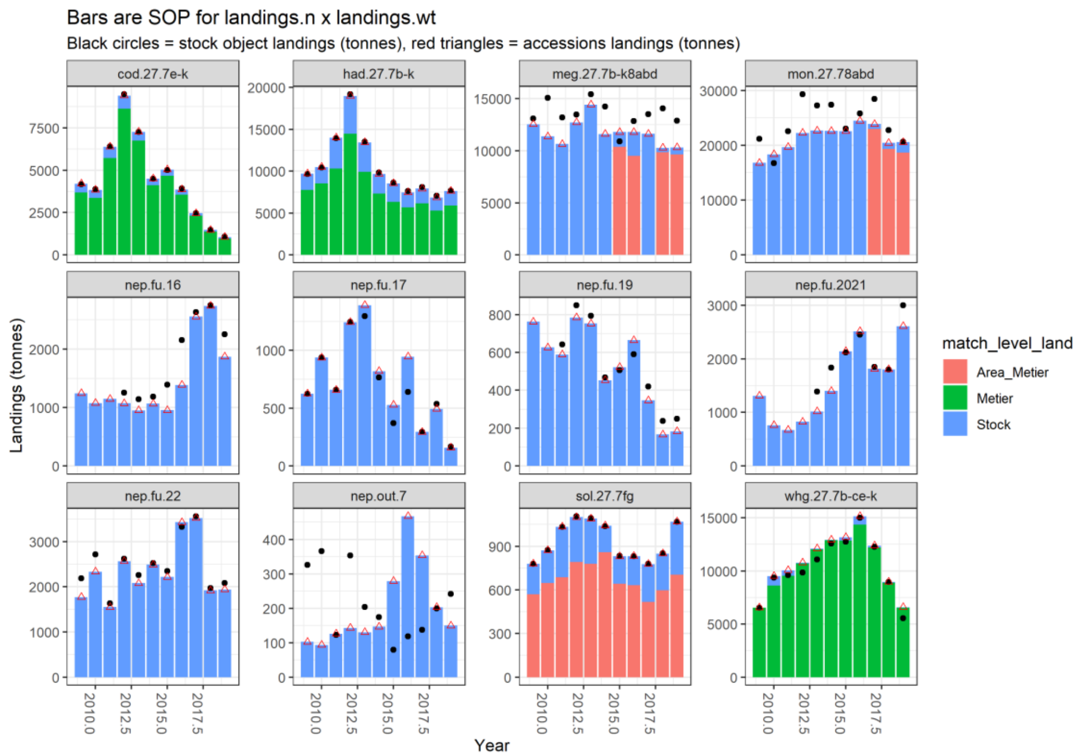


Figure A.2.4.2.4. Summary of the total landings in tonnes available in single species stock object (black dot) and the mixed fisheries fleet object (bars). The plots also highlight the resolution at which the sample data (age, weight and discards) were partitioned across the fleet structure: country*métier*ICES area (red), métier (green) or stock (blue).

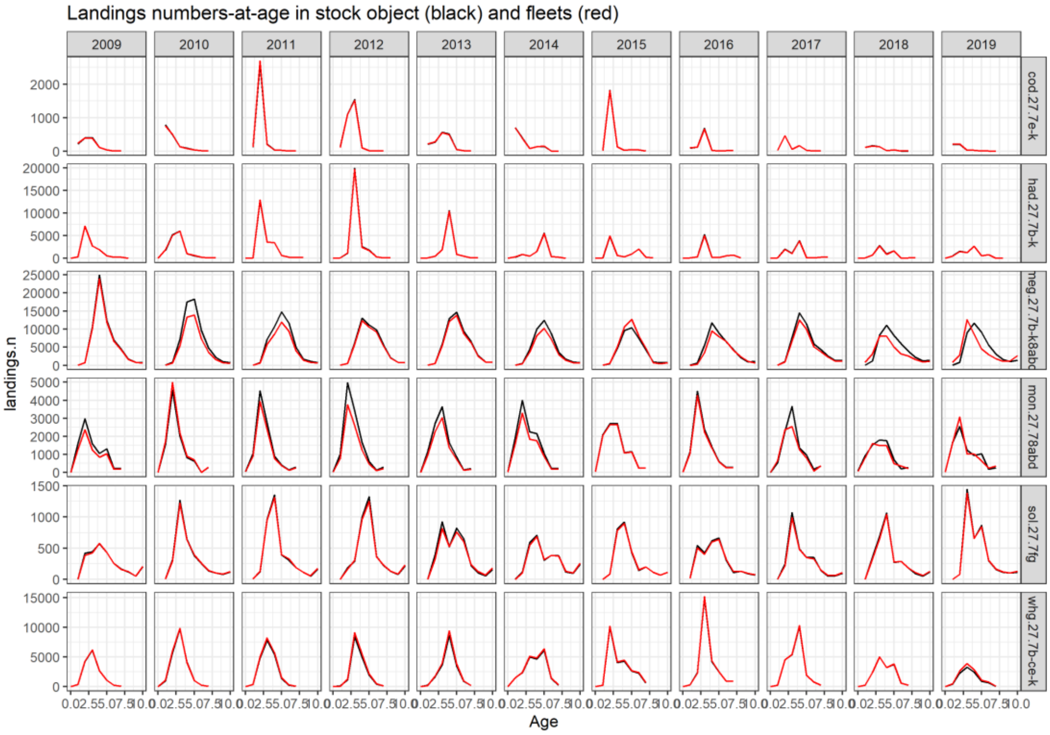


Figure A.2.4.2.5. Summary of the landings numbers of age (thousands) available in the single species stock object (black) and the mixed fisheries fleet object (red) after the merging process has been completed.

All three WGBIE stocks are raised outside of InterCatch and do not follow a common format. A possible solution in the future would be to follow the process implemented by cod.27.7e-k, had.27.7b-k and whg.27.7b-ce-k in the Celtic Sea, where during a recent benchmark a common R script was developed for raising the data in a consistent manner across all three stocks. This script was peer reviewed, the structure accounted for the data requirements of WGMIXFISH and is shared annually on the working group SharePoint, making it a fully transparent and reproducible process (ICES 2020c).

This common script also allowed the stock assessors to agree a common best practice when portioning discards and ages across métiers in the Celtic Sea, allowing for increased estimation of discards within the fishery. Currently there appears to be no allocating of discard rates across unsampled fleets within the three WGBIE stocks. For example, in 2019 countries submitted estimations of discards to InterCatch meg.27.7b-k8abd totalling 632 tonnes in area 27.7. This value did not change within the WGBIE raising process which when completed still remained at 632 tonnes of discards in ICES division 27.7. However, when WGMIXFISH applied its allocation process base on the InterCatch data supplied it resulted in a discard rate which is three times greater than the WGBIE estimate (1934 tonnes) (Table A.2.3.2.1). Common raising procedures would help to clarify these inconstancies, particularly in situations of widely distributed stocks such as hke.27.3a46-8abd where wide ranging discard rates due to varying sample sizes, fisher behaviour, gear and ICES divisions result in scientific estimates (Figure A.2.3.2.6) which cannot be reproduced easily within an age disaggregated fleet object.

Table A.2.3.2.1. Comparison of the total tonnage of landings, discards, and crude discard rate (discards/(landings+dsicards) available in the three data sources in ICES division 27.7 in 2019: raw InterCatch submissions, raised WGBIE data, and raised InterCatch data.

Stock	Catch type	Raw InterCatch submission	WGBIE raised	WGMIXFISH raised
mon.27.78abd	Landings	19085	19085	20547
	Discards	1333	1394	856
	Crude discard rate	0.07	0.07	0.04
meg.27.7b-k8abd	Landings	10226	10226	10315
	Discards	632	632	1934
	Crude discard rate	0.06	0.06	0.16

Figure A.2.3.2.6. Wide ranging levels of catch (pre-raising) submitted to InterCatch (2009 – 2019) for hke.27.3a46-8abd.

The incompatibility between the landings in WGMIXFISH fleet-based data (accessions) and the WGBIE raised data was particularly evident in the case of hke.27.3a46-8abd where the total tonnage of landings available in the three data sources (raw InterCatch submission, raised data, and stock object) varied, therefore hke.27.3a46-8abd was excluded from any further age disaggregated analysis for this case study. However, hke.27.3a46-8abd was included in an additional age aggregated FLBEIA model that was run during the IBP meeting. The fleet object used in this model assumed the same discard rates and age structures as the single species stock assessment. This required that all fleets have the same age structure. Although this improved the ability to replicate the advice produced by FCube and FLBEIA there were still a number of concerns (see section 2.5.2). Within this age-aggregated run the fleet data was scaled to match the single species stock. Although this did improve consistency in the Fs between FLBEIA and the single species stock assessment, there were still concerns that it would not capture the mixed fisheries interactions for fleets in the Celtic Sea as it did not represent the varying selectivity of each fleet.

Conditioning

Several decisions were made around how to handle the data and parameterise the model. These decisions focused on remaining as true as possible to the single species advice while still enabling the stocks in question to be modeled within a mixed fisheries context. These decisions have been outlined below.

Conditioning future weights

For conditioning the forecast the fleet and métier specific mean weights-at-age for the landings, discards, and the stock were available an average of the past three years (2017–2019) was used. In some If unavailable, the stock level information was used.

Incorporation of *Nephrops*

Nephrops stocks were conditioned in a different way to the fish stock for which age-structured population dynamics were available. *Nephrops* were incorporated in simulations with a fixed biomass which was generated from the underwater TV survey abundance estimates used to provide advice (provided in the assessment in numbers), back calculated to total biomass using the assumed stock weight in the assessment, the harvest ratio (in numbers) and advised catch (in tonnes).

Intermediate year

In this case study FLBEIA was implanted using a common intermediate year assumption for all stocks, which fixed effort ad electivity pattern for fleets at an average of the last three years (2017-2019) effort was assumed for each fleet. Although these assumptions differed from the single species advice it provided a consistent pattern for all stocks. Details of single species assumptions can be found in the individual advice sheets available in Table A.2.5.1.1.

TAC and quota shares

The TAC used for the intermediate year and advice year were taken from the last single species advice issued for each stock. The quota shares were calculated from the average share of landed weight of a stock for a given fleet, for the three years prior to the projection years (2017-2019). The *Nephrops*, for which the TAC is set at the level of ICES area 27.7, the quota was calculated by splitting the overall TAC according to recent landings by FU, then split among fleets according to observed landings shares over the past years.

Recruitment

Future recruitment is conditioned by the FLSRsim function within FLBEIA; this can either be based on a functional relationship between recruitment and SSB (e.g. a beverton-holt, or ricker) or a fixed input value. For the simulations in this case study fixed values were set to match those used in the single species stock assessment. For the single stock forecasts stock assessments which implement a stochastic are stochastic (e.g. using the SAM assessment models for cod, haddock, whiting and sole), the median value from the stochastic projections was used for the fixed recruitment value. This however can sometimes lead to small differences as the median of the stochastic projections does not exactly match the deterministic forecast from the median of the assessment outputs but generally these are within a few percent.

Rationalising the fleet

The diversity of fleets and behaviour executed in the Celtic Sea case study results in a data set with a large number of fleets and métiers, some of which contributing to a very small percentage of landings for any stock in the model. Therefore, to reduce the complexity of the model a threshold was defined whereby fleets that contribute to less than 1% to a stock are moved to the “other fleet”, métiers within a fleet contributing less than 2% to a stock's landings for that fleet are moved to the “other” métier (Figure A.2.4.6.2). Consolidating the data in this way reduces the complexity of the model, the runtime, and simplifies outputs making it easier to derive conclusions form the scenarios produced.

The fleet data and model were future simplified by reducing the complexity of the ICES divisions in the model. The mixed fisheries advice for the Celtic Sea covers eight ICES divisions (27.7.b, 27.7.c, 27.7.e, 27.7.f, 27.7.g, 27.7.h, 27.7.j, 27.7.k) (Fig 2.4.6.1). In this case study the areas have been aggregated into groupings, that are often combined for sampling, management and advice purposes: 27.7bc, 27.7e, 27.7fg, 27.7h-k.
This allows us to combine essentially identical métiers that are fished by the same fleet, only separated due to how the métier have been structured for mixfish. Like aggregating the fleets and métiers this reduces computation time for the model and retains a clear pattern of the overall trends taking place.

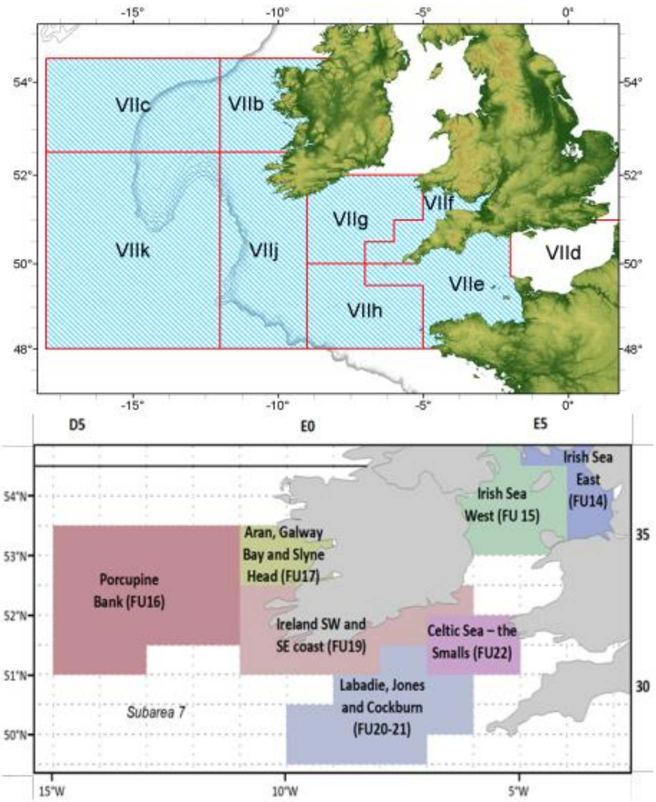


Figure A.2.4.6.1. Area description for finfish advice and *Nephrops* Functional Units (FU) in the Celtic Sea region.

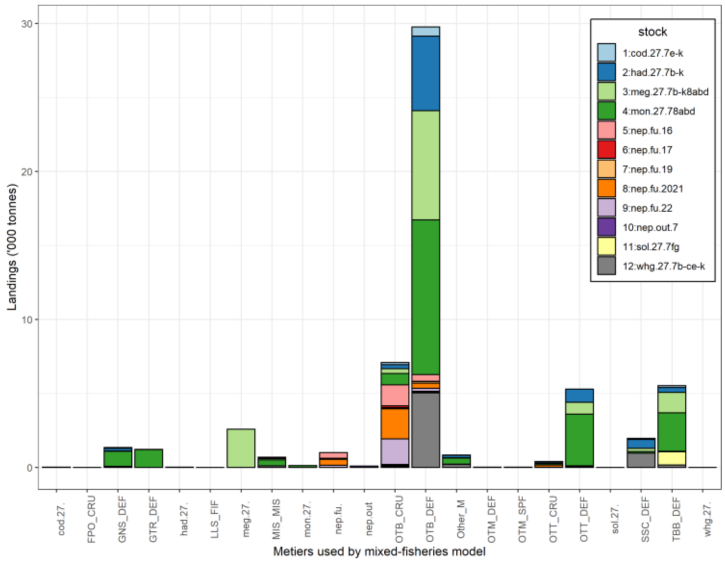


Figure A.2.4.6.2. Landings distribution of species by métier with landings consisting of ≥ 1% of any of the stocks (see Table 6) in 2019 (list of métiers available in Table 4). Note: The "other" (OTH) displayed here is a mixed category consisting of (i) landings without corresponding effort and (ii) landings of any combination of fleet and métier with landings < 1% of any of the stocks (Table 4) in 2019. The stock specific métier (e.g. cod.27) represent the catches for the stock which are outside of the modelled fleets (principally for megrim and anglerfish caught in division 8).

Forecasting

Reproduce the advice

As a quality control procedure, the single species advice was modelled within the FLBEIA framework. The purpose of this baseline run was to assess how closely FLBEIA could reproduce the single-species advice produced by WGCSE/WGBIE, and to act as the reference scenario for subsequent mixed fisheries analyses. The various single-stock forecasts produced by the single species working groups are performed using different software and setups (Table A.2.5.1.1). The stock objects provided by the single species stock assessors were converted into simple FLBiols and FLFleetExt objects and treated as a single fleet. The same forecast settings as the single species assessment are used for each stock regarding weight-at-age, selectivity, and recruitment, as well as assumptions on the catch in the intermediate year and basis for advice (MSY approach and Management plan). Some differences can occur in the forecast calculations because of the diversity of single-stock assessment methods used but are investigated in depth the reasons for potential discrepancies. The baseline runs therefore acts as a quality control procedure to ensure that the projections were set up correctly within the script. The baseline run has the additional benefit of acting as a quality control check on the projections produced by the single species stock assessors. The main differences in forecast in single species and the FLBEIA is due to the stochastic forecast used by the single species forecast which cannot be recreated identically in the determinist forecast in FLBEIA (Table A.2.5.1.2).

Table A.2.5.1.1: Relative difference between single stock and FLBEIA forecasts

Stock	Assessment	Forecast	Single species advice sheet
cod.27.7.e–k	Age-based stochastic analytical assessment (SAM)	SAM	https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/cod.27.7e-k.pdf
had.27.7.bc,e–k	Age-based stochastic analytical assessment (SAM)	SAM	https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/had.27.7b-k.pdf
whg.27.7.bc,e–k	Age-based stochastic analytical assessment (SAM)	SAM	https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/whg.27.7b-ce-k.pdf
meg.27.7b-k8abd	Bayesian statistical catch-at-age using catches in the model and forecast	Stochastic	https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/meg.27.7b-k8abd.pdf
mon.27.78abd	a4a	FLR STF	https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/mon.27.78abd.pdf
sol.27.7fg	Age-based stochastic analytical assessment (SAM)	SAM	https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/sol.27.7fg.pdf
nep.fu.16	Underwater TV survey	NA	https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/nep.fu.16.pdf
nep.fu.17	Underwater TV survey	NA	https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/nep.fu.17.pdf
nep.fu.19	Underwater TV survey	NA	https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/nep.fu.19.pdf
nep.fu.2021	Underwater TV survey	NA	https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/nep.fu.2021.pdf
nep.fu.22	Underwater TV survey	NA	https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/nep.fu.22.pdf
nep.out.7	Precautionary approach	NA	https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/nep.27.7outFU.pdf

Table A.2.5.1.2. Relative difference between single stock and FLBEIA forecasts. In red are values that are more than 10% difference between the single species and FLBEIA forecast

Stock	Metric	2019	2020	2021	2022
cod.27.7.e–k	F	0.965	0.857		
	SSB	1	1.17	1.1	1.02
	Catches	1.01	1		
	Landings	1.02	INF		
	Discards	0.998	INF		
had.27.7.bc,e–k	F	0.995	1.07	1.16	
	SSB	1	1.03	0.96	0.902
	Catches	0.998	1	1	
	Landings	1	0.707	0.752	
	Discards	0.995	1.24	1.28	
whg.27.7.bc,e–k	F	0.96	1.08	1.11	
	SSB	1	0.972	0.95	0.955
	Catches	1	1	1	
	Landings	1	0.899	0.885	
	Discards	2.5	1.38	1.46	
meg.27.7b-k8abd	F	0.987	1.04	1.03	
	SSB	0.994	0.991	0.983	0.979
	Catches	1.12	1	1	
	Landings	1.05	1.01	1.01	
	Discards	1.89	0.954	0.96	
mon.27.78abd	F	0.997	0.994	1.01	
	SSB	1	1.01	1.01	1.01
	Catches	0.972	1	1	
	Landings	0.972	0.977	0.985	
	Discards	0.965	1.36	1.33	
sol.27.7fg	F	1.04	1.03	1.06	
	SSB	1	0.975	0.953	0.928
	Catches	1	1	1	

Stock	Metric	2019	2020	2021	2022
	Landings	0.999	0.977	0.985	
	Discards	1	1.28	1.19	

Issues encountered due to differences in mean weights at age for landings and discards

FLBEIA simulates catches in mixed fisheries given past catchabilities, selection patterns and quota constraints. As such, a difference from FCube is that it estimates over-quota catches for each stock in weight (tonnes) and then calculates the corresponding discard numbers based on the conditioned discard weight. FCube calculates the effort required to catch the partial fishing mortality share for given landings, then includes discards based on a fixed proportion of catch in numbers, similar to a single stock forecast.

For the Celtic Sea case study there are significant differences between the mean landed weight and discard weights for stocks (Figure A.2.5.2). For example, where discard weights were four times higher than the landings weights, this led to catch numbers four times higher than if the fish landed. This caused a particular issue under a fixed effort scenario (or any scenario where catch is above advice) where the fishing mortality resulting from the scenario was considerably higher than might be expected under constant fishing effort (a positive bias).

Two alternative conditioning scenarios were explored:

- Where the discard weights were set to the catch weights (the landings weights and discard weights, weighted by numbers landed and discarded). The improved consistency in the simulated scenarios where catch was over-quota (fishing mortality was more consistent with the level of fishing effort) but resulted in a negative bias due to catch weights being lower than in the observed data.
- Where the stock level weights-at-age were used for all fleets, and the discard weights were conditioned to be the same as the catch weights. This resulted in a similar outcome as above but had some inconsistencies in the SOP at the fleet and métier level (the sum of landings and discard numbers * weights no longer matched the fleet data).

The Celtic Sea case study concluded these differences needed further investigation for a solution to be found. Potential solutions would require changes to the FLBEIA code, but this would need further consideration. For example, this might include projecting discards in numbers rather than weight, though this may be difficult, due to the need to simulate over-quota discards, and quotas being based on weight. Or calculating discards weights dynamically within FLBEIA in the projections: for example, it might make sense to separate past observed discard weights based on small fish from those resulting from over-quota discards (where mean weights may be closer to the landings weights, or stock weights). Rather than find a rushed solution during the IBP, it was considered these issues should be considered as part of a follow up workshop.

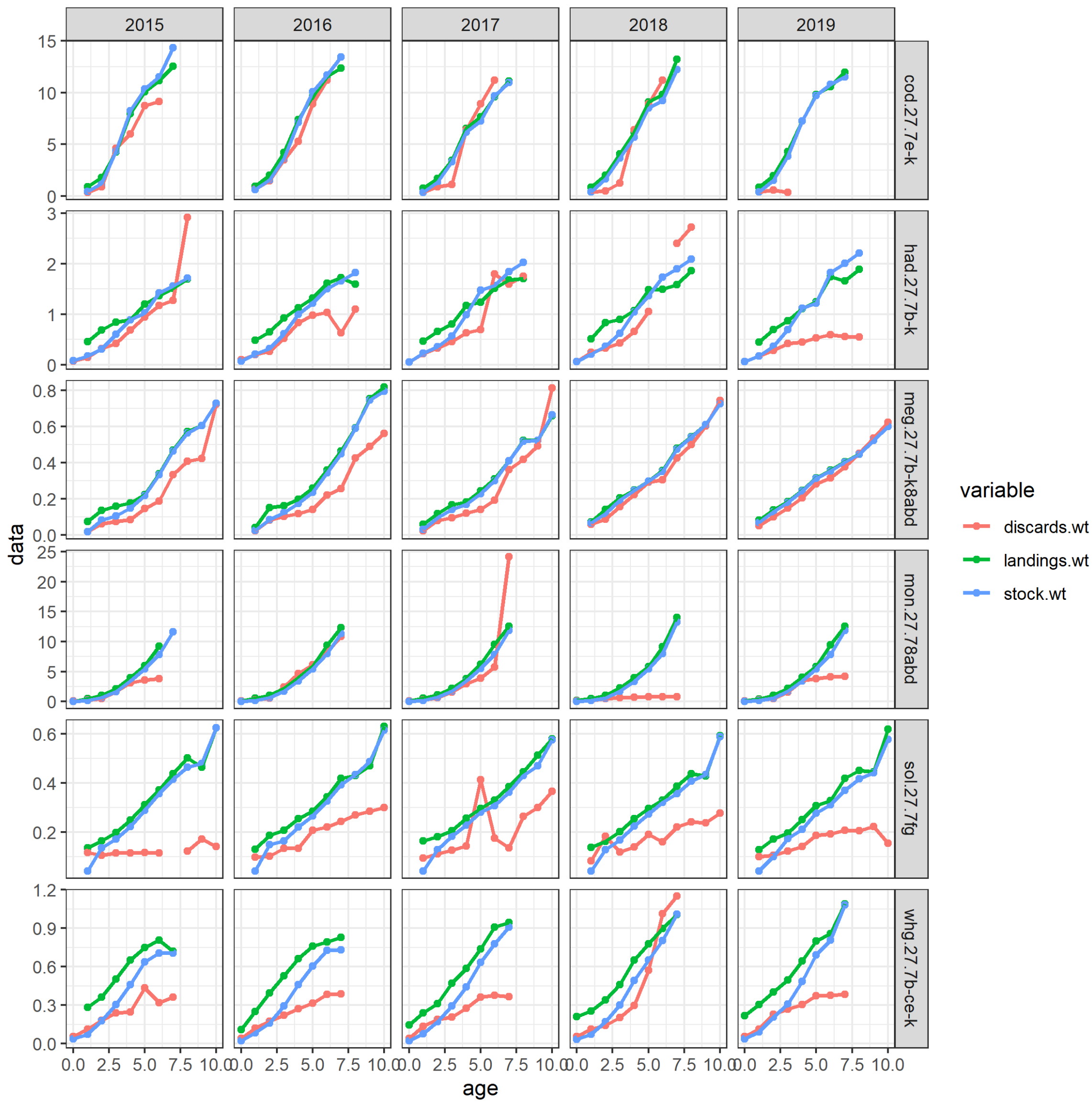


Figure A.2.5.2. Mean weight-at-age in landings, discards, and stock for each stock in the model.

Issues with Cobb–Douglas conditioning for cod stock

As referenced in Section 2.2 there can be differences in realised fishing mortalities when applying a Cobb-Douglas production function instead of a Baranov catch equation. This is due to the fact that Cobb-Douglas production function discretises catch at a single point in time halfway through the year. While in general these differences are small at moderate fishing mortality rates and moderate to high natural mortality rates, it led to inconsistencies for Celtic Sea cod that were considered problematic. These inconsistencies are due to the current high fishing mortality on the stock and historic low stock size. As a result, when the model was conditioned on average catchabilities from the past three years (2017 – 2019) fishing effort only slightly higher than current levels results in a very large fishing mortality which in fact at only 1.1x current effort causes catches higher than the current population (Figure A.2.5.3.1). This was investigated in depth, and was particularly problematic for the ages 3-7 (which encompass the Fbar range for the stock of 2-5) where the catch projections deviate, and calculated fishing mortalities are quite different between the Baranov approach and the Cobb-Douglas approach.

The higher catchabilities (Figures A.2.5.2.4 and A.2.5.2.5) and fishing effort (Figures A.2.5.3.2 and A.2.5.3.3) in 2017 when the population was in a better condition were leading to higher average values than the values in 2019 (2017-2019 average was higher than 2019). As such, with a much-depleted population the higher catchability combined with the Cobb-Douglas approximation leads to catches higher than the available population for some ages (at effort levels corresponding to F = 2 in Figure A.2.5.3.1, which was fishing effort of around 1.1x current levels). At this point fishing mortality is artificially capped at 90% of the population biomass, meaning there is no difference in catch and F on cod at any fishing levels > 1.1x of current levels.

Conditioning the model-based catchabilities and effort levels in 2019 led to an improved model (Figure A.2.5.3.6) but with still a ceiling of 1.3x current effort levels before the artificial cap on fishing mortality was introduced (and a non-linear effort-F relationship).

Ideally, the Baranov catch equation would be used in FLBEIA to provide consistency with single stock approaches. However, this is difficult to implement due to the need to apply it simultaneously to all fleets (see Section 1.2) and work so far has not yet found a satisfactory solution. This should be a priority and considered necessary for the Celtic Sea case study to progress given the divergence in catch model between the single stock advice and FLBEIA at levels of effort only moderately higher than currently observed. This analysis is detailed in an Rmarkdown document in Annex 6.3.

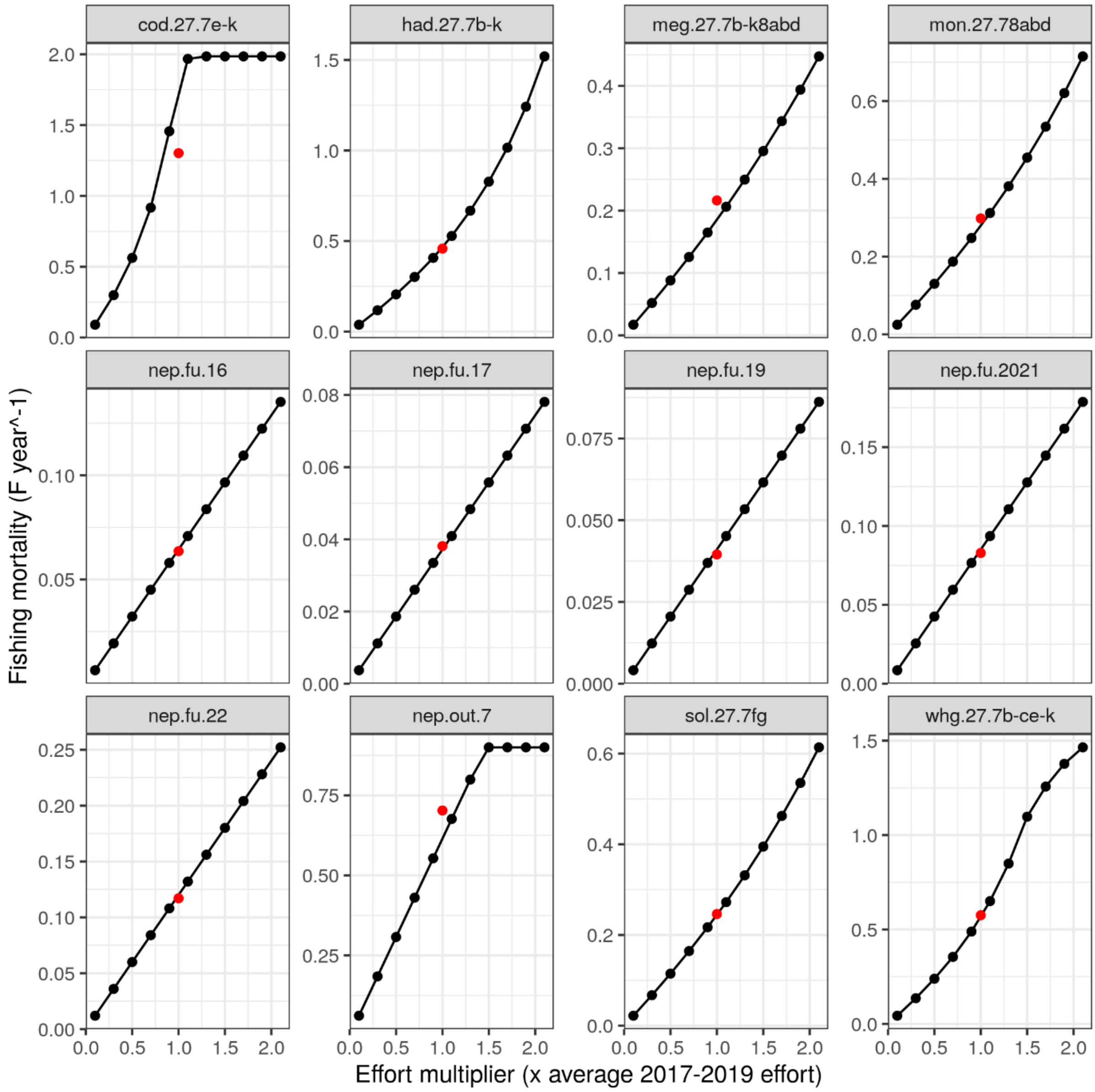


Figure A.2.5.3.1. The relationship between fishing effort and realised fishing mortality (Fbar) for each stock in the Celtic Sea model (conditioned on average catchabilities 2017-2019).

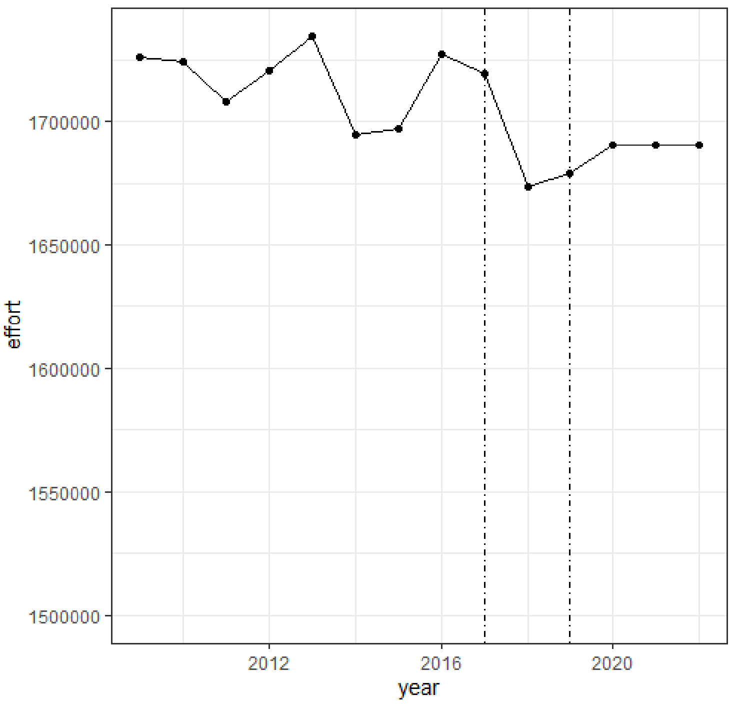


Figure A.2.5.3.2. Fishing effort trends for all fleets in the model. The conditioning years are indicated by the dashed lines, with the fixed effort average following (2020 onwards).

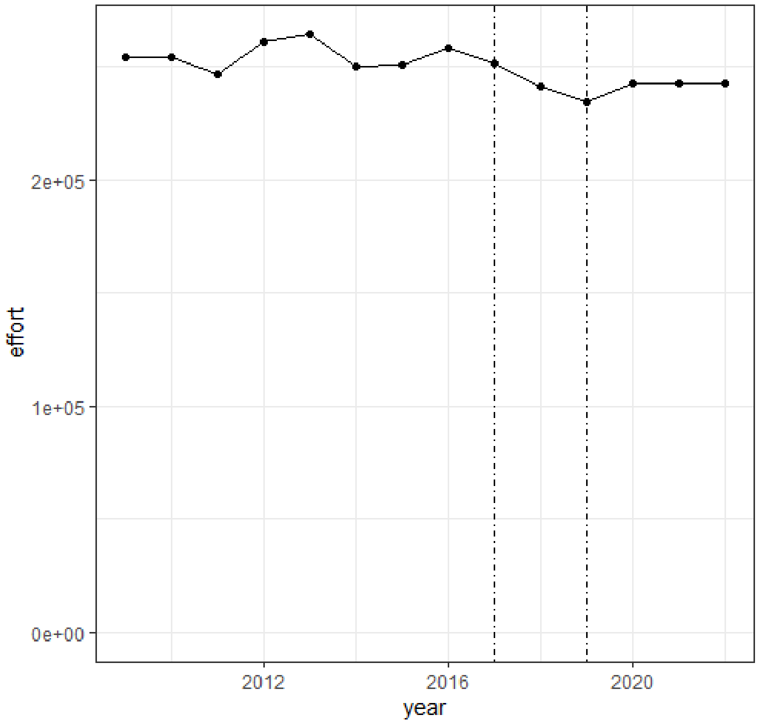


Figure A.2.5.3.3. Fishing effort trends for the three main fleets catching cod in the model (French 10-40 m otter trawlers, Irish 10-24 m otter trawlers and Irish 24-40 m otter trawlers). The conditioning years are indicated by the dashed lines, with the fixed effort average following (2020 onwards).

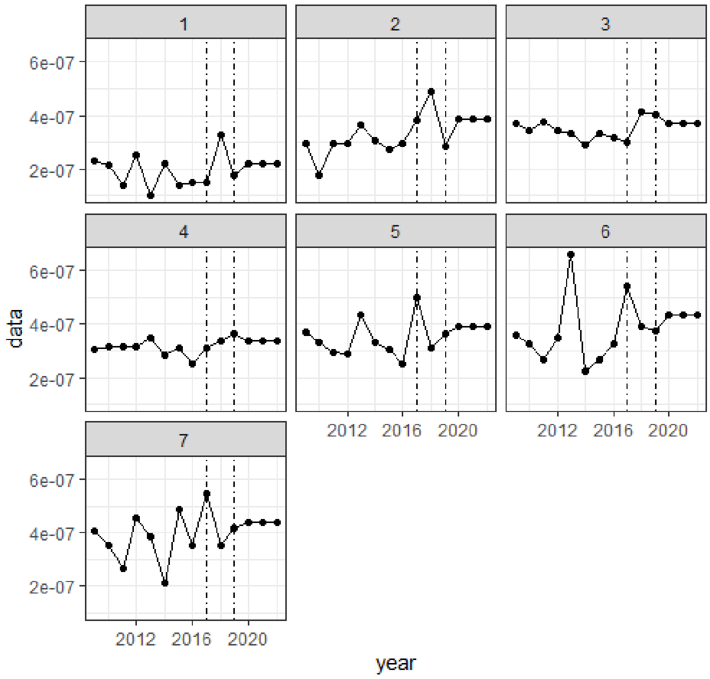


Figure A.2.5.2.4. Catchability-at-age parameters for all fleets combined. The conditioning years are indicated by the dashed lines, with the simulation values following (2020 onwards).

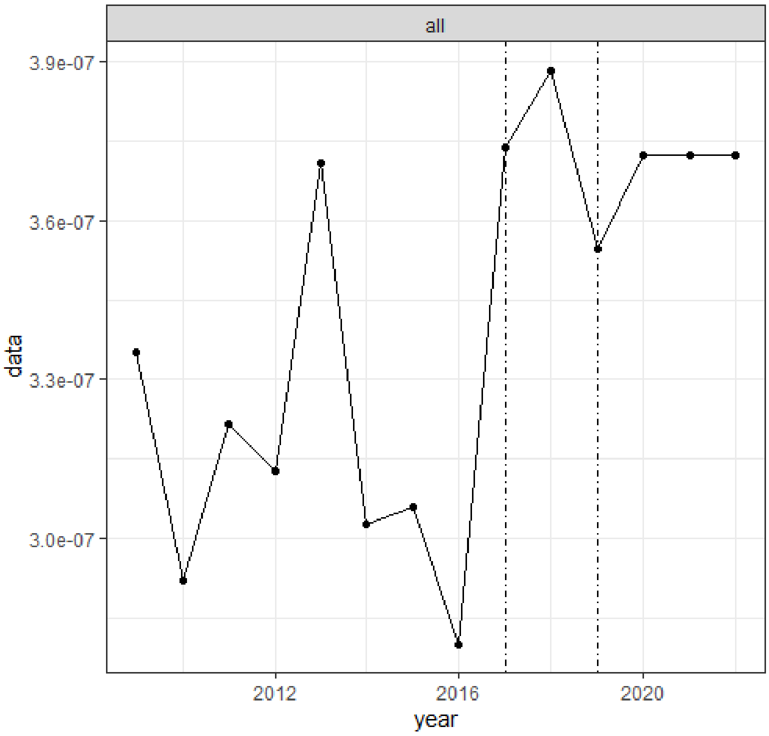


Figure A.2.5.2.5. Average catchability across the Fbar range (2-5) for all fleets combined. The conditioning years are indicated by the dashed lines, with the simulation values following (2020 onwards).

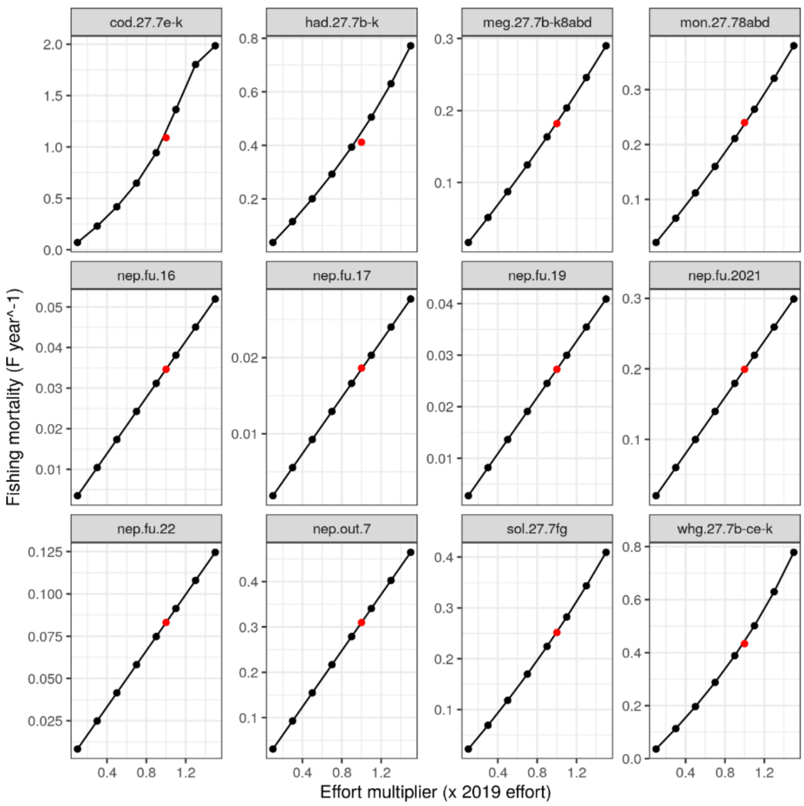


Figure A.2.5.3.6. The relationship between fishing effort and realised fishing mortality (Fbar) for each stock in the Celtic Sea model (conditioned last year's catchabilities; 2019).

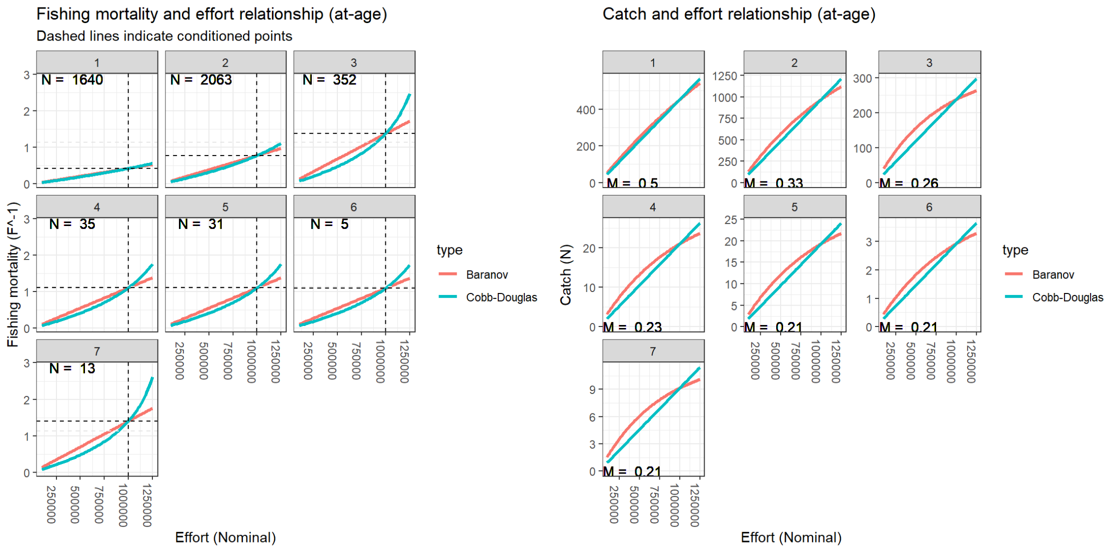


Figure A.2.5.3.7. The relationship between fishing effort and fishing mortality-at-age (left panels) and catch (numbers in 000, right panels) under a Cobb-Douglas and Baranov equation. The numbers of fish in the population are shown inset in the left panels, the natural mortality in the right panels.

Mixed fisheries scenarios

Mixed-fisheries scenarios consider the implications of mixed fisheries operating under single-stock TAC regimes, considering the fishing patterns of the various fleets in 2017–2019 (i.e. the catchability for the different stocks and effort distribution among métiers as well as access to quota). In this analysis we have focused on four scenarios to compare the outputs of Fcube and FLBEIA (Table A.2.5.4.1).

Table A.2.5.4.1. Mixed-fisheries scenarios considered for the Celtic Seas demersal fisheries.

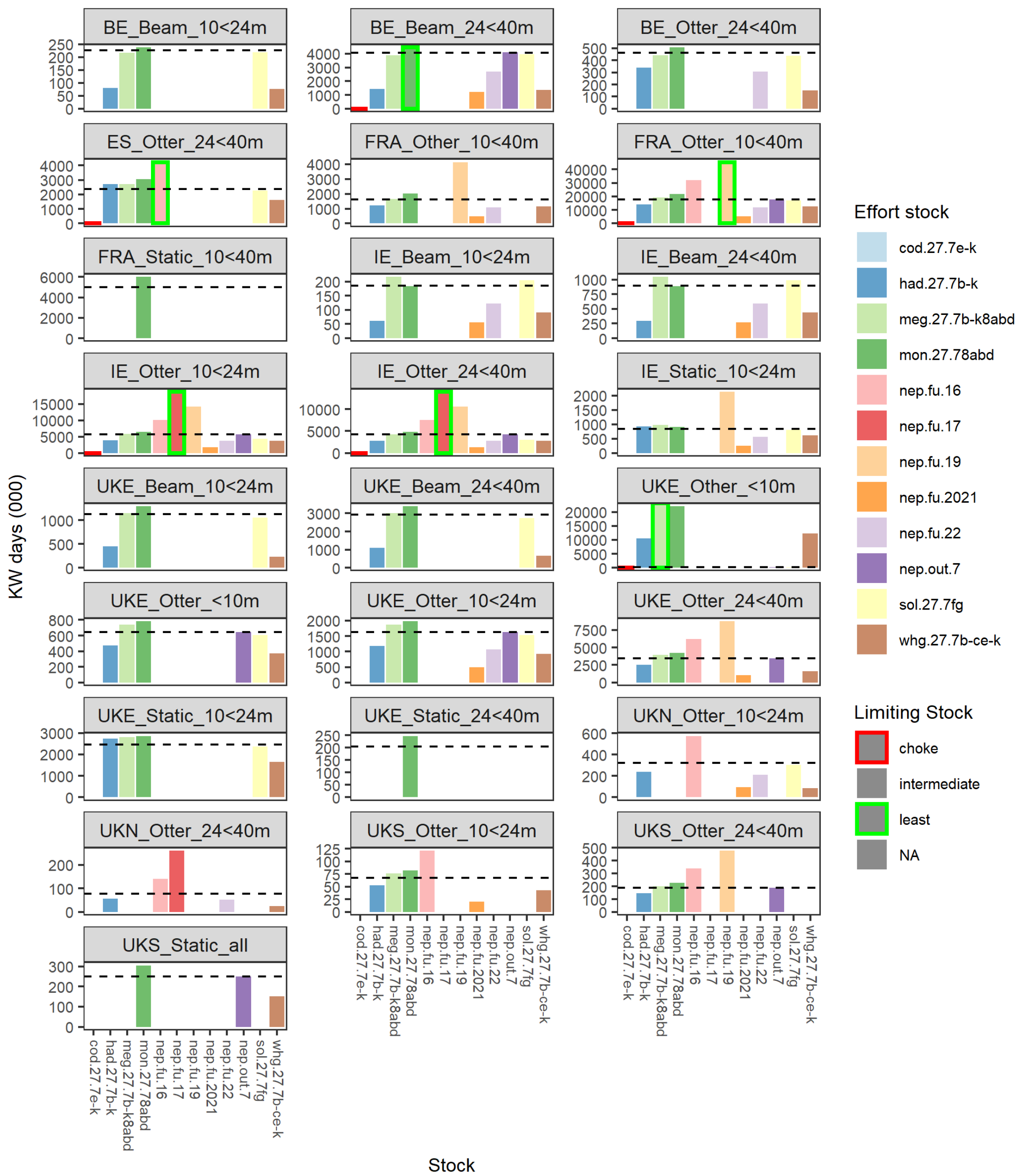
Scenario codes	Scenarios
max	**"Maximum":** For each fleet, fishing stops when all stocks have been caught up to the fleet's stock shares*. This option causes overfishing of the single-stock advice possibilities of all stocks.
min	**"Minimum":** For each fleet, fishing stops when the catch for any one of the stocks meets the fleet's stock share. This option is the most precautionary option, causing underutilization of the single-stock advice possibilities of other stocks.
had.27.7b–k	**"Haddock MSY approach":** All fleets set their effort corresponding to that required to catch their haddock stock share, regardless of other catches.
sq_E	**"*Status quo* effort":** The effort of each fleet in the TAC year (2021) is set equal to the average effort in the most recent 3 years (2017–2019) for which catch and effort data are available.

*** The term "fleet's stock share" or "stock share" is used to describe the share of the fishing opportunities for each particular fleet, calculated based on the single-stock advice for 2021 and the historical proportion of the stock landings taken by the fleet (2017–2019).**

The results of this analysis show that there are a number of differences between the forecasted scenarios produced by FCube and FLBEIA. Minor differences are to be expected, as the fleet structure of both models are different due to the addition of age disaggregated data and some changes to fleet conditioning. The catchabilities and fixed effort used for mixed fisheries considerations in 2020 were based on an average of 2017-2019, whereas this comparison (FCube and FLBEIA) are based on 2019 only. The simulations have resulted in a slightly different pattern of projected effort in each model (Figure A.2.5.4.1). The main findings are summarised below (Figure A.2.5.4.3):

- Under the fixed effort scenario monkfish undershoot substantially in FLBEIA, not in FCube. The detailed age disaggregated fleet structure provided by FLBIEA may result in some fleets not being choked by monkfish, resulting in missed fishing opportunities under the 'fixed effort' scenario.
- Under the 'maximum' scenario, *Nephrops* overshoot more in FLBEIA and not in FCube, again this is driven by differences in the fleet structure of the two models.
- The 'haddock' scenario produces similar perceptions of the fishery in both models.
- Major differences between the two models for cod in the intermediate and TAC year, between both models.
- Increased overshoot of catches of megrim and monkfish in FLBEIA under the max scenario are due to catches in area 8, which are not accounted for in FCube due to a different model set up.

During the IBP a comparison was made between the results of an age aggregated FLBEIA and an age disaggregated, and their respective differences with FCube. Catch (Figure A.2.5.4.4), F (Figure A.2.5.4.5) and SSB (Figure A.2.5.4.6) all showed varying impact on the age aggregation. Although age aggregation brought the results of FLBEIA closer to Fcube there were still a number of inconsistencies that require future exploration.


BE_Beam_10<24m
BE_Beam_24<40m
BE_Otter_24<40m
ES_Otter_24<40m
FRA_Other_10<40m
FRA_Otter_10<40m
FRA_Static_10<40m
IE_Beam_10<24m
IE_Beam_24<40m
IE_Otter_10<24m
IE_Otter_24<40m
IE_Static_10<24m
UKE_Beam_10<24m
UKE_Beam_24<40m
UKE_Other_<10m
UKE_Otter_<10m
UKE_Otter_10<24m
UKE_Otter_24<40m
UKE_Static_10<24m
UKE_Static_24<40m
UKN_Otter_10<24m
UKN_Otter_24<40m
UKS_Otter_10<24m
UKS_Otter_24<40m
UKS_Static_all
KW days (000)
Stock
Effort stock
cod.27.7e-k
had.27.7b-k
meg.27.7b-k8abd
mon.27.78abd
nep.fu.16
nep.fu.17
nep.fu.19
nep.fu.2021
nep.fu.22
nep.out.7
sol.27.7fg
whg.27.7b-ce-k
Limiting Stock
choke
intermediate
least
NA

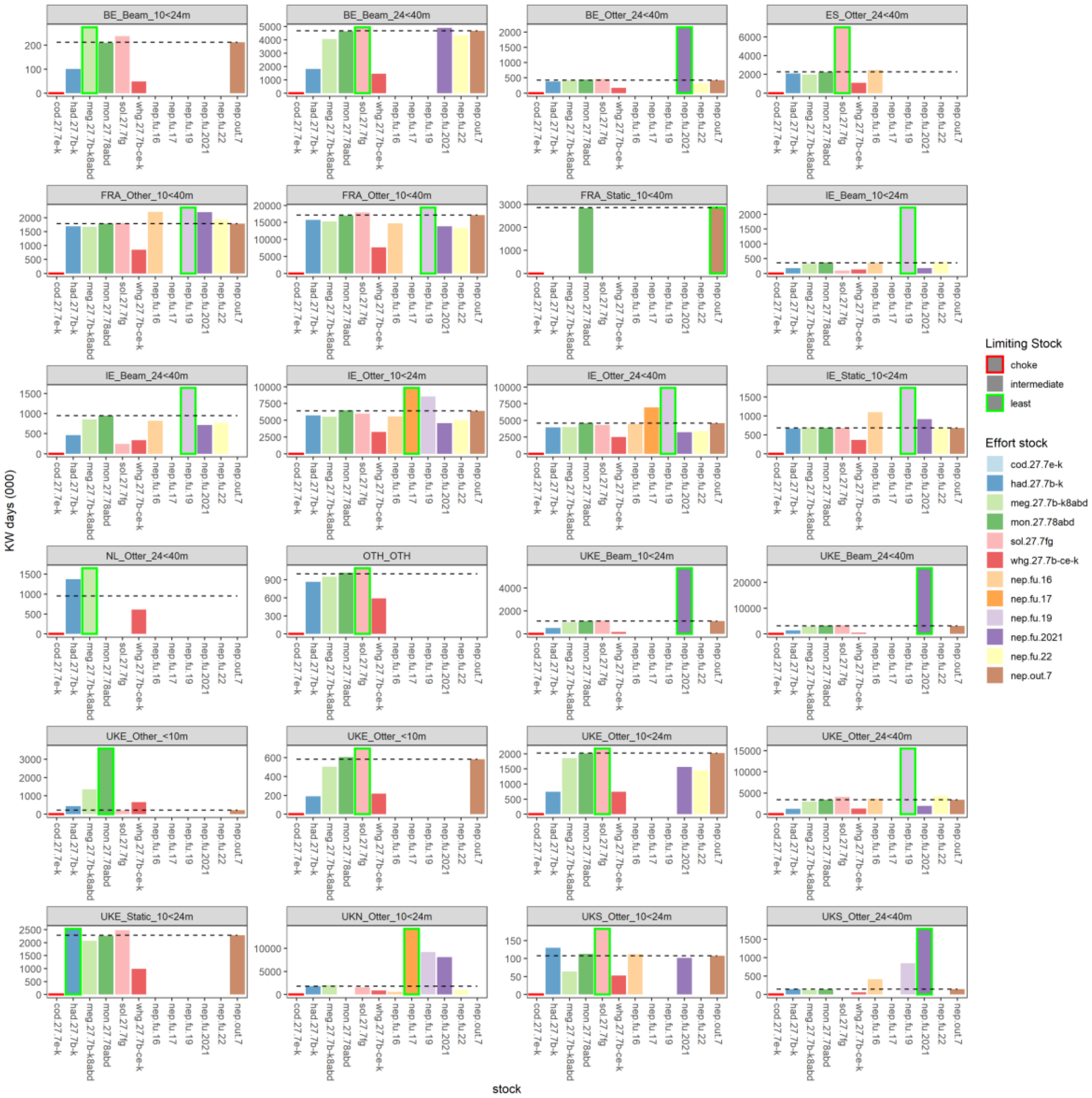
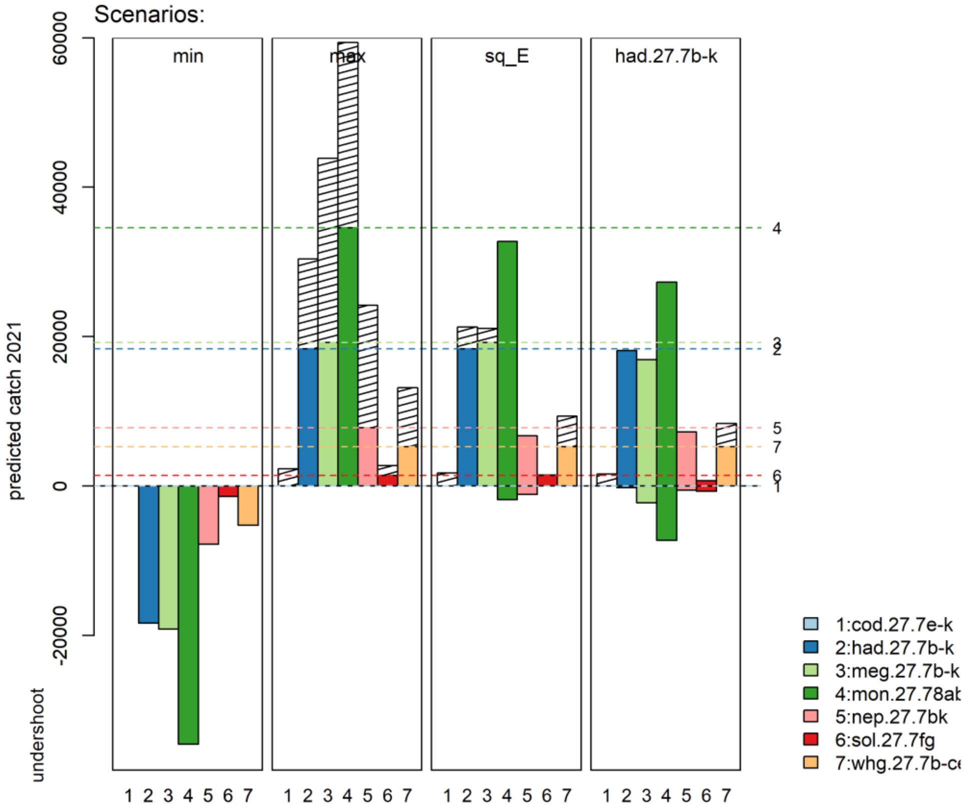


Figure A.2.5.4.1 Estimates of effort by fleet needed to reach each single-stock advice using and FLBEIA (right) and Fcube (left). The stocks are coded by colour, with the most limiting stock ("choke species") for each fleet in 2021 highlighted with a red border and the least limiting species highlighted with a green border. Fleet names are given by country, main gear, and vessel size (m).



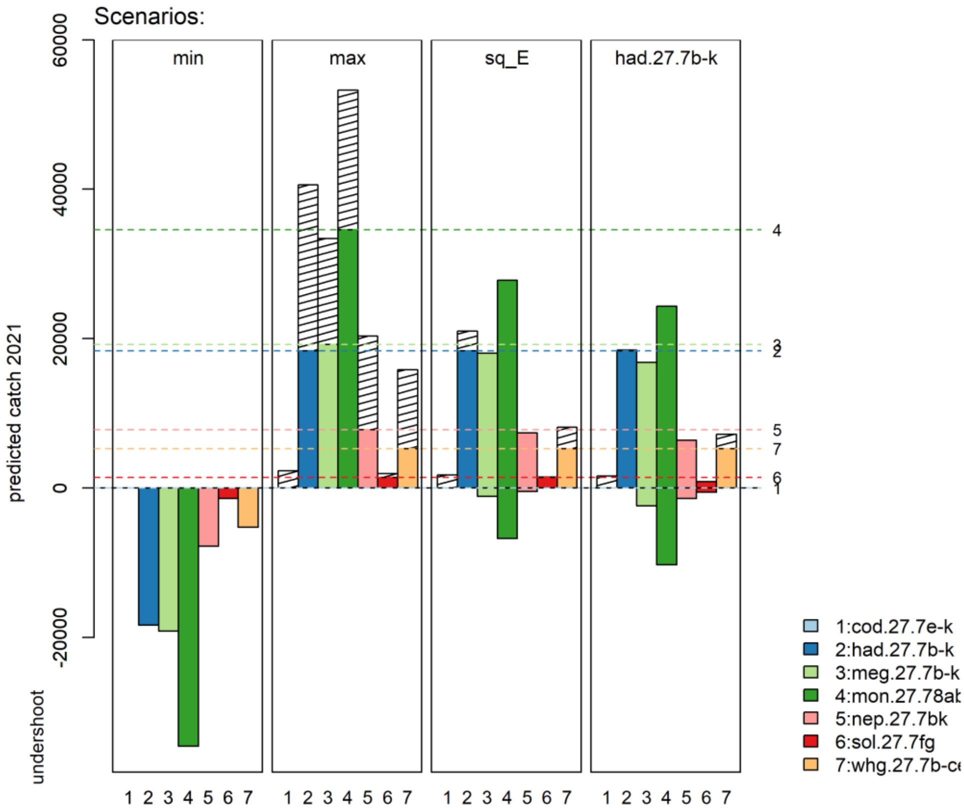


Figure A.2.5.4.3 Estimates of effort by fleet needed to reach each single-stock advice using and FLBEIA (top) and Fcube (bottom). The stocks are coded by colour, with the most limiting stock ("choke species") for each fleet in 2021 highlighted with a red border and the least limiting species highlighted with a green border. Fleet names are given by country, main gear, and vessel size (m).

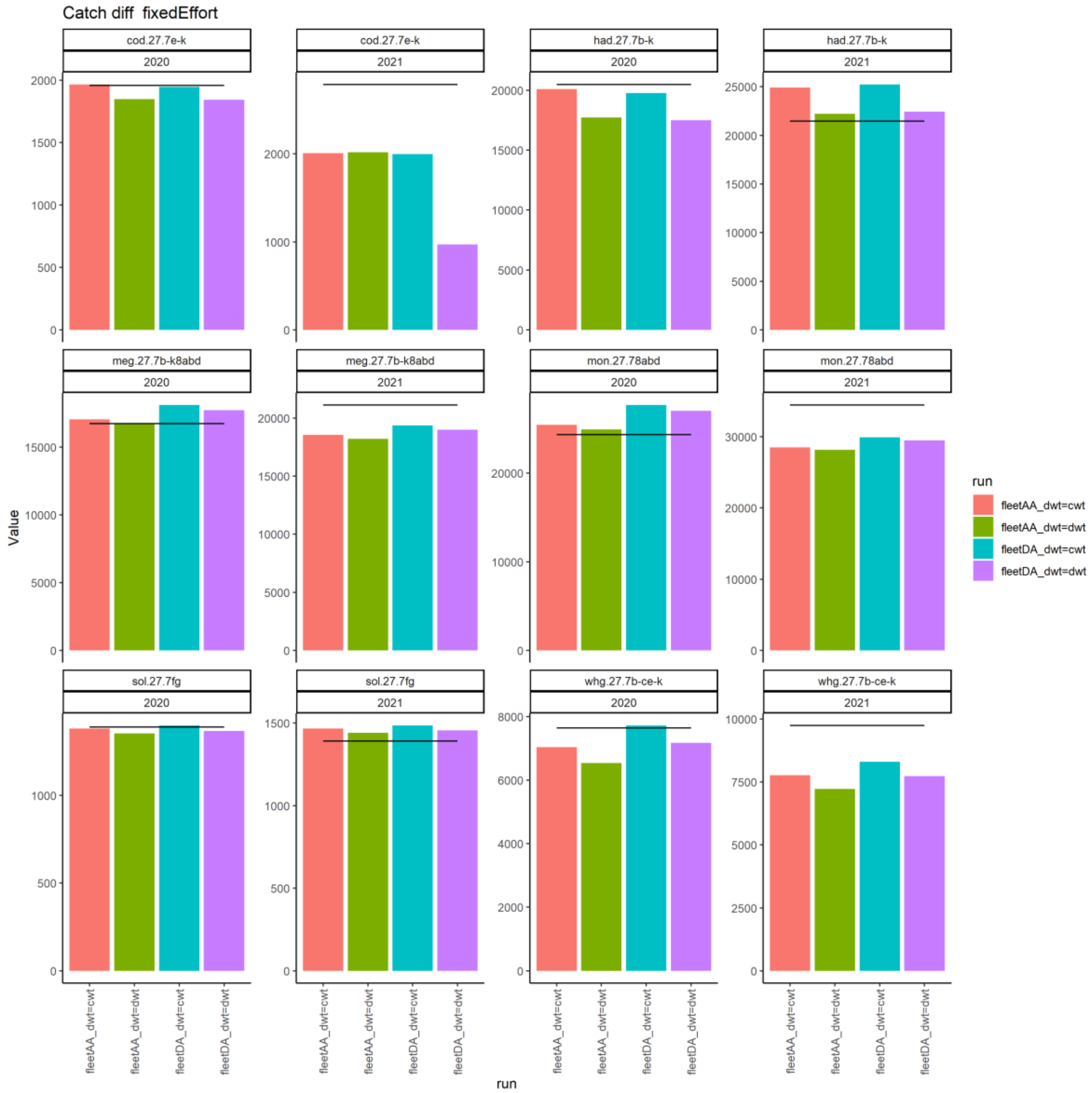


Figure A.2.5.4.4. Comparison between the forecast *catch in 2020 and 2021* for four different conditioned FLBEIA models under the *fixedEffort* scenario. fleet_AA: fleet age-structure and weights are the same as the stock level age-structure in catch; fleet_DA = fleet and métier specific age-structure and weights are used. dwt=dwt: the discard weights in simulations are conditioned with observed discard weights, dwt=cwt: the discard weights in simulations are conditioned with observed catch weights. The black line indicates the corresponding FCube model value.

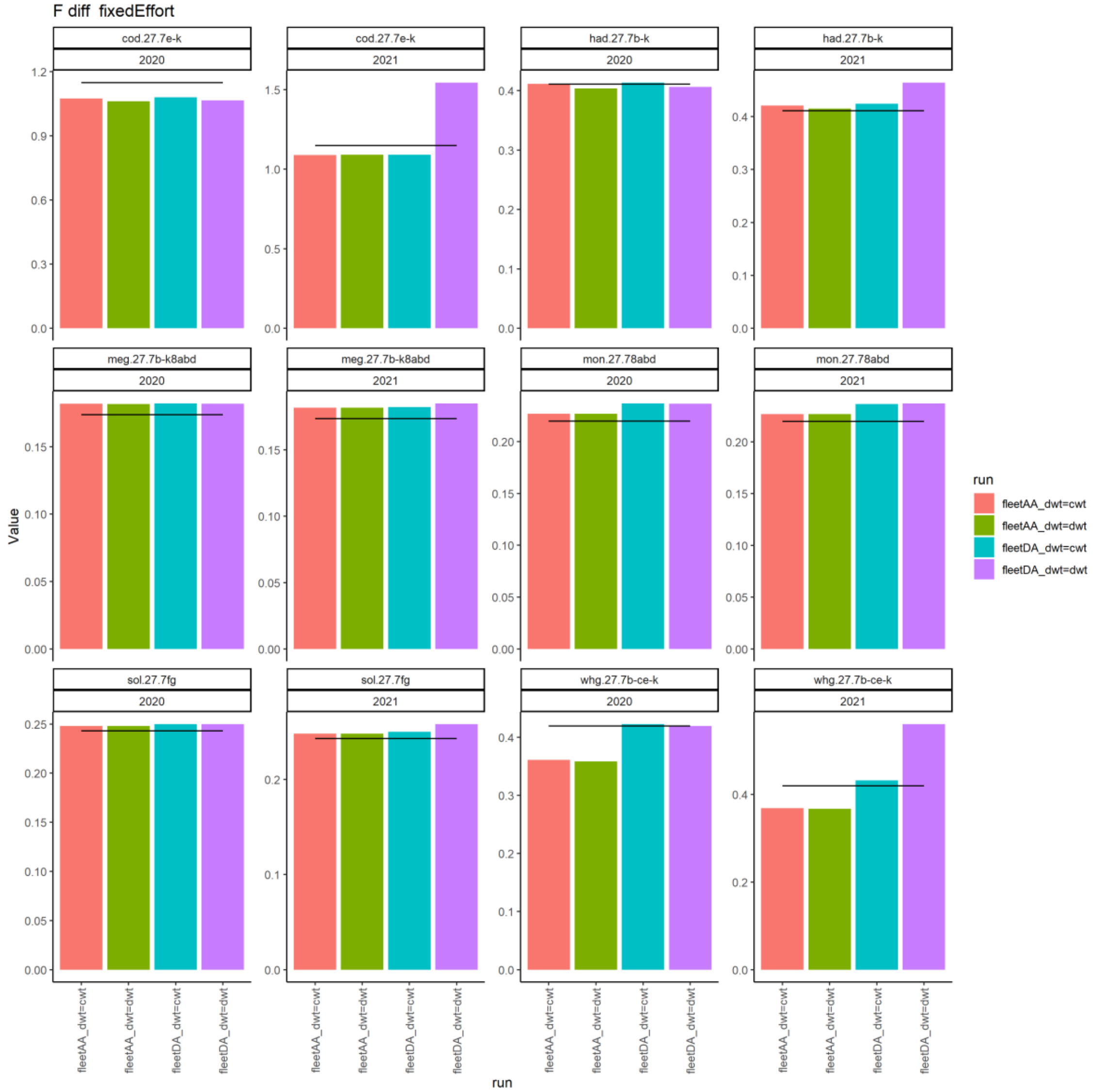


Figure A.2.5.4.5. Comparison between the forecast *fishing mortality in 2020 and 2021* for four different conditioned FLBEIA models under the *fixedEffort* scenario. fleet_AA: fleet age-structure and weights are the same as the stock level age-structure in catch; fleet_DA = fleet and métier specific age-structure and weights are used. dwt=dwt: the discard weights in simulations are conditioned with observed discard weights, dwt=cwt: the discard weights in simulations are conditioned with observed catch weights. The black line indicates the corresponding FCube model value.

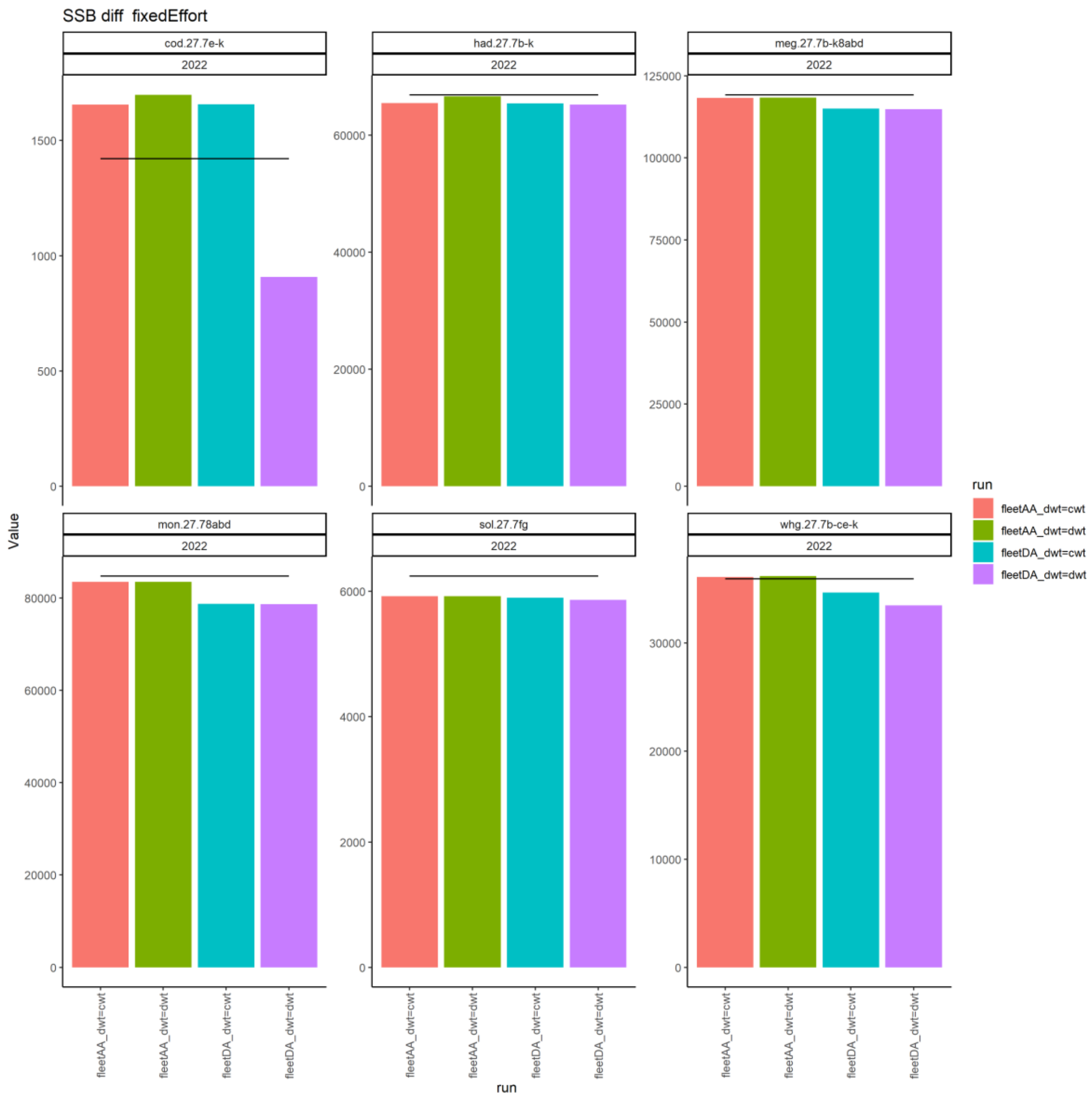


Figure A.2.5.4.6. Comparison between the forecast *SSB in 2022* for four different conditioned FLBEIA models under the *fixedEffort* scenario. fleet_AA: fleet age-structure and weights are the same as the stock level age-structure in catch; fleet_DA = fleet and métier specific age-structure and weights are used. dwt=dwt: the discard weights in simulations are conditioned with observed discard weights, dwt=cwt: the discard weights in simulations are conditioned with observed catch weights. The black line indicates the corresponding FCube model value.

Future work

It was considered that further work was required to be able to transition from FCube to FLBEIA for this case study. Resolving issues around the use of the Cobb-Douglas catch production function and projecting discard weights in the simulation was considered the main challenge. In addition, there were some other areas which were considered important (and potentially beneficial) changes that could be implemented with FLBEIA:

Capacity limits: Should a capacity limit for fleets be set in the simulations? This is not academic in FLBEIA, as would limit fleets in a 'max' scenario. This may be more realistic but could also result in not all quotas being taken up. For example, we could limit fleet effort so that it does not change by more than the previously observed inter-annual change (or a two-year change, given the intermediate year). Ideally this would be based around the physical capacity of fleets (number of vessels x average power x days in year), but we don't have the information and would need to be requested within the data call.

Conclusions

Due to data issues, the differences in fishing mortality from the Cobb-Douglas production function compared to the single stock Baranov approach for cod and the difficulty in projecting discards consistently the Celtic Sea subgroup do not propose changing models at this time. We recommended WGMIXFISH methods sped some time in developing a way to incorporate the Baranov equation to FLBEIA and consider the most appropriate way to condition over quota discard weights. Also, we recommend that a number of stocks from WGBIE which currently raise data outside increase reproducibility of the raising process (like WKCELTIC) so that we can use their valuable assessments and data in an age disaggregated manner in WGMIXFISH.

North Sea case study

Description

Area definition and stocks considered

This mixed fisheries advice will consider finfish species in the ICES area 4, 3.a, 6 and 7.d (eastern English Channel) (Figure 1) and *Nephrops norvegicus* in functional units FU5, FU6, FU7, FU8, FU9, FU10, FU32, FU33, FU34 and ICES' rectangles outside of these nine functional units – denoted FU_OuTH.

The species considered are part of the demersal mixed fisheries of the North Sea and eastern English Channel, and are cod, haddock, whiting, saithe, plaice, sole, turbot, witch (Table A.3.1.1.1) and *Nephrops norvegicus* (Table A.3.1.1.2). There are nine *Nephrops* functional units in the North Sea, which are considered as separated stocks. However, only four of these can be assessed through fishery-independent abundance estimates from underwater video surveys, and these were kept as distinct stocks. These cover the stocks along the English and Scottish coast; i.e. FU 6 (Farn Deep), FU 7 (Fladen Ground), FU 8 (Firth of Forth) and FU 9 (Moray Firth). The five other functional units (FU 5, FU 10, FU 32, FU 33 and FU 34) have no independent abundance estimates.

Table A.3.1.1.1. Finfish stocks

Species	ICES single stock advice area
Cod	Subarea 4, Divison 7.d and Subdivision 3.a.20 (North Sea, eastern English Channel, and Skagerrak)
Haddock	Subarea 4, Division 6.a and Subdivision 3.a.20 (North Sea, West of Scotland and Skagerrak)
Whiting	Subarea 4 and Division 7.d (North Sea and eastern English Channel)
Saithe	Subarea 4, 6 and Division 3.a (North Sea, Rockall and West of Scotland, Skagerrak and Kattegat)
Plaice	Subarea 4 and Subdivision 3.a.20 (North Sea and Skagerrak)
Sole	Subarea 4(North Sea)
Plaice	Division 7.d (eastern English Channel)
Turbot	Subarea 4(North Sea)
Witch	Subarea 4, Divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel)

Table A.3.1.1.2. *Nephrops* Functional Units (FU) in the North Sea.

FU no.	Name	ICES area	Statistical rectangles
5	Botney Gut - Silver Pit	4.b, 4.c	36–37 F1–F4; 35F2–F3
6	Farn Deeps	4.b	38–40 E8–E9; 37E9
7	Fladen Ground	4.a	44–49 E9–F1; 45–46E8
8	Firth of Forth	4.b	40–41E7; 41E6
9	Moray Firth	4.a	44–45 E6-E7; 44E8
10	Noup	4.a	47E6
32	Norwegian Deep	4.a	44–52 F2-F6; 43F5–F7
33	Off Horn Reef	4.b	39–41E4; 39–41F5
34	Devil's Hole	4.b	41–43 F0–F1

Herring, mackerel and the industrial fisheries (sandeel, Norway pout and sprat) are not considered in a mixed fisheries advice context given the targeted nature of their fleets.

Fleet definition

In the North Sea, otter trawl and beam trawls are the main gears used in the region's demersal fisheries, and pelagic trawls and seines are the primary gears used in the pelagic fisheries. Otter trawls are the most common gear types, and has a typical mixed catch, with gadoids, other groundfish, plaice, and Norway lobster; however, the species composition of the catch depends on the area, depth and gear design. Bottom seine fisheries operate mainly in the Skagerrak, central North Sea, and in the eastern English Channel with similar catch to the otter trawl fisheries in these areas. Beam-trawl fisheries operate in the shallow parts of the southern and central North Sea, with sole and plaice as main species, as well as other flatfish species (e.g. turbot and brill). Gillnet fisheries primarily operate in the shallower areas of the southern North Sea, the eastern English Channel, and in the Skagerrak, targeting flatfish and demersal fish, and anglerfish in the deeper areas. Longline fisheries operate mostly in the northern North Sea and target saithe, cod, haddock, ling, and tusk. Pelagic trawl and seine fisheries operate throughout most parts of the North Sea targets sandeel, Norway pout, sprat, and blue whiting for reduction purposes (small meshed codend) and herring, mackerel, and horse mackerel by the refrigerated seawater and freezer trawlers. Finally, the dredge fisheries for scallops occur in inshore areas along the east coasts of Scotland and England and throughout the English Channel. The static gear pot fisheries, mainly for edible crab, lobster, and whelk operate in the inshore areas of several countries bordering the North Sea.

For mixed fisheries analysis purpose, the Intercatch (IC) and MIXFISH Accession métier codes are used to define fleet and métiers following the procedure listed below:

1. Define basic fleet based on 1st level of IC métier code (i.e. country and main gear used (Table A.3.1.2.1):
   a) Static (FPO, GNS, GTR, GND, GTN, LLS, LHM)
   b) Pelagic (OTM, PS, PTM)
   c) DSeine (SDN, SSC)
   d) Otter (OTB, OTT, PTB, OTG)
   e) Beam (TBB)
   f) Other (remaining categories)

The description of the métier levels is presented in Table A.3.1.2.1.

2. The finer fleet divisions are based on vessel length. Typically, we split using the divisions <10 m, 10-24 m, 24-40 m and >40 m. These are the divisions used by the EU for other economic parameters (e.g. FDI database).
3. Define métier gears using further information on mesh size (where applicable) based on levels 3-6 of IC codes
   a) Otter and Dseine are typically divided into 3-4 tiers by mesh size (<30 mm – TR3, OTB 30-69 mm – OTB32-69, 70-99 mm – TR2, >100 mm – TR1)
   b) Beam are also divided by mesh size (70-99 mm – BT2, >100 mm – BT1)
   c) Static is divided into gillnets (GN1), gill-trammel nets (GT1), long-lines (LL1), and pots (pots)
   d) Pelagic is combined into a single gear (pelagic). There is only one pelagic fleet in the model at the moment (NL_Pelagic).
4. Define métier areas (some aggregation is done; e.g. 4a-c = 4) - Only fishing in area 3AN, 4, 6A, & 7D are included in the fleets/métiers, so all remaining catches outside of those areas get packed into the fleet OTH_OTH.
5. Combine métier gears and areas – simply merges the results of steps 3 & 4 to come up with unique métiers. Any segments that contribute to less than 1% of the catches to any of the modelled stocks are aggregated together (métier = "OTH").

The current model, which is conditioned with data up to 2020, includes 40 fleets. The number of fleets has, however, varied slightly from year to year depending upon the data and changes to fleet segment importance.

Table A.3.1.2.1. Gear coding as defined under the Data Collection Framework of the EU (DCF).

Métier level	Description
FPO	Pots and Traps
GNS	Gillnet
GTR	Trammel nets
GTN	Trammel nets and gill nets
LLS	Longline
LHM	Hand lines
OTM	Midwater otter trawl
PS	Purse seine
PTM	Midwater pair trawl
SDN	Anchored seine
SSC	Fly shooting seine
OTB	Bottom otter trawl
OTT	Multi-rig otter trawl
PTB	Bottom pair trawl
TBB	Beam trawl

Data

The assessment of the mixed fisheries is based on catch and effort data that are compiled mostly on the basis of the data collected in annual ICES data calls (InterCatch database: discards and landings by age and métier), and data collected for the evaluation of the effort regime (so called accessions data, that contains information on landings and fishing effort by age and métier). The assessment data for the different stocks is taken from the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). The information of the actual final quota taken by fleet and/or country (final after swaps) was obtained from the FIDES database, and was used to assess the model sensitivity and potential impact of using the actual quota by fleet/country when computing partial F.

A data quality control process was initiated by WGMIXFISH in 2020, which, in collaboration with the designated experts in the different countries, will help to improve the standardization in the format that data are presented. All the data are structured by fleets and métiers.

More information regarding the ecology and fisheries of the North Sea can be found in the Fisheries Overview of the Greater North Sea (ICES Advice 2020 – https://doi.org/10.17895/ices.advice.7605), and the approach to model the mixed fisheries is described in the North Sea Stock Annex (https://www.ices.dk/sites/pub/Publication%20Reports/Stock%20Annexes/2021/mix.ns_SA.pdf).

Proposed changes

The main proposed changes include conditioning the fleets object with age-disaggregated data and use of FLBEIA for forecasting advice scenarios. With regards to the first point, we use all the same steps for processing the original data from INTERCATCH and WGMIXFISH-Accessions into fleet/métier definitions. However, for FLBEIA we define fleet/métier/stock interactions in an age-disaggregated manner; specifically, our inputs into the FLBEIA fleet conditioning function are the numbers and mean weights for landings and discards in each interaction. The same is done for biomass-based and fixed stocks, but only a single age-class is defined.

FLBEIA will then be used for all advice scenarios, and the main differences are those listed above in section (*Structural differences between FCube and FLBEIA*). FCube and FLBEIA differ in their how quotas are divided (FCube uses partial F while FLBEIA uses catch share), yet the distribution of their proportions among fleets will likely be very similar as they consider the catches of the final data year. We expect that, although some differences in catchability will result from the age-disaggregated approach, limitations to fishing effort will be fairly similar.

It was suggested during IBPMIXFISH to compare both age-aggregated (FLBEIA AA) and age-disaggregated (FLBEIA AD) outputs from FLBEIA to FCube, and these have both been included in the sections below. Where applicable, we also compare mixed fishery model outputs to those of the single stock advice (SSA) as conducted by WGNSSK.

Conditioning

Reproduce the advice

Before running the mixed fisheries projections, a baseline scenario is run that corresponds to deterministic single-species projections using our newly conditioned FLStock objects (see model_01_ReproduceTheAdvice_2020 modif for SAM stocks.R). The objective of the single-species stock baseline run is to check that we can reproduce as closely as possible the single-species advice produced by ACOM. The intention of the baseline runs was mainly to act as a check to ensure that the projections were set up correctly within the script, but these runs also have the incidental benefit of acting as a quality control check on the single-species projections themselves.

The various single-stock forecasts presented by WGNSSK are performed using different software and setups. However, for the purpose of the mixed fisheries analyses, it is necessary to gather all forecasts into a single unified framework, which builds on the 'fwd()' method in FLR (FLash R package). The same forecast settings as in WGNSSK are used for each stock regarding weight-at-age, selectivity and recruitment, as well as assumptions on the F in the intermediate year and basis for advice (EU Multiannual Plan or MSY approach).

When the single-species advice is run using FLash, no difference is expected between our baseline run and the ICES single-species advice, although discrepancies can occur when the advice is run using other software or stochasticity is included. In these cases, we usually assume that a difference of less than 5-10% is acceptable.

Figure A.3.3.1.1 shows the difference between the 2020 baseline run and the single-species advice for finfish stocks. When differences occur, explanatory text was given in the last mixed fisheries advice report (ICES 2021).

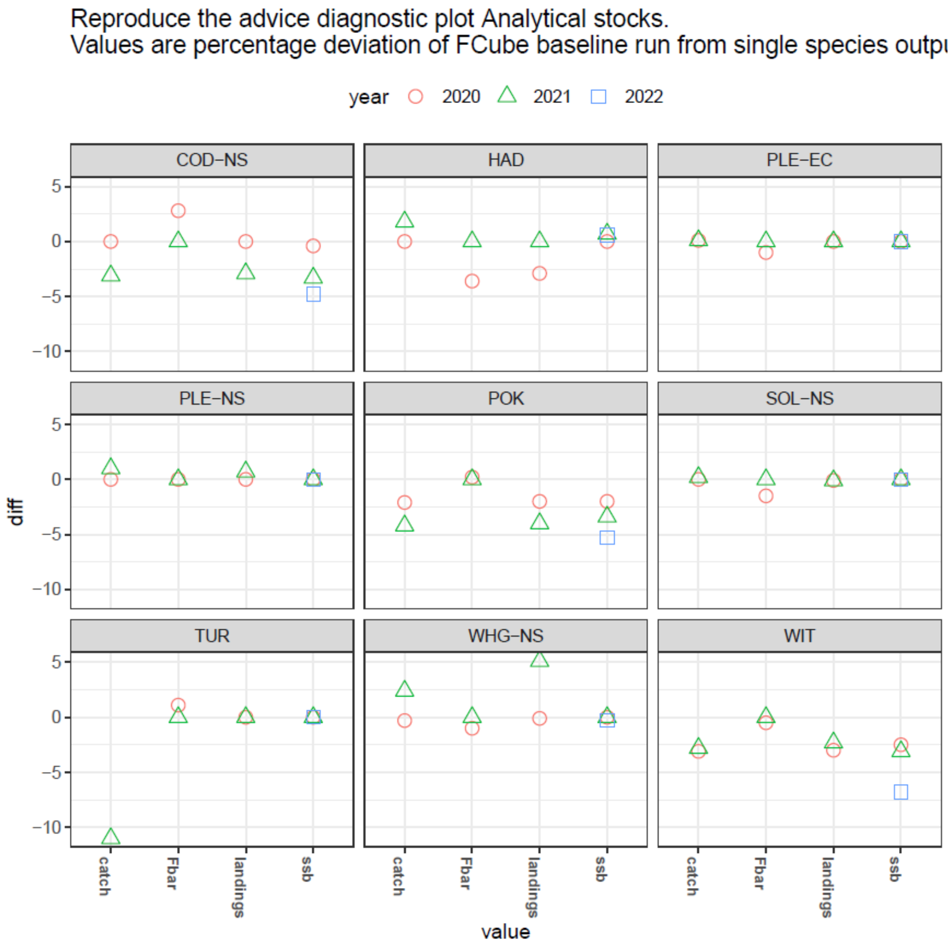


Figure A.3.3.1.1. Differences in the short-term forecasted catch, Fbar, landings and SSB between the baseline run and the ICES single-species advice for finfish stocks. 2020 is the intermediate year and 2021 is the advice year.

Consistency of fleet object

While reproducing the advice is a good check of our stock conditioning, the fleet conditioning could be checked by comparing catch and fishing mortality in the final year of assessment between our mixed fisheries fleet object (WGMIXFISH, see outputs of data_03_make_new_fleets_aa_ad.R) and the outputs of the stock assessments (WGNSSK).

Figures A.3.3.2.1-6 show the catch-, landings- and discards-at-age per stock between WGMIXFISH (FLBEIA age-aggregated (AA) and age-disaggregated (AD)) and WGNSSK (i.e. single stock advice). Overall, the differences are small, in particular between the WGNSSK and the age-aggregated FLBEIA, and the overall selectivity pattern conserved when aggregated across fleets. The corresponding total catch, landings, and discards in tonnes are given in Tables A.3.3.2.1-3. The largest difference is observed for haddock despite the catches in numbers by FLBEIA AD are smaller than the one of WGNSSK. This is mainly due to some differences in weight-at-age in the catch and landings between both methods, since the SOP are more different than the catch and landings in numbers. In FLBEIA AD, mean weight-at-age is given at the métier level and might not sum up exactly to the catch weights in WGNSSK.

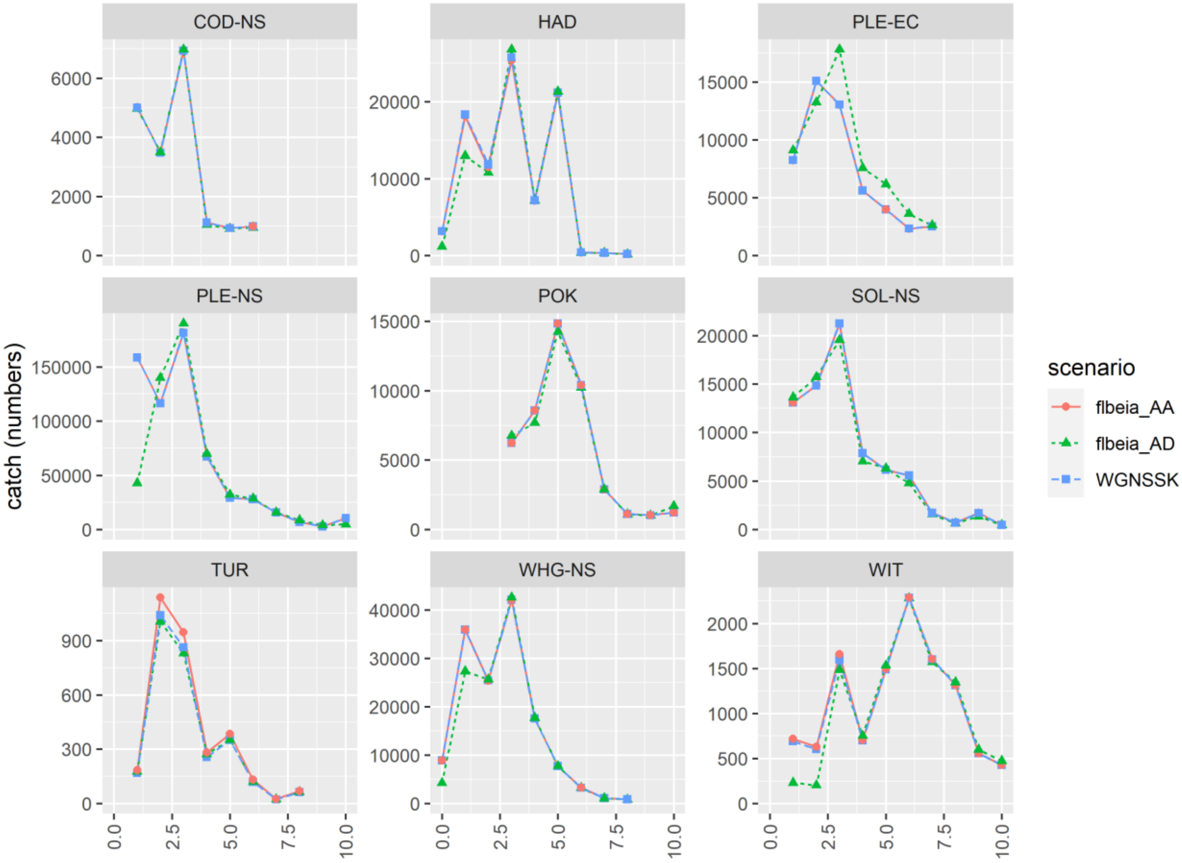


Figure A.3.3.2.1. Comparison of catch-at-age (numbers) by species in the last year of assessment (2019) between the single stock assessment (WGNSSK) and FLBEIA with age aggregation (FLBEIA_AA) and age disaggregation (FLBEIA_AD).

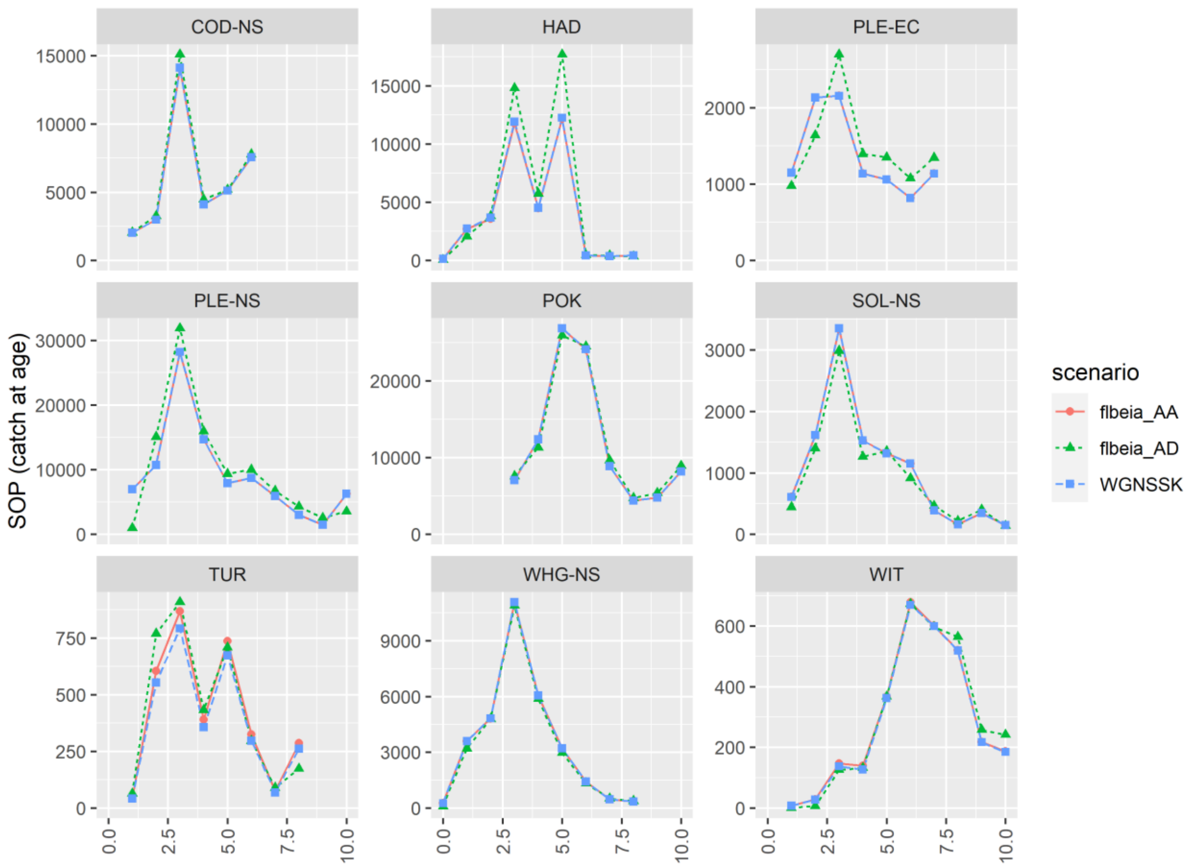


Figure A.3.3.2.2. Comparison of SOP catch-at-age (catch.n*catch.wt) by species in the last year of assessment (2019) between the single stock assessment (WGNSSK) and FLBEIA with age-aggregation (FLBEIA_AA) and age-disaggregation (FLBEIA_AD).

Table A.3.3.2.1. Summary table of total catches (tonnes) in 2019 between the single stock assessment (WGNSSK), FLBEIA AA and AD, and Fcube.

stock	WGNSSK	FLBEIA_AA	FLBEIA_AD	Fcube	Diff_FLBEIA_AA/WGNSSK	Diff_FLBEIA_AD/WGNSSK	Diff_Fcube/WGNSSK
COD-NS	35920	35922	37820	35922	0.000	0.053	0.000
HAD	36453	36088	45398	36088	-0.010	0.245	-0.010
PLE-EC	9600	9600	10492	10615	0.000	0.093	0.106
PLE-NS	93839	93839	100264	93839	0.000	0.068	0.000
POK	96645	96634	98031	96634	0.000	0.014	0.000
SOL-NS	10607	10607	9585	10607	0.000	-0.096	0.000
TUR	3046	3334	3446	3334	0.095	0.131	0.095
WHG-NS	31281	31259	30075	31259	-0.001	-0.039	-0.001
WIT	2853	2897	2968	2897	0.015	0.040	0.015

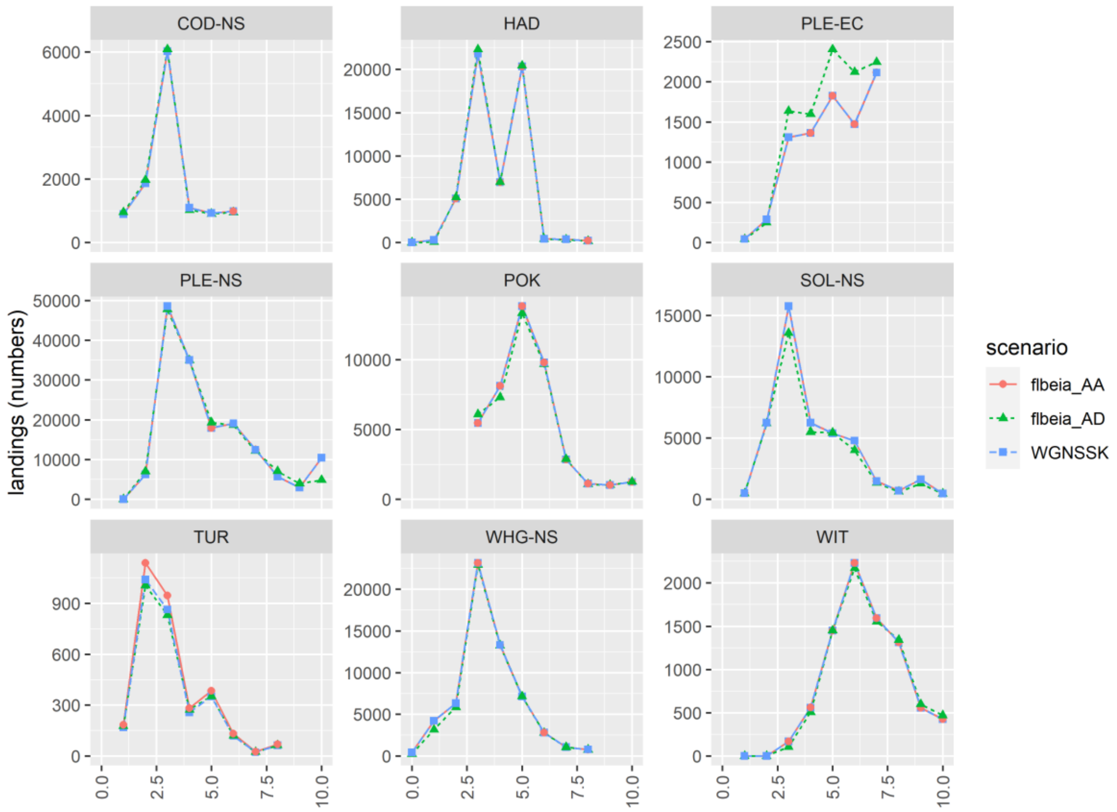


Figure A.3.3.2.3. Comparison of landings at age (numbers) by species in the last year of assessment (2019) between the single stock assessment (WGNSSK) and FLBEIA with age-aggregation (FLBEIA_AA) and age-disaggregation (FLBEIA_AD).

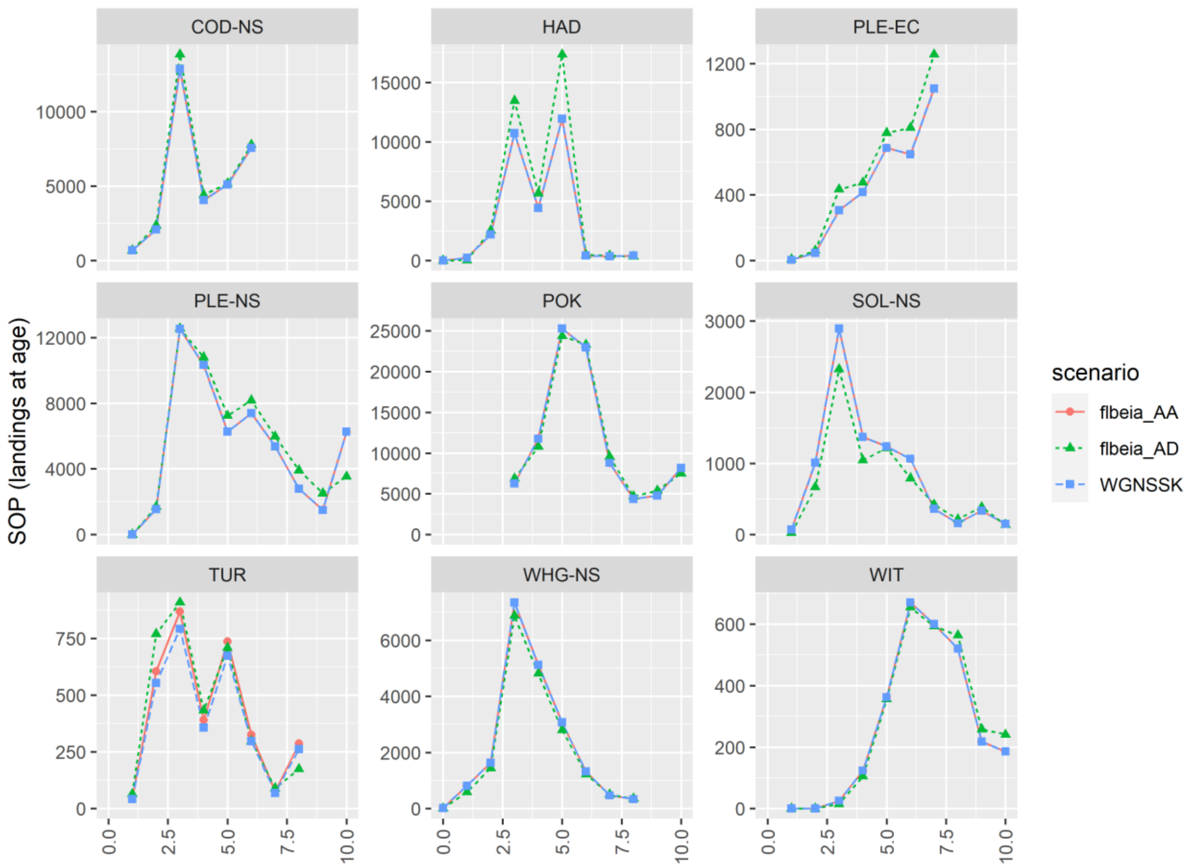


Figure A.3.3.2.4. Comparison of SOP landings at age (landings.n*landings.wt) by species in the last year of assessment (2019) between the single stock assessment (WGNSSK) and FLBEIA with age-aggregation (FLBEIA_AA) and age-disaggregation (FLBEIA_AD).

Table A.3.3.2.2. Summary table of total landings (tonnes) in 2019 between the single stock assessment (WGNSSK), FLBEIA AA and AD, and FCube.

stock	WGNSSK	FLBEIA_AA	FLBEIA_AD	Fcube	Diff_FLBEIA_AA/WGNSSK	Diff_FLBEIA_AD/WGNSSK	Diff_FCube/WGNSSK
COD-NS	32363	32363	34245	32363	0.000	0.058	0.000
HAD	30743	30743	40266	30743	0.000	0.310	0.000
PLE-EC	3156	3156	3819	3722	0.000	0.210	0.179
PLE-NS	53967	53967	56385	53967	0.000	0.045	0.000
POK	92390	92390	92476	92390	0.000	0.001	0.000
SOL-NS	8658	8658	7226	8658	0.000	-0.165	0.000
TUR	3046	3334	3446	3334	0.095	0.131	0.095
WHG-NS	20099	20099	18587	20099	0.000	-0.075	0.000
WIT	2707	2707	2786	2707	0.000	0.029	0.000

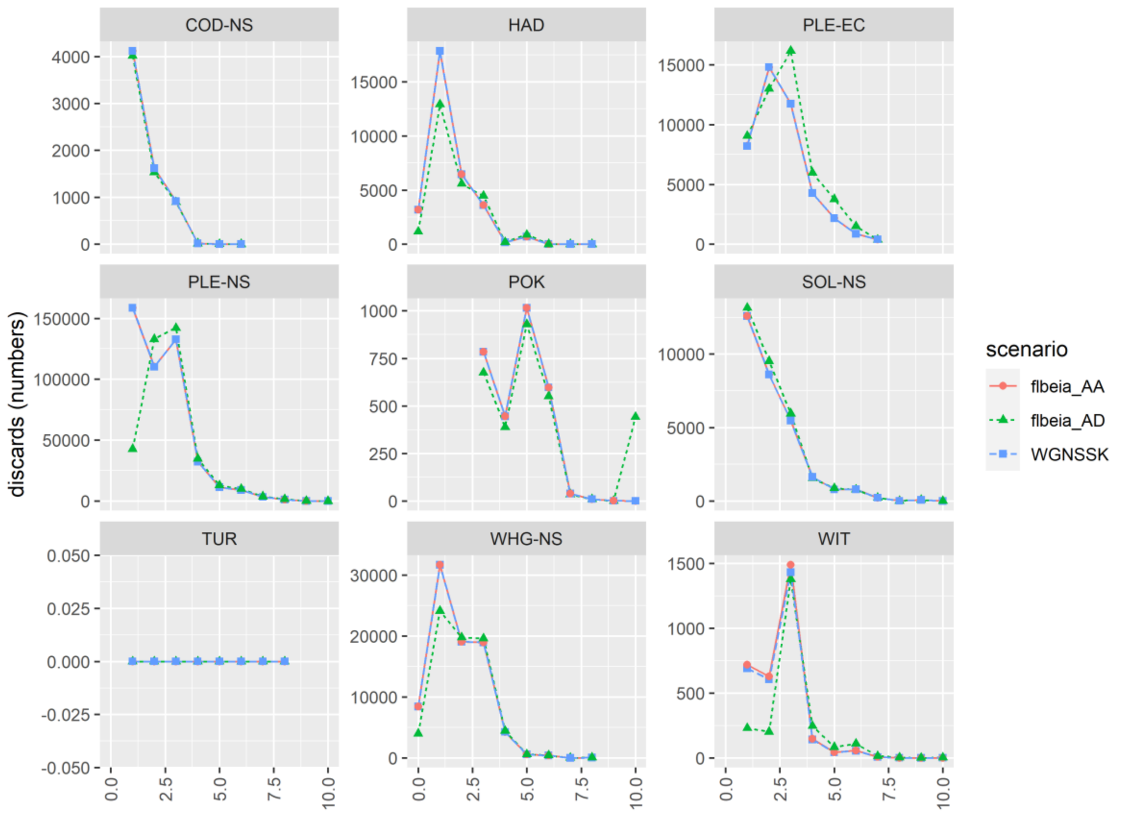


Figure A.3.3.2.5. Comparison of discards at age (numbers) by species in the last year of assessment (2019) between the single stock assessment (WGNSSK) and FLBEIA with age aggregation (FLBEIA_AA) and age disaggregation (FLBEIA_AD).

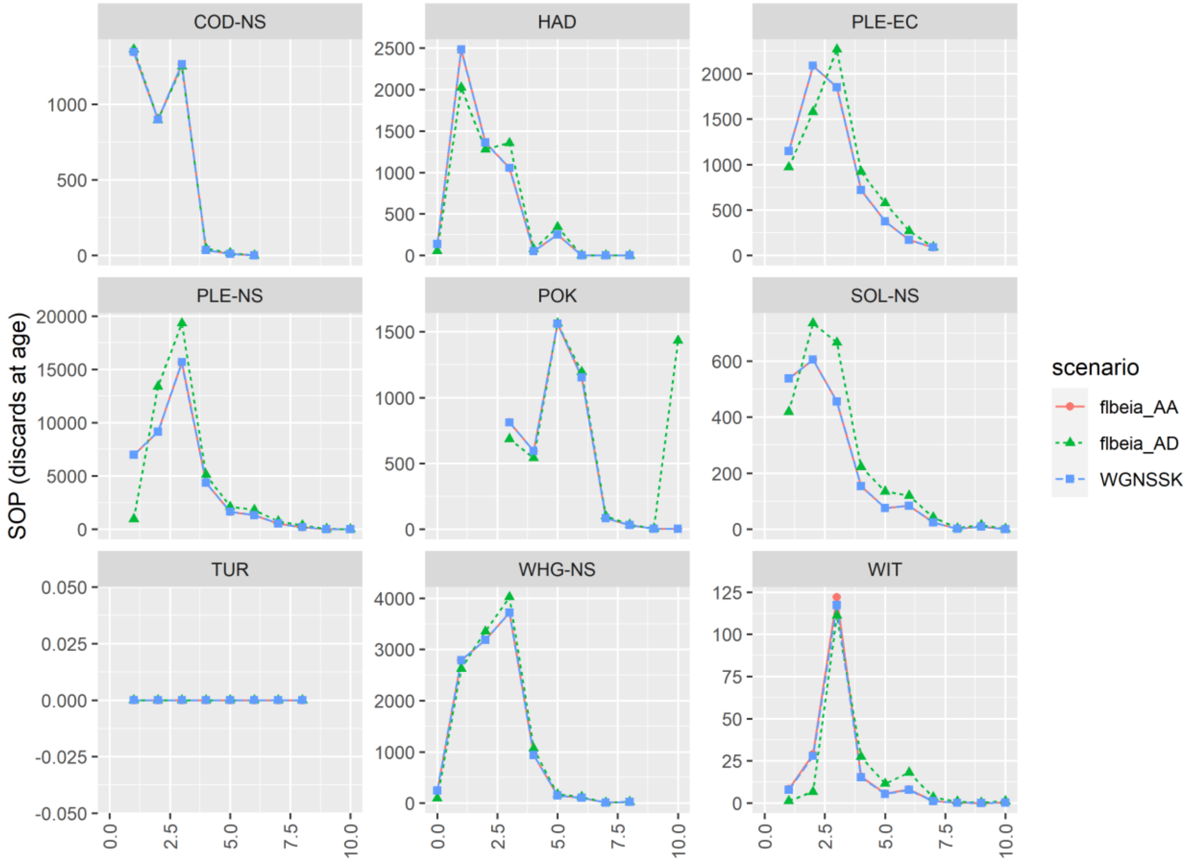


Figure A.3.3.2.6. Comparison of SOP discards at age (discards.n* discards.wt) by species in the last year of assessment (2019) between the single stock assessment (WGNSSK) and FLBEIA with age aggregation (FLBEIA _AA) and age disaggregation (FLBEIA _AD).

Table A.3.3.2.3. Summary table of total discards (tonnes) in 2019 between the single stock assessment (WGNSSK), FLBEIA AA and AD, and Fcube.

stock	WGNSSK	FLBEIA_AA	FLBEIA_AD	Fcube	Diff_FLBEIA_AA/WGNSSK	Diff_FLBEIA_AD/WGNSSK	Diff_Fcube/WGNSSK
COD-NS	3558	3558	3576	3558	0.000	0.005	0.000
HAD	5345	5345	5132	5345	0.000	-0.040	0.000
PLE-EC	6444	6444	6673	6893	0.000	0.035	0.070
PLE-NS	39872	39872	43879	39872	0.000	0.101	0.000
POK	4244	4244	5556	4244	0.000	0.309	0.000
SOL-NS	1949	1949	2359	1949	0.000	0.210	0.000
TUR	0	0	0	0	0.000	0.000	0.000
WHG-NS	11161	11161	11488	11161	0.000	0.029	0.000
WIT	183	190	182	190	0.040	-0.007	0.040

Comparison of fishing mortality rates between FLBEIA AA and AD, and WGNSSK are given at age in Figure A.3.3.2.7 and as average in Table A.3.3.2.4. Fishing mortality at age differs most for PLE-EC, SOL-NS and WIT but affects the Fbar mainly for PLE-EC due to a Fbar range taken between ages 3 and 6 where the difference with WGNSSK is largest.

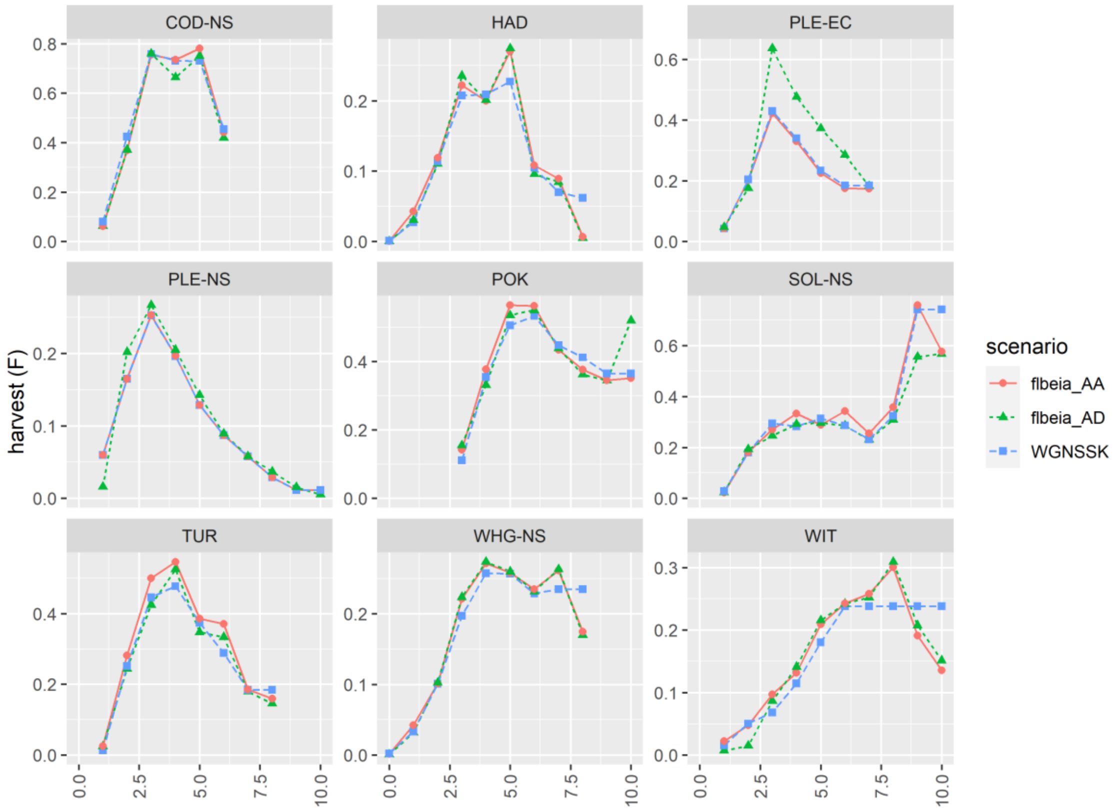


Figure A.3.3.2.7. Comparison of fishing mortality at age by species in the last year of assessment (2019) between the single stock assessment (WGNSSK) and FLBEIA with age aggregation (FLBEIA_AA) and age disaggregation (FLBEIA_AD).

Table A.3.3.2.4. Summary table of mean fishing mortality (Fbar) in 2019 between the single stock assessment (WGNSSK), FLBEIA AA and AD, and FCube

stock	WGNSSK	FLBEIA_AA	FLBEIA_AD	Fcube	Diff_FLBEIA_AA/WGNSSK	Diff_FLBEIA_AD/WGNSSK	Diff_Fcube/WGNSSK
COD-NS	0.638	0.619	0.598	0.638	-0.030	-0.063	-0.001
HAD	0.177	0.180	0.182	0.177	0.020	0.032	0.002
PLE-EC	0.297	0.289	0.443	0.297	-0.029	0.489	-0.001
PLE-NS	0.166	0.166	0.181	0.166	0.002	0.092	0.001
POK	0.461	0.485	0.464	0.461	0.053	0.008	0.001
SOL-NS	0.272	0.283	0.262	0.272	0.042	-0.034	0.002
TUR	0.367	0.417	0.375	0.367	0.134	0.021	-0.001
WHG-NS	0.208	0.217	0.218	0.208	0.045	0.048	-0.001

stock	WGNSSK	FLBEIA_AA	FLBEIA_AD	Fcube	Diff_FLBEIA _AA/WGNSSK	Diff_FLBEIA _AD/WGNSSK	Diff_Fcube/WGNSSK
WIT	0.202	0.228	0.232	0.202	0.132	0.149	0.001

Forecasting

Intermediate year assumptions

The mixed fisheries intermediate year assumption can differ from the single stock assessment (WGNSSK) for different reasons.

First, to allow for mixed fisheries interactions, the mixed fisheries scenarios assume status quo effort (from the last year of assessment) for each fleet in the intermediate year. This assumption may differ from that of the single stock advice (SSA); in particular, when the SSA assumes TAC constraint. When the SSA assumes constant F, this would be equivalent to status quo effort under a Baranov catch formulation used by FCube. The use of the Cobb-Douglas catch equation by FLBEIA can deviate from a linear relationship between F and effort, especially when fishing mortality is high. Whereas the Baranov equation assumes a linear relationship between F and effort, the Cobb-Douglas assumes a linear relationship between catch and effort (Figure A.3.4.1.1). FLBEIA allows the user to define a maximum allowed catch / biomass ratio in order to prevent situations where advised catch exceeds the available biomass. Such a situation can be seen in the panel plotting COD-NS catch, where catch plateaus with higher effort values due to the limitation of this catch / biomass ratio.

Second, some stocks in WGNSSK use a stochastic forecast for advice. The mixed fisheries forecasts are currently deterministic and this can sometimes lead to some differences in the outputs.

Finally, some stocks, such as cod, have an assessment that runs up to the intermediate year, which means that SSB in the intermediate year is estimated as part of the assessment rather than as part of the forecast. This could lead to differences in starting conditions for the forecast as the mixed fisheries simulations do not currently considered assessment estimates in the intermediate year.

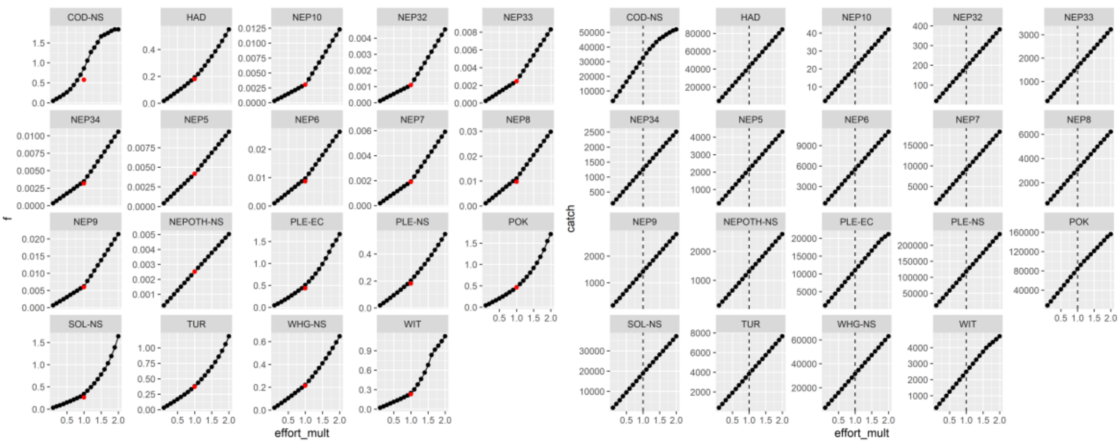


Figure A.3.4.1.1. Effect of variable effort on harvest rate (left) and catch (right) in the intermediate year (2020) in the age-disaggregated FLBEIA model of the North Sea.

Reporting of deviations with single stock advice

The deviations between the North Sea mixed fisheries forecast and the single stock forecast in terms of fishing mortality, landings and catches in the intermediate year (2020), as well as SSB in the advice year (2021), are presented in Figure A.3.4.2.1. In the 2020 WGMIXFISH advice, the largest discrepancy is observed for COD-NS, for which the mixed fisheries assumption of constant effort for all fleets corresponds to a fishing mortality in the intermediate year of 120% larger than the WGNSSK assumption (catch in 2020 equal to TAC2020). This means that the mixed fisheries forecast starts the advice years with smaller abundances at age than was assumed by the single stock advice (SSB in the advice year is about 20% lower than that assumed by the SSA). Consequently, the advised fishing mortality (F) becomes associated with a lower catch in the mixed fishery forecast than was assumed by the SSA.

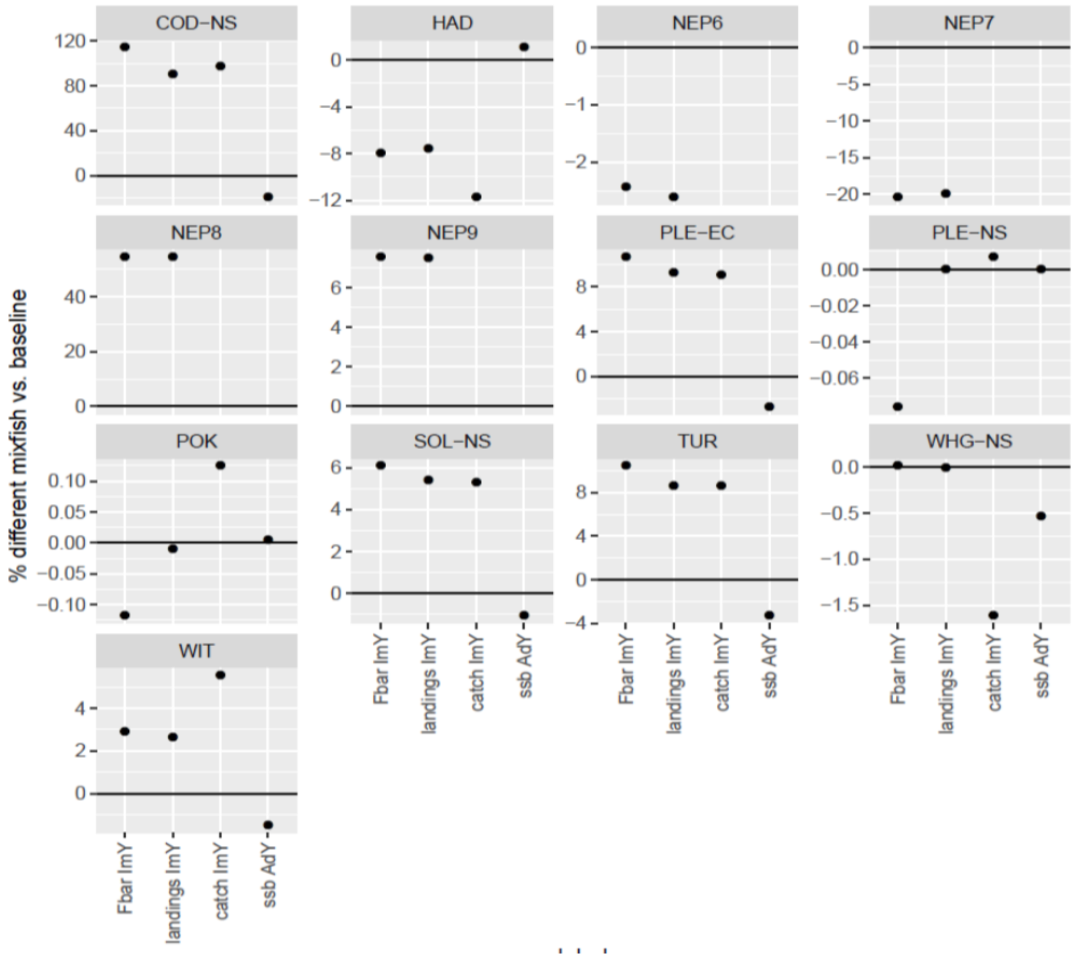


Figure A.3.4.2.1. Percent differences between the North Sea mixed fisheries forecast (FCube) and the single stock forecast for the fishing mortality, landings and catches in the intermediate year of the forecast and SSB in the advice year. ImY = intermediate year (2020), AdY = advice year (2021).

The summary of the SSB, catch, fishing mortality and recruitment for the finfish stocks in the "min" scenario of the FCube, FLBEIA AD and AA models is presented in Figure A.3.4.2.2 and compared to the single species advice (WGNSSK). Principal differences as compared to the single stock assessment are due to differences in the intermediate year assumptions (status quo effort) and mixed fishery interactions for the advice year, as only the "min" scenario is shown here.

In addition to deviations attributable to intermediate year assumptions, advice year forecasts will differ between the two models due to different approaches used for restricting fishing effort. FCube uses of an F-constraint to fleet effort, which are defined by the SSA and are independent of the changes in SSB during the intermediate year. FLBEIA's use of a catch-constraint maintains the original TAC levels. In the case of COD-NS, the higher catches during the intermediate year result in a lower SSB at the start of the advice year. Consequently, the advised TAC will result in result in a higher associated F than assumed by the SSA.

Another deviation observed in Figure A.3.4.2.2 is that FLBEIA estimates of SSB for WIT are positively biased for all years. This is due to the fact that this stock's SSB is calculated in the middle of the year by the SSA, as opposed to the start of the year for other stocks. The internal SSB as calculated by the management loop in FLBEIA correctly considers this adjustment (i.e. in the FLStock), but it is not considered in the summary statistics built with information by the FLBiol object, which are plotted here.

Overall, the results of the three mixed fishery models produced similar outcomes. FLBEIA_AD and FLBEIA_AA models were more similar to each other than to FCube likely due to the differences in catch model (Baranov vs. Cobb-Douglass) and effort constraint (F versus catch).

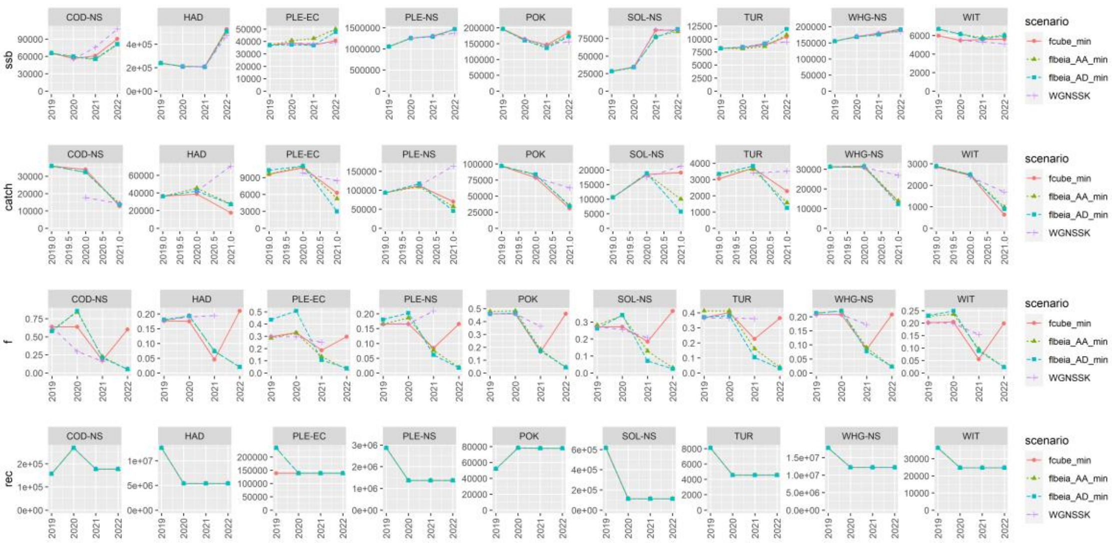


Figure A.3.4.2.2. Summary of short-term forecast stock variables by model under the "min" scenario. The single stock forecast (WGNSSK) is shown for reference.

Fleet behaviour

A comparison of quota uptake by fleet and stock is shown in Figure A.3.4.3.1. The figure shows that for each fleet, FLBEIA outputs identify the choke stock as that stock whose quota uptake equals exactly 1.0. This is not the case for the FCube scenario, as most values can be seen having a maximum around 0.75, but these maximum values per fleet also reflect the chocking stock. The reason for this discrepancy in quota uptake magnitude is due to the FCube's use of an F-restriction to effort. In the advice year (2021), COD-NS was the main choking stock for 39/40 fleets in FCube while only in 30/40 for FLBEIA AD and 31/40 for FLBEIA AA (Table A.3.4.3.1).

One further advantage of the FLBEIA approach for short-term forecasts lies in the catch-based (rather than F-based) definitions for controlling effort in the advice year. Even if the intermediate year assumptions using FLBEIA will likely deviate from some of those of the single stock assessments, resulting in different SSBs at the start of the advice year, the quotas used for defining fishing effort are still linked to the single stock advice. This is much more in line with the reality as quotas are decided without the complete knowledge of the stock status at the beginning of the advice year. As FCube uses previously defined F restrictions, any deviation in SSB will result in a change to the catch associated with the advised F.

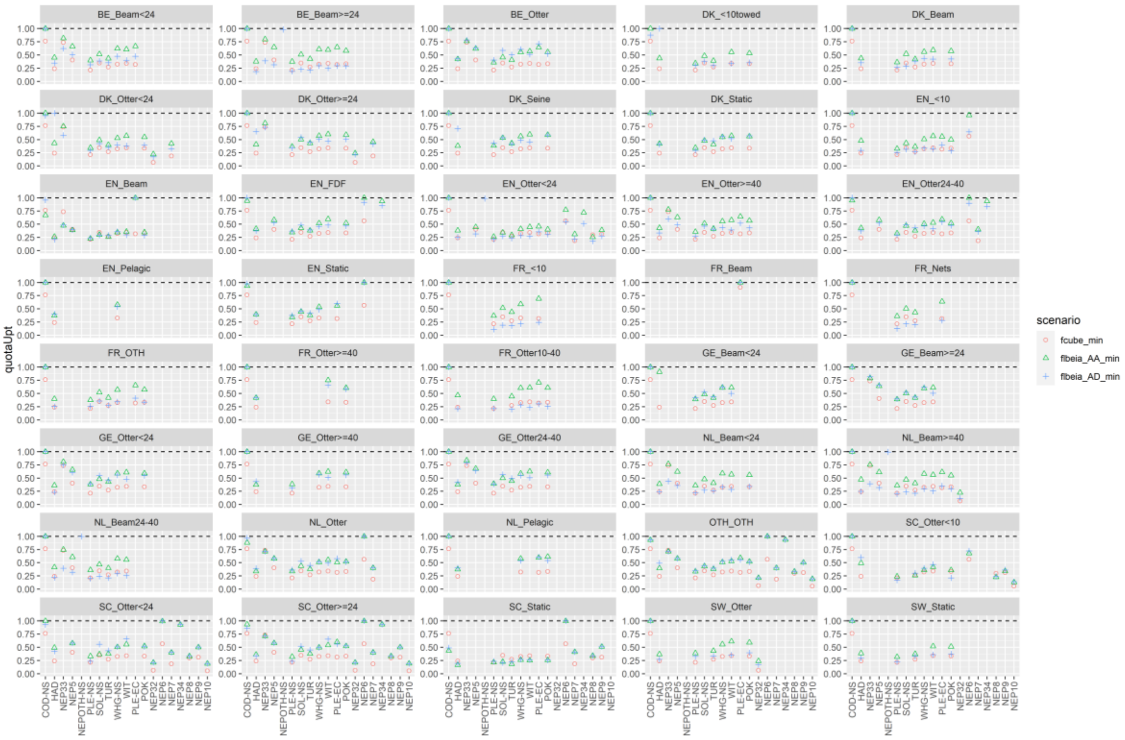


Figure A.3.4.3.1. Quota uptake in the advice year by fleet and mixed fishery model for the "min" scenario (choking once the first quota share is filled) for FCube and FLBEIA with age aggregation (FLBEIA _AA) and age disaggregation (FLBEIA _AD).

Table A.3.4.3.1. Choke and least limiting species per fleet for FCube and FLBEIA with age aggregation (AA) and age disaggregation (AD).

fleet	choke_FCube	choke_FLBEIA_AD	choke_FLBEIA_AA	Least limiting FCube	Least limiting FLBEIA AD	Least limiting FLBEIA AA
BE_Beam<24	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS
BE_Beam>=24	COD-NS	COD-NS	COD-NS	PLE-NS	HAD	PLE-NS
BE_Otter	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS
DK_<10towed	COD-NS	HAD	COD-NS	PLE-NS	TUR	PLE-NS
DK_Beam	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS
DK_Otter<24	COD-NS	HAD	COD-NS	NEP7	PLE-NS	PLE-NS
DK_Otter>=24	COD-NS	COD-NS	COD-NS	NEP7	PLE-NS	PLE-NS
DK_Seine	COD-NS	COD-NS	COD-NS	PLE-NS	TUR	HAD
DK_Static	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS

fleet	choke_FCube	choke_FLBEIA_AD	choke_FLBEIA_AA	Least limit-ing FCube	Least limit-ing FLBEIA AD	Least limit-ing FLBEIA AA
EN_<10	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS
EN_Beam	COD-NS	PLE-EC	PLE-EC	PLE-NS	HAD	PLE-NS
EN_FDF	COD-NS	COD-NS	NEP6	PLE-NS	PLE-NS	PLE-NS
EN_Otter24-40	COD-NS	COD-NS	NEP6	NEP7	PLE-NS	PLE-NS
EN_Otter<24	COD-NS	COD-NS	COD-NS	NEP7	NEP8	NEP8
EN_Otter>=40	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS
EN_Pelagic	COD-NS	COD-NS	COD-NS	HAD	HAD	HAD
EN_Static	COD-NS	NEP6	NEP6	PLE-NS	PLE-NS	PLE-NS
FR_<10	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS
FR_Beam	PLE-EC	PLE-EC	PLE-EC	PLE-EC	PLE-EC	PLE-EC
FR_Nets	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS
FR_OTH	COD-NS	COD-NS	COD-NS	PLE-NS	HAD	PLE-NS
FR_Otter10-40	COD-NS	COD-NS	COD-NS	PLE-NS	TUR	PLE-NS
FR_Otter>=40	COD-NS	COD-NS	COD-NS	HAD	HAD	HAD
GE_Beam<24	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS
GE_Beam>=24	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS
GE_Otter24-40	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	HAD
GE_Otter<24	COD-NS	COD-NS	COD-NS	PLE-NS	HAD	HAD
GE_Otter>=40	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	HAD
NL_Beam24-40	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS
NL_Beam<24	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS
NL_Beam>=40	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS
NL_Otter	COD-NS	NEP6	NEP6	NEP7	PLE-NS	PLE-NS
NL_Pelagic	COD-NS	COD-NS	COD-NS	HAD	HAD	HAD
OTH_OTH	COD-NS	NEP6	NEP6	NEP7	NEP8	NEP8
SC_Otter<10	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	NEP8
SC_Otter<24	COD-NS	NEP6	COD-NS	NEP7	PLE-NS	NEP8
SC_Otter>=24	COD-NS	NEP6	NEP6	NEP7	PLE-NS	PLE-NS

fleet	choke_FCube	choke_FLBEIA_AD	choke_FLBEIA_AA	Least limiting FCube	Least limiting FLBEIA AD	Least limiting FLBEIA AA
SC_Static	COD-NS	NEP6	NEP6	NEP7	HAD	HAD
SW_Otter	COD-NS	COD-NS	COD-NS	PLE-NS	HAD	HAD
SW_Static	COD-NS	COD-NS	COD-NS	PLE-NS	PLE-NS	PLE-NS

Specific advice scenarios

The results of the mixed fisheries projections per scenario are given in Figure A.3.4.4.1 for FCube, FLBEIA AA and AD. The results differ slightly between the models but the overall patterns are similar.

If we compare the status quo effort scenario for the three models, we see that the results are very similar between the three models with only a small difference in the catch for sole that has a larger overshoot for FCube than the FLBEIA models. Differences to FCube are due primarily to differences in the FLBEIA catch model (AA and AD) and fleet conditioning (AA only).

Given that FCube works with F constraints instead of catch constraints in the forecasts, the scenario such as cod-ns, where the whole quotas of cod should be taken still shows a small undershoot of the quotas, while the scenario works as expected for both FLBEIA models.

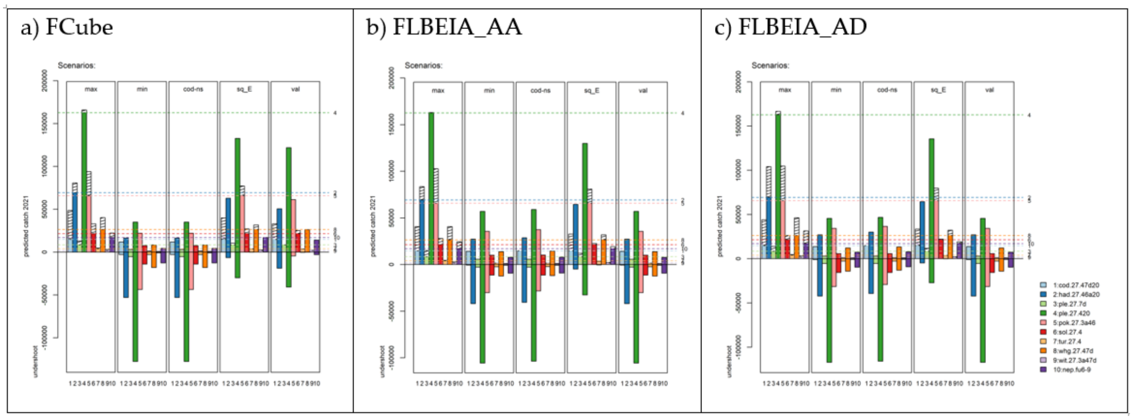


Figure A.3.4.4.1. Mixed-fisheries projections for the North Sea with FCube (a) and FLBEIA with age aggregation (AA, b) and age disaggregation (AD, c). Estimates of potential catches (in tonnes) by stock and by scenario. The horizontal lines correspond to the single-stock catch advice for 2021. Bars below the value of zero show undershoot (compared to single-stock advice) where catches are predicted to be lower when applying the scenario. Hatched columns represent catches that overshoot the single-stock advice. Note: the "val" scenario has not yet been set-up for FLBEIA, and the "min" output has simply been duplicated in those FLBEIA_AA and FLBEIA_AD plots as a temporary placeholder.

The results of the range scenario are given in Figure A.3.4.4.2. The results are very similar for both FLBEIA models. The results compared to FCube differ most for English Channel plaice where FCube predicts a F_{target} at F_{MSY}, while both FLBEIA models predict an increase in F_{target} compared to F_{MSY}. The main difference between FCube and FLBEIA regarding PLE-EC is that, for FLBEIA AA and AD, the fleet EN-Beam is choked by PLE-EC (Table A.3.4.3.1). This fleet is composed of 3 métiers: BT1.4, BT2.4, BT2.7D, for which only the latter (BT2.7D) catches PLE-EC. The other 2 métiers, however, have large catches of PLE-NS. As a result, the choke of BT2.7D on PLE-EC reduces how much the other 2 fleets can take of PLE-NS in the min scenario. The main difference between the min and max scenarios is the amount of catch for PLE-NS that are highly overshot in the min scenario (Figure A.3.4.4.1). Increasing the fishing mortality for PLE-EC in the range scenario (Figure A.3.4.4.2) allows more PLE-NS to be landed for the EN-Beam fleet and can possibly explain why the F_{target} in the range scenario for the FLBEIA models is increased for PLE-EC compared to FCube.

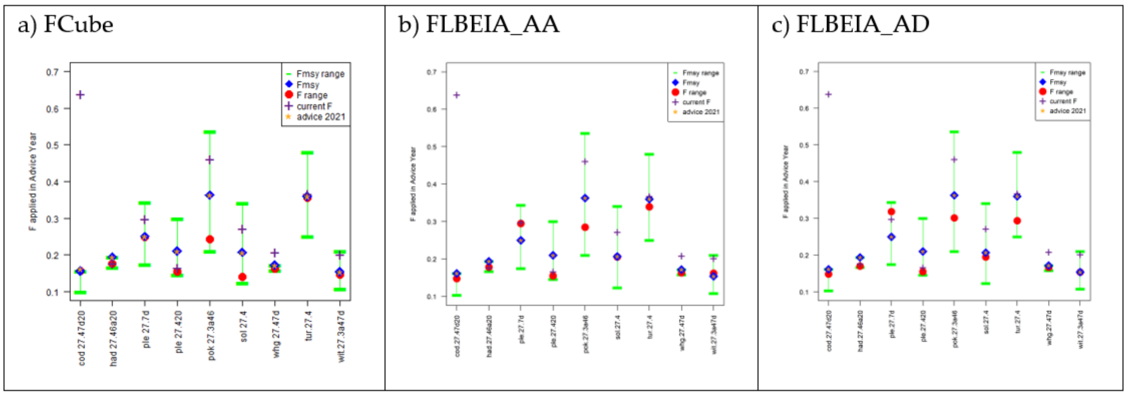


Figure 3.4.4.2. Mixed fisheries for the a) North Sea with with FCube, b) FLBEIA with age-aggregation (FLBEIA_AA) and c) FLBEIA with age-disaggregation (FLBEIA_AD). North Sea mixed-fisheries 2021 "range" fishing mortality within the F_{MSY} range, compared with F_{MSY}, the current F (2019), and F in the single-stock advice for 2021. For cod in the North Sea, F_{MSY} ranges are limited in accordance with the MSY approach and the MAP when the cod SSB is below $MSYB_{trigger}$.

Suggestion for North Sea case study

Both FCube and FLBEIA have their advantages and limitations (see Section 2.3).

The results of the mixed fisheries projections between FCube and FLBEIA are very similar. Some of the differences observed between the models are due to the age-disaggregation of the data (differences between FLBEIA AA and FLBEIA AD) and others are due to the difference in assumptions catch models between FCube and FLBEIA; namely, the Cobb-Douglas catch equation in FLBEIA based on catch constraints versus the Baranov catch equation in FCube, based on F constraints.

Regarding the age-disaggregation of the data and runs for the finfish stocks, we unanimously agreed in the meeting that this is the most realistic assumption since it allows a catchability at age that varies between métiers.

Regarding the catch constraint in the forecast, this is also more realistic as the management for the stocks are currently implemented through quotas.

The Cobb-Douglas equation assumes that the catch varies linearly with effort, while for the Baranov equation, it is the fishing mortality that varies linearly with effort. The Baranov assumption is a common assumption in single species assessments, while the Cobb-Douglas is relevant in bioeconomic simulations. The discrepancies between both catch equations increase in cases of high fishing mortality (Figure A.3.4.1.1). For the mixed fisheries simulations, the Cobb-Douglas catch equation can therefore induce problems for short-term forecasts in cases where a given stock's current fishing mortality is high (cf. Celtic Sea case study). For the North Sea case study, this does not seem to be problematic at the moment and the gains from moving to FLBEIA outweigh this limitation.

Annex 3: References

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