WORKING GROUP ON MIXED FISHERIES METHODOLOGY (WGMIXFISH-METHODS)

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Contents

i Executive summary

The ICES Working Group on Mixed Fisheries Methodology (WGMIXFISH-METHODS) met to progress work on the improvement and development of the mixed fisheries advice. In this report the group provides a summary of the work completed in 2022.

The work addressed included improving workflows for the advice process, presenting methodological advances, developing new ecoregions and responding to issues encountered during WGMIXFISH-ADVICE 2022. Additionally, plans for a second scoping workshop were discussed and the contribution of WGMIXFISH to mixed fisheries information in the Fisheries Overviews was reviewed.

A key methodological advance used data on quota exchanges between countries to update the Min mixed fisheries scenario to address concerns over choking behaviour in fleets that generally do not entirely consume their initial quota allocation. This update is predicated on the assumption that when TAC changes become restrictive, the usual quota exchanges will become less likely.

An Irish Sea model has been in development for several years and a mature version was presented. A formal review process has been initiated to evaluate this model with a timescale consistent with incorporating this ecoregion into the formal mixed fisheries advice process for 2022.

To help improve the understanding of the main outputs from the mixed fisheries model a new design for the headline “advice” plot was approved at this meeting. This new design presents the results from each mixed fisheries scenario for a particular stock. This should enable stakeholders to draw easier comparisons between the different scenarios presented for their stock of interest.

Future work ahead of next year’s meeting will focus on finalising the plans initiated at this meeting for a second scoping workshop and refining the contribution of WGMIXFISH to mixed fisheries information presented in the Fisheries Overviews.

ii Expert group information

Expert group name	Working Group on Mixed Fisheries Methodology (WGMIXFISH-METHODS)
Expert group cycle	Annual
Year cycle started	2022
Reporting year in cycle	1/1
Chair(s)	Marc Taylor, Germany
	Harriet Cole, UK
Meeting venue and dates	20-24 June 2022, Nantes (hybrid), (30 participants)

1 Introduction

The Working Group on Mixed Fisheries Advice Methodology (WGMIXFISH-METHODS) was formed in response to the need to further develop how ICES provides mixed fisheries advice and to progress the application of methods, independent of the annual advisory meeting (ICES, 2014). Annually this meeting focuses on the development and improvement of mixed fisheries analysis and advice.

WGMIXFISH-METHODS - Working Group on Mixed Fisheries Advice Methodology

2021/2/FRSG17 The Working Group on Mixed Fisheries Advice Methodology (WGMIXFISH-METHODS), chaired by Marc Taylor*, Germany, and Harriet Cole*, UK, will hold a hybrid meeting in Nantes, on 20 – 24 June 2022, to:

a) Continue the improvement of WGMIXFISH-ADVICE data call, data processing, workflow, auditing, updating associated documentation and increasing transparency;

b) Respond to the outcomes of the Mixed Fisheries Scoping Meeting;

c) Exploration of developments in methodology and advice;

d) Respond to the outcomes and issues encountered during WGMIXFISH-Advice;

e) Develop mixed fisheries models for sea regions not currently covered in the mixed fisheries advice;

f) Plan a second scoping workshop to present developments made since WKMIXFISH and to close the remaining knowledge gaps on the use and value of mixed fisheries advice.

g) Review the contribution of mixed-fisheries advice to the fisheries overviews and propose alternatives, to provide valuable fleet level information to stakeholders and raise awareness of the work done by WGMIXFISH.

WGMIXFISH-METHODS will report by 30 July 2022 for the attention of ACOM.

Only experts appointed by national Delegates or appointed in consultation with the national Delegates of the expert's country can attend this Expert Group.

Supporting information

Priority:	The work is essential to ICES to progress in the development of its capacity to provide advice on multispecies fisheries. Such advice is necessary to fulfil the requirements stipulated in the MoUs between ICES and its client commissions.
Scientific justification and relation to action plan:	The issue of providing advice for mixed fisheries remains an important one for ICES. The Aframe project, which started on 1 April 2007 and finished on 31 march 2009 developed further methodologies for mixed fisheries forecasts. The work under this project included the development and testing of the FCube approach to modelling and forecasts. In 2008, SGMIXMAN produced an outline of a possible advisory format that included mixed fisheries forecasts. Subsequently, WKMIXFISH was tasked with investigating the application of this to North Sea advice for 2010. AGMIXNS further developed the approach when it met in November 2009 and produced a draft template for mixed fisheries advice. WGMIXFISH has continued this work since 2010.
Resource requirements:	No specific resource requirements, beyond the need for members to prepare for and participate in the meeting.
Participants:	Experts with qualifications regarding mixed fisheries aspects, fisheries management and modelling based on limited and uncertain data.
Secretariat facilities:	Meeting facilities, production of report.
Financial:	None
Linkages to advisory committee:	ACOM
Linkages to other committees or groups:	SCICOM through the WGMG. Strong link to STECF.
Linkages to other organizations:	This work serves as a mechanism in fulfilment of the MoU with EC and fisheries commissions. It is also linked with STECF work on mixed fisheries.

2 ToR A: Continue the improvement of WGMIXFISH-ADVICE data call, data processing, workflow, auditing, updating associated documentation and increasing transparency.

2.1 Advice sheet development

Headline advice

In the interest of improving the clarity and utility of the mixed fishery considerations, there are several ongoing efforts to provide stakeholders with new options to communicate the results of WGMIXFISH. In addition to other efforts related to the communication of additional layers of detail (see ToRs b and f), the group has explored other option for our headline advice.

Currently, the headline advice consists of a single graphic that summarizes mixed fishery scenarios in terms of over- and under-shoot of single stock advice (Figure 2.1). Panels are used for each scenario and the associated catch of all stocks are shown on a single axis, making comparison straightforward but with some loss of detail for less abundant stocks. Figure 2.2 shows an alternate presentation whereby panels separate scenarios by stock, with the addition of background coloration to further emphasize catches associated with above (red) and below (green) single stock advice. Smaller stocks are more easily seen, but one loses the emphasis on most important stocks in terms of catch. Besides single stock advice additional reference lines could be added without cluttering the figure (e.g. historical catch level).

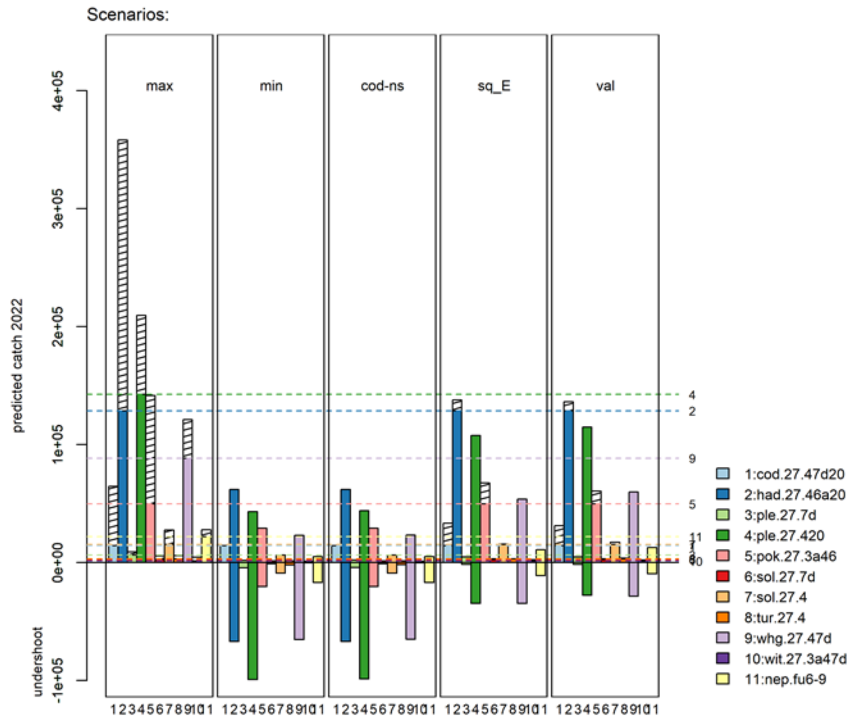


Figure 2.1. North Sea headline advice figure from the WGMIXFISH-Advice 2021 (ICES 2022) showing mixed fisheries projections. Estimates of potential catches (in tonnes) by stock and by scenario. Horizontal lines correspond to the single-stock catch advice for 2022. Bars below the value of zero show undershoot (compared to single-stock advice) where catches are predicted to be lower when applying the scenario. Hatched columns represent catches that over-shoot the single-stock advice.

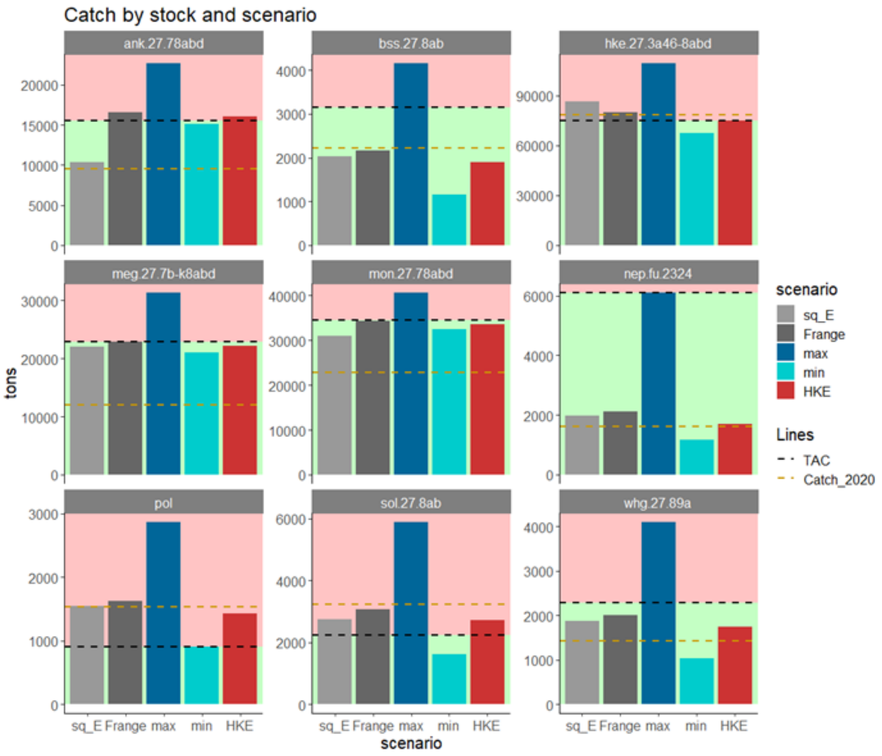


Figure 2.2. Alternate headline advice figure summarizing mixed fishery scenarios in different panels by stock (Bay of Biscay case study). Reference lines provide the catch level of the TAC year (2022) for each stock (dashed black lines) and the last data year (dashed yellow lines).

Presentation of *Range* scenario in mixed fishery context

The group also considered whether the results of the *Range* scenario might also be presented more front and centre in the headline advice. The Range scenario presents an optimization of single stock advice values within the FMSY range ($FMSY_{lower}$ – $FMSY_{upper}$) (Figure 2.3) that minimizes the difference between total catch of the *min* and *max* scenarios. This results in catches in the upper part of the FMSY range for most-limiting stocks and lowest part of the range for least-limiting stocks. Currently, this scenario is only conducted in the Celtic Sea and North Sea case studies, but all case studies are expected to include this in the future.

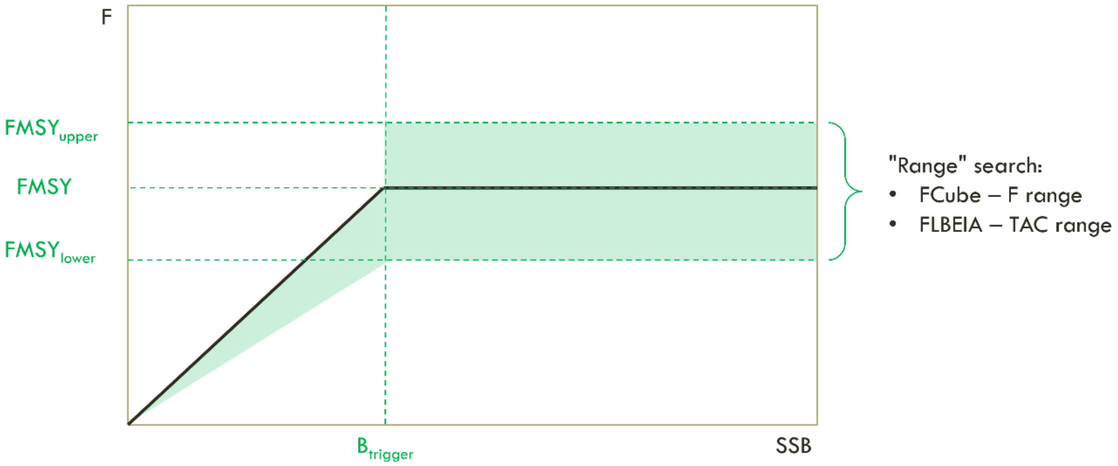


Figure 2.3. Schematic of the *Range* scenario optimization. The optimisation allows for single stock advice to vary within the FMSY range (if SSB < Brtrigger, then then $FMSY_{upper}$ may not be considered). In the FCube operating model, fishing effort is constrained by fishing mortality (F) which the FLBEIA operating model is constrained by catch.

The results of the Range scenario are currently presented graphically in terms of the resulting optimised F value in the FMSY range (Figure 2.4), and also in summary tables of catch (Table 2.1) and F in the advice year, and SSB at the end of the advice year. In contrast to the columns representing mixed fishery scenarios, the Range values are presented in terms of single stock advice, by translating the optimized values for advised F/catch back into the single stock projections. This has the advantage of facilitating the use of the results in later TAC negotiations, while the disadvantage is that the tables provide a mixture of mixed fishery and single stock scenarios, which can be confusing. An alternate approach, discussed at the meeting, could be to present the results in terms of a mixed fishery scenario; e.g. a *Range*/*Min* scenario would present the results in an additional *Min* scenario. This would also allow for the Range results to be presented along the other mixed fishery scenarios in the headline figure (e.g. Figure 2.5). In the example for the North Sea, the Range optimization is unable to increase catches due to the strong choking effect of COD-NS, whose SSB < Btrigger and is therefore unable to explore the upper part of the Fmsy range. If this were not the case, one would be able to easily observe the gains in catch as compared to the Min scenario. The yellow shading of the FMSY – $FMSY_{upper}$ region reflects the multiannual plan (MAP) for demersal stocks in the North Sea, allowing for fishing in the upper FMSY range under some situations (Preamble 17 of regulation (EU) 2018/973):

> *"For the purposes of fixing fishing opportunities, there should be an upper threshold for ranges of FMSY in normal use and, provided that the stock concerned is considered to be in a good state, an upper limit for certain cases. It should be possible to fix fishing opportunities at the upper limit only if, on the basis of scientific advice or evidence, it is necessary to achieve the objectives of this Regulation in mixed fisheries or necessary to avoid harm to a stock caused by intra- or inter-species stock dynamics, or in order to limit the year-to-year variations in fishing opportunities."*

Such allowances are not expected to be adopted over extended periods and may be of particular utility in short-term situations in order to achieve "pretty good yield" in a mixed fishery context.

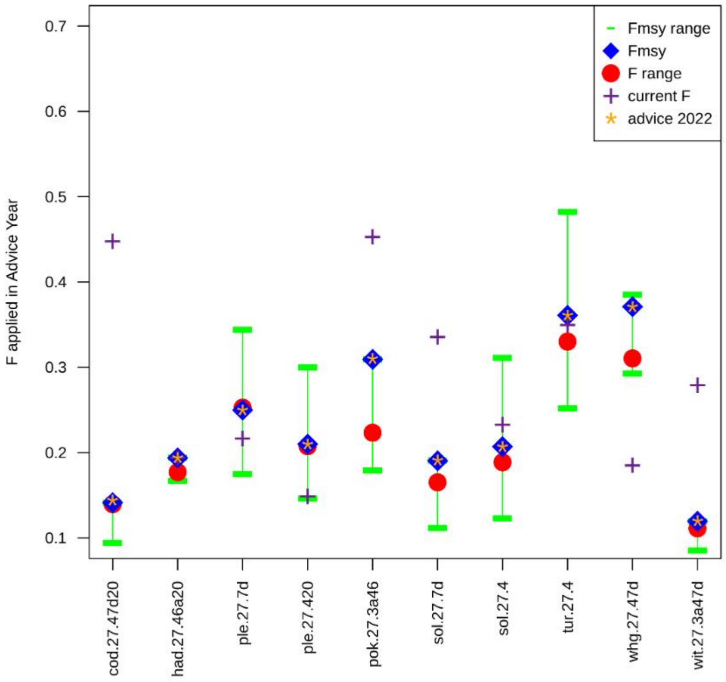


Figure 2.4. Mixed fisheries for the Greater North Sea. Mixed-fisheries 2022 "F range" fishing mortality within the F_{MSY} range, compared with F_{MSY}, the current F (2020), and F in the single-stock advice for 2022. For cod, saithe, witch, and eastern English Channel sole, F_{MSY} ranges are reduced as SSB is below MSY $B_{trigger}$.

Table 2.1. Mixed fisheries for the Greater North Sea. Catch per mixed-fisheries scenario 2022, in tonnes.

Stock	Single-stock catch advice (2022)*	Catch per mixed-fisheries scenario (2022)					Range^
		max	min	cod-ns	sq_E	val	
cod.27.47d20	14276	64648	14273	14276	33236	31252	13780
had.27.46a20	128708	358303	61824	61827	137790	136443	112251
ple.27.7d^^	6365	8895	1971	2166	4649	4873	6418
ple.27.420	142508	209543	43212	43856	107730	115343	142085
pok.27.3a46	49614	141642	29151	29151	67594	60673	35142
sol.27.7d^^	2380	5525	1339	1417	3138	3154	2009
sol.27.4	15330	27434	6234	6338	15503	17172	13999
tur.27.4	3609**	5832	1285	1313	3244	3604	3083
whg.27.47d	88426	121077	23047	23341	53698	59953	73087
wit.27.3a47d	1206	4382	987	987	2315	2221	1105
nep.fu.5	1570	1866	333	333	770	773	n/a

Stock	Single-stock catch advice (2022)*	Catch per mixed-fisheries scenario (2022)					Range^
		max	min	cod-ns	sq_E	val	
nep.fu.6	1940	5408	1039	1039	2240	2522	n/a
nep.fu.7	14803	14803	2617	2617	5576	6497	n/a
nep.fu.8	3216	4982	897	897	1993	2335	n/a
nep.fu.9	2062	2600	477	477	1157	1252	n/a
nep.fu.10	46	29	5	5	11	13	n/a
nep.fu.32	381	475	76	76	180	162	n/a
nep.fu.33	956	3900	695	695	1612	1627	n/a
nep.fu.34	566	4359	946	946	2167	1612	n/a
nep.27.4outFU	301	1570	287	287	654	688	n/a

n/a: stocks for which ranges of FMSY are either not available or not yet included in the scenario.

* Advised catches of no more than the indicated value.

** Corresponding to (projected landings)/(1–average discard rate); projected landings = 3291 and average discard rate by weight = 8.8%. Catches per mixed-fisheries scenario correspond to projected landings.

^ The results of the “range” scenario are bounded by the single-stock MSY ranges (or reduced ranges) and do not directly account for any technical interactions. These catches could only be achieved with substantial changes in fishing patterns.

^^ See Quality Considerations for an explanation of differences between the single stock projections and the mixed fisheries projections.

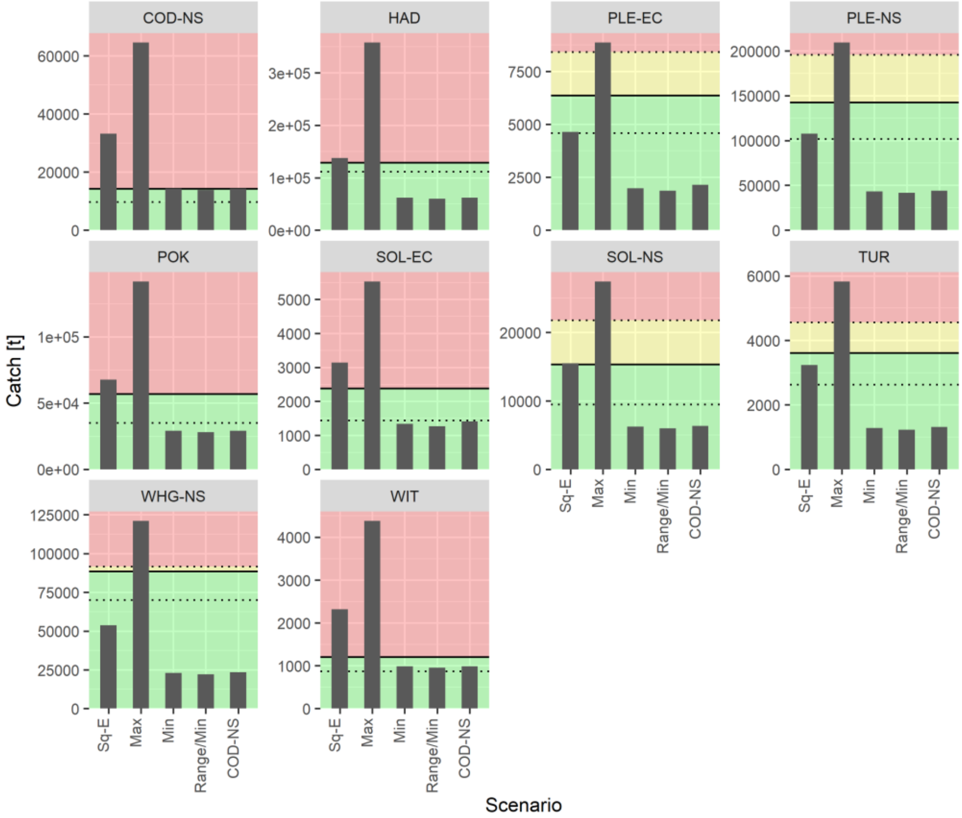


Figure 2.5. Alternate headline advice figure summarizing mixed fishery scenarios in different panels by stock (North Sea case study). Total catch by stock under different mixed fishery scenarios. Catch associated with FMSY (solid line) and FMSY range ($FMSY_{lower}$, $FMSY_{upper}$, dotted lines) reference point levels are indicated. Backgrounds are shaded for catch values at or below FMSY (green), between FMSY and $FMSY_{upper}$ (yellow) and above $FMSY_{upper}$ (red). No $FMSY_{upper}$ is defined for HAD and $FMSY_{upper}$ is not considered for stocks below $B_{trigger}$ (COD-NS, POK, SOL-EC, WHG-NS, WIT).

Resolution on headline advice

The group was in favour of adopting a new figure, along the lines of Figure 2.2, for headline advice in 2022. The presentation of the Range results as an additional mixed fishery scenario (e.g. Range/Min) was also favourably received and may improve understanding the possible catch gained via fishing in the upper FMSY range through reduced choking. Nevertheless, it was decided that this addition would not be included in the mixed fishery considerations in 2022, but would be presented to stakeholders in the next scoping workshop on future of mixed fisheries advice (WKMIXFISH2) for additional feedback (see ToR f for further details).

2.2 Transparent Assessment Framework (TAF) updates and improvements

Bay of Biscay

Bay of Biscay case study TAF repository for year 2022 has been created (https://github.com/ices-taf/2022_BoB_MixedFisheriesAdvice), where the code has been restructured to follow the TAF principles. The new repository structure is outlined in Table 2.2, including a list of the scripts, their description and input/output files.

Table 2.2. List of scripts used to implement the data preparation and model for the FLBIEA short-term forecast, details of inputs, outputs and summary notes on each scripts function.

Code	Input	Output	Notes
Data scripts			
data.R			Source all data_*.R files and document functions and software
data_01_BoB_EDA.Rmd	1) Accessions data (\bootstrap\initial\data\accessions\catch_2021.RData and effort_2021.RData) 2) ICES InterCatch files (\bootstrap\initial\data\intercatch\2022 06 03 CATON for stocks with distributions for all WG 2002-2021.csv and 2022 06 03 CATON for stocks without distributions for all WG 2002-2021.csv)	1) .RData of fleet, métier, stock input variables (\bootstrap\initial\data\eff_cat.RData)	Per fleet: - effort, - capacity. Per fleet, métier: - effort share. Per fleet, métier, stock: - total landings, - total discards.
data_02_BoB_Data.R	1) Output from data_01_BoB_EDA.R	1) Catch and effort final data (\bootstrap\initial\data\catch_effort.RData) 2) Fleet-metier combinations (\bootstrap\initial\data\fleet_metiers.csv)	Do some checks and compare catch data with WG's catch info.
data_03_BoB_FLR_Objs.R	1) Catch and effort data from data_02_BoB_Data.R	FLR input objects for FLBEIA (\bootstrap\initial\data\FLR_Objs.RData): 1) biols (FLBiols), 2) fleets (FLFleets), 3) SRs (list of FLSRsim) and 4) advice (list)	Creates FLBiols(), FLSRs() and FLFleets() objects. Check input objects' validity.
data_04_BoB_ctrls.R	1) Output from data_02	FLBEIA control objects (\bootstrap\initial\data\ctrls.RData): 1) simultation control (main.ctrl) 2) biols control (biols.ctrl) 3) fleets control (fleets.ctrl) 4) obs control (obs.ctrl) 5) assess control (assess.ctrl)	Create FLBEIA controls

Code	Input	Output	Notes
		6) advice control (advice.ctrl)	
Model scripts			
model.R			Copy required data to data folder and source all model_*.R files.
model_01_BoB_Single_Stock_Forecast.R	Output from model_01 (\data): 1) \data\FLR_Objs.RData 2) \data\ctrls.RData	1) Conditioned FLFLeetsExt object 2) fleets.ctrl	
model_02_BoB_Sims.R	Output from data.R and model_01 (\data): 1) \data\FLR_Objs.RData 2) \data\ctrls.RData 3) \output\Single-Stock_STF.RData 4) \data\Fleets_Correct.RData	FLBEIA runs for MIXFISH scenarios (xx): 1) min 2) max 3) assess control 4) List of FLSRsim objects	Run the alternative MIXFISH scenarios:
Report scripts			
report.R			Source all report_*.R files
report_01_BoB_mixed_fisheries_overview.Rmd	Output from 1) data_02_BoB_Data.R	Production of mixed fisheries overview of CS	
report_01_advice-sheet.R	Output from 1) model_02	Production of advice sheet figures and tables	Pending
report_02_WGreport.R	Output from 1) model_02	Production of QA/QC figures and tables	Pending

Celtic Sea

Details for the Celtic Sea TAF are provided in ToR D, section 5.2.

Iberian Waters

TAF skeleton for year 2022 has been created (https://github.com/ices-taf/2022_IW_MixedFisheriesAdvice) and some work for the automatization of data input has been done. The required data for advice was collected and available for download in the 2022 WGMIXFISH ADVICE SharePoint (folder 06. Data.Iberian Waters) using icesSharePoint library in R and it has been stored into the TAF bootstrap/data folder. Original data input source is also specified at the title field in the DATA.bib file. An entry was also created in the SOFTWARE.bib file for FLBEIA v1.15.5.

A lot of effort was dedicated to adjust the scripts to new data input format for hake and megrims which single-species advice was provided by using a different stock assessment model, SS3 for hake and a4a for megrims.

At the time of the meeting, the following data was missing in the TAF bootstrap/data folder to properly run the script 01_MixFish22_IW_Data.R:

- catch and effort data by Portugal (data had some formatting issues)
- ank.27.8c9a and hke.27.8c9a stock information missing in ICES InterCatch files
- Anglerfishes and megrims landings proportion by species estimated by year, quarter and gear, based on regional sampling, still not applied to correct Portugal submitted landings at the species level.

North Sea

During 2021 the North Sea changed modelling framework, from Fcube to FLBEIA. This change required the creation of several new scripts in the 2021 TAF repository both for comparison between the two methodologies and to produce the advice based on FLBEIA. During the 2022 meeting the TAF repository for the North Sea model has been cleaned by removing old scripts that are not going to be used in 2022 for the advice production. The organization of the repository has also been improved in several ways, for example, by reorganizing the subdirectories created by the scripts, by moving all the scripts containing functions to be sourced in the bootstrap folder and by streamlining package loading throughout the entire repository.

Improvements were also made to the output section of the TAF repository which has been modified to be in line with the rest of the scripts. The README file has also been updated with the changes that occurred during last year IBP and ADVICE meeting. Additionally, a few cosmetic changes have been made to the "report.rmd", regarding the style of the tables and figure captions to match the advice report. Finally, a thorough check has also been carried out to check for potential compatibility issues due to the release of the new R version 4.2.

2.3 Calculation of fishing effort

Fishing effort is requested as part of WGMIXFISH data call in two forms: Fishing effort in KWdays (engine power in kW times fishing days); and DaysAtSea (Number of days at sea). The simplistic description of these variables in the data call requires clarity as the calculation fishing days can be strongly influenced by the baseline unit (absence days or activity days) and the methodology used to account for the soak time of static gears (Castro Ribeiro *et al.*, 2016). WGMIXFISH will contact data submitters and request detailed information on how they calculate these effort metrics (see Table 2.3 for an example of the proposed table). This information will be synthesised and an improved wording will be developed for the future data call.

Table 2.3. Proposed structure of clarification effort data request

Country	Metric	Definition in data call	Calculation	Other information / known limitations	Data submitter
Ireland	KWdays	Fishing effort in KWdays, i.e. total metier engine power in kW times fishing days	At the level of fishing operation (métier * day * ICES division). Based on absence days (from the moment they leave port)	Use fecR logic to calculate soak time for static gear but missing gear on many <12m boats. We don’t account for steaming time. This could impact long distance fisheries, or even Porcupine Bank fisheries.	claire.moore@marine.ie
	DaysAtSea	Number of days at sea.	Based on absence days (from the moment they leave port)		
	NoVessels	Number of vessels executing this activity at this level of aggregation.	Based on stratum requested.	There could be duplicates when summing across divisions	

2.4 Provision of stock object data

At the 2021 WGMIXFISH-Advice meeting (ICES 2022) routine diagnostics for the North Sea FLBEIA model revealed some discrepancies between the catches reported to WGMIXFISH (accessions) and the catches reported by WGNSSK (stock object) for Eastern Channel plaice and sole (Figure 2.6). Catches for 2020 (last data year) in the WGMIXFISH data were ~50% higher than those reported in the stock object. In FLBEIA, the catches in 2020 are the reference from which the catchabilities of the fleets are calculated (based on catches-at-age and effort per fleet). Therefore, higher catches in 2020 resulted in higher catchabilities in the fleet object than would have been calculated from the WGNSSK catches. This then influenced the fishing mortality (Fbar) estimated by FLBEIA which were seen to be much higher for these two stocks than reported in the single stock advice.

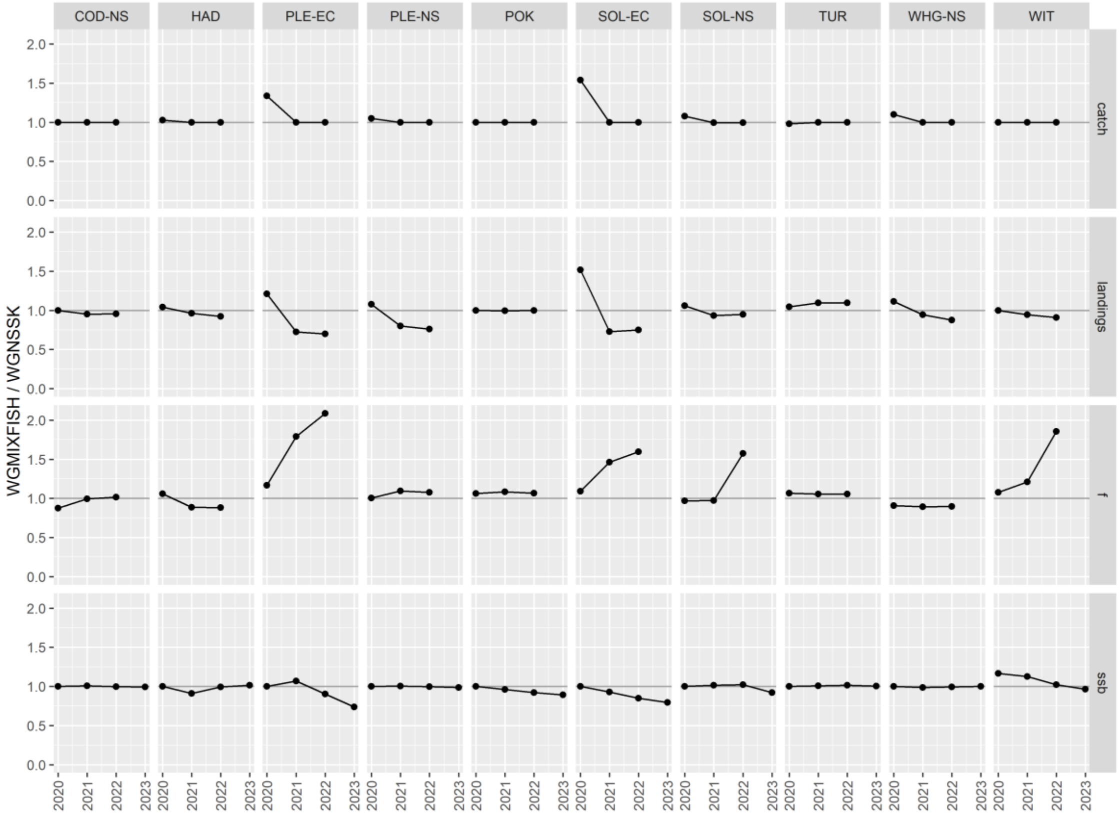


Figure 2.6. North Sea. Diagnostic plot from WGMIXFISH-ADVICE 2021 comparing single stock forecast results (WGNSSK) to the mixed fisheries forecast (WGMIXFISH) results for total catch, landings, fishing mortality (f) and spawning stock biomass (ssb) for stocks included in the North Sea model.

It was thought that the issue might come from whether observed or estimated catches were being provided to WGMIXFISH. This prompted two concerns:

1. that greater clarity was needed on the exact source of data WGNSSK stock assessors are providing (observed catches or model estimated catches);
2. which data source is the most appropriate for use as input to the mixed fisheries scenarios.

To address these issues a form was sent to stock assessors from WGNSSK, WGCSE and WGBIE to collect details on the data provided to WGMIXFISH. We would like to express our gratitude to the stock assessors for providing this information. The results from the return of the forms showed that while the majority of stock assessors were providing observed catches a large proportion were providing model estimated catches.

The primary use of the stock objects is as inputs to the mixed fisheries models. Using model estimated catches rather than observed catches is more consistent with the procedures used to produce the single stock advice. The catches as estimated by the stock assessment model are used as the input to the short-term forecasts and so using them as input to the mixed fisheries models ensures the same starting point as the single stock forecasts. Furthermore, the model estimated catches would be consistent with the associated estimated fishing mortalities.

The stock objects are also used to check the total catches in the fleet data against those reported by the single stock advice WGs and so provision of observed catches would aid this process. When discrepancies are found between the fleet data and the stock object catches the fleet data are “topped up” with the missing catches by adding those catches to an ancillary fleet (usually called “OTH_OTH”). Access to the observed catches may still be useful for identifying the source of these differences which may inform on the method used to account for missing catches. Additionally, during the discussion on stock data sources it became apparent that there is a need for a scaling down procedure for the opposing situation (i.e. where the catches in the fleet data exceed the stock object catches). Observed catches, in addition to information from the stock assessor, may be useful for correcting for excess catches in the fleet data appropriately.

The final consensus was that the model estimated catches are most appropriate data source for WGMIXFISH. Stock assessors for the relevant stocks were contacted to request an updated stock object containing model estimated catches instead of observed catches. In the first instance, alternative sources of observed catches will be investigated to prevent overburdening the stock assessors with data requests. Finally, a "scaling down" procedure for the fleet data should be developed.

2.5 Methodological framework

A new *WGMIXFISH Methodological Framework* document was drafted prior to this year's meeting with the purpose of defining "best practices" for the developing models for use in mixed fisheries advice. The focus is on documenting broader methodological approaches that span across case studies and have been approved and adopted by the working group. This includes guidance according to differing levels of data quality, which can guide case studies in decisions concerning model conditioning and forecasting. Currently, the document is divided into sections covering: 1. Input data (stocks, catch, effort, data merging), 2. Model conditioning (stocks, fleets and metiers, fleet behaviour), 3. Scenarios (reproducing single stock advice, mixed fishery scenarios), and 4. Further methodological options (e.g. procedures for different stock categories, zero-catch advice scenarios).

Case studies will continue to document specific model configurations in their respective annexes, but could eventually cite the Methodological Framework when describing the rationale for specific decisions. In addition to guiding model development of existing case studies, the document is expected to be of particular use to the development of new case study models (e.g. see ToR e). The group plans on releasing the first public version of the document at the conclusion of the method meeting next year.

2.6 Summary of WGMIXFISH data submission

A total of 15 countries submitted data to the WGMXIFSH data call. Three of these submissions were late and will be reported to ACOM as so. All submitted data has been quality controlled using the Rmarkdown developed by WGMIXFISH. This Rmarkdown produces a QC report per country, providing an overview of consistency and trends in reported species, metier, landings and effort over time. These reports are available through the ICES Transparent Assessment Framework (https://github.com/ices-taf/2022_wgmixfish_accessions).

Planned developments for 2023 will focus on streamlining these quality control procedures to ensure that it requires less resources such as man-hours. A smaller QC script will be developed to provide directly to data submitter for application to their own data prior to submission. This should reduce the amount of time required by the working group in processing and cleaning the data.

Future data call improvements were also discussed. The working group would like to prepare for future needs and requests by expanding the number of species requested. However, this will be addressed in future years when we move to using the RDBES as a data source. In the interim WGMIXFISH will approach the RDBES core group to determine what steps need to be taken to prepare both the RDBES and WGMIXFISH for this transition. Consideration will need be given to the resolution of data to which WGMIXFISH will have access.

2.7 Advice plan

As per last year an advice plan was drafted during WGMIXFISH-Methods. This plan sets out the stocks to be included, support materials and accounts for all information learned from the single species advice production process such as the availability of stock information and benchmarking processes. The key responsibilities per advice region have been identified and allocated members of the group. An online meeting has been scheduled (5th Sept 2022) ahead of the WGMIXFISH-ADVICE 2022 meeting to provide an opportunity to discuss any data and model conditioning issues encountered and share developments on any intersessional work relevant to the outputs of the Advice meeting.

Bay of Biscay

Advice 2022	Yes	ank.27.78abd, bss.27.8ab, hke.27.3a46-8abd, hom.27.2a4a5b6a7a-ce-k8, mac.27.nea, meg.27.7b-k8abd, mon.27.78abd, nep.fu.2324, pol.27.89a, sdv.27.nea, sol.27.8ab, whb.27.1-91214, whg.27.89a
TAF repo	Yes	https://github.com/ices-taf/2022_BoB_MixedFisheriesAdvice
Stock Annex	Yes	Stock Annex: Bay of Biscay Mixed Fisheries Annex (figshare.com)
Subgroup leader	Sonia Sanchez, ssanchez@azti.es	
Advice Meeting Participants	Sonia Sanchez, ssanchez@azti.es Dorleta García, dgarcia@azti.es Youen Vermard, youen.vermard@ifremer.fr	

Celtic Sea

Advice 2022	Yes	ank.27.78abd, cod.27.7e-k, had.27.b-k, whg.27.7b-ce-k, sol.27.7fg , nep.27.7bk , hke.27.3a46-8abd, meg.27.7b-k8abd ,mon.27.78abd
TAF repo	Yes	https://github.com/ices-taf/2022_CS_MixedFisheriesAdvice
Stock Annex	Yes	mix.cs_SA.pdf (ices.dk)
Subgroup leader	Paul Dolder, paul.dolder@cefas.co.uk	
Advice Meeting Participants	Claire Moore, claire.moore@marine.ie Lionel Pawlowski, Lionel.Pawlowski@ifremer.fr Mikel Aristegui-Ezquibela, Mikel.Aristegui@Marine.ie Paul Dolder, paul.dolder@cefas.co.uk Johnathan Ball, johnathan.ball@cefas.co.uk Miren Altuna, maltuna@azti.es	

Iberian Waters

Advice 2022	Yes	ank.27.8c9a, mon.27.8c9a, ldb.27.8c9a, meg.27.8c9a, hke.27.8c9a, hom.27.9.a
TAF repo	Yes	https://github.com/ices-taf/2022_IW_MixedFisheriesAdvice
Stock Annex	Yes	Stock Annex: Iberian Waters Mixed Fisheries Annex (figshare.com)
Subgroup leader	Hugo Mendes hmendes@ipma.pt	
Advice Meeting Participants	Hugo Mendes, hmendes@ipma.pt Margarita Rincón Hidalgo, margarita.rincon@csic.es Cristina Silva, csilva@ipma.pt Santiago Cervino, santiago.cervino@ieo.csic.es Paz Sampedro, paz.sampedro@ieo.es	

North Sea

Advice 2022	Yes	cod.27.47d20, had.27.46a20, ple.27.7d, ple.27.4, pok.27.3a46, sol.27.4, sol.27.7d, tur.27.4, whg.47d, wit.27.3a47d, NEP.FU. 5, NEP.FU. 6, NEP.FU. 7, NEP.FU. 8, NEP.FU. 9, NEP.FU. 10, NEP.FU. 32, NEP.FU. 33, NEP.FU. 34, NEP.FU. 4, outside FUs
TAF repo	Yes	https://github.com/ices-taf/2022_NrS_MixedFisheriesAdvice
Stock Annex	Yes	North Sea Mixed Fisheries Annex (ices.dk)
Subgroup leader	Vanessa Trijoulet, vtri@aqua.dtu.dk	
Advice Meeting Participants	Alessandro Orio, alessandro.orio@slu.se Harriet Cole, harriet.cole@gov.scot Klaas Sys, klaas.sys@ilvo.vlaanderen.be Marc Taylor, marc.taylor@thuenen.de Thomas Brunel, thomas.brunel@wur.nl Vanessa Trijoulet, vtri@aqua.dtu.dk Marieke Desender, marieke.desender@cefas.co.uk Jasper Bleijenberg, jasper.bleijenberg@wur.nl Bernhard Kühn, bernhard.kuehn@thuenen.de Côme Denechaud, come.denechaud@hi.no	

Irish Sea

Advice 2022	Yes	cod.27.7.a, had.27.7.a, ple.27.7.a, sol.27.7.a, whg.27.7.a, NEP.FU.15, NEP.FU.14
TAF repo	Yes	https://github.com/ices-taf/2022_IrS_MixedFisheriesAdvice
Stock Annex	No	In development

Subgroup leader	Ruth Kelly, ruth.kelly@afbini.gov.uk
Advice Meeting Participants	Ruth Kelly ruth.kelly@afbini.gov.uk Mathieu Lundy, mathieu.lundy@afbini.gov.uk

3 ToR B: Respond to the outcomes of the Mixed Fisheries Scoping Meeting

Point 1: Progress work on mixed fishery management strategy evaluations; with a focus on key issues highlighted by a global sensitivity analysis, including inter alia fleet dynamics, catchability conditioning and inclusions of technical measures in management strategies. These issues should be considered by WGMIXFISH-Methods.

3.1 Discussions held with other expert groups

WKMIXFISH identified opportunities to increase collaboration and cross-working with other ICES expert groups on issues where WGMIXFISH would benefit from wider expertise. A series of recommendations were made to stimulate discussion and methodological development in relation to priority areas, including i) the use of more fine-scale spatial information in advisory products and/or models – to WGSFD (working group on spatial fisheries data), ii) the incorporation of economic information in mixed fisheries models and the production an economic impact assessment of mixed fisheries scenarios – to WGECON (working group on economics), and on iii) incorporation of the effects of gear changes on selectivity in mixed fisheries models – to WGFTFB (working group on fishing technology and fish behaviour). Feedback was provided to the group on progress in these discussions.

i. Initial contact with WGSFD was made immediately following WKMIXFISH in March 2020, but only limited progress has been made in advancing the collaboration. This is due to a lack of opportunity to meet and discuss the work during national lockdowns arising from the COVID-19 pandemic. To progress this topic requires a series of meetings for i) data scoping, ii) data acquisition, and iii) development of prototype data products. It was suggested now that there is a resumption of in-person meetings it would be a good time to reinitiate this work.
ii. A discussion was held with WGECON during their recent meeting (9–20 May 2022) concerning next steps to progress towards an economic impact assessment approach for presenting results from mixed fisheries scenarios. There was a fruitful discussion that identified the need to establish the demand for economic outputs and what kind of outputs that mangers and stakeholder would want. The need for harmonisation of fleet definitions and data inputs were also raised and identified as a significant issue that would require further work. It was considered that the development of annual economic focused advice products would require significant resource and input equivalent to those for the development of mixed fisheries scenarios, and it wasn't clear that resource was available. However, it was suggested that to progress the idea WGECON could develop a design for a parallel advice sheet equivalent to mixed fisheries considerations that summarise important economic impacts of scenarios. This could then be used to demonstrate to managers and stakeholders the added value in developing this advice, and to receive feedback at the planned WKMIXFISH2 workshop.
iii. Following initial contact with WGFTFB there has been limited opportunity to progress this topic, as WGFTFB postponed their 2022 meeting due to external events and instead had a one-day update meeting. The expectation is to hold this discussion at a future time.

3.2 Uncertainty

Mixed fisheries forecasts are typically run deterministically, combining stock and harvest rate estimates from stock assessments, stock-specific Total Allowable Catch (TAC), and best-estimates of metier-stock catchability, fleet effort-shares across metiers and fleet-stock quota-shares (Ulrich *et al.*, 2011). Outputs are used to generate advice-products that provide mixed fisheries context to single stock advice, highlighting stocks that choke fleet activity (e.g. ICES, 2022a).

Currently, the effect of uncertainty in input parameter values on model behaviour is seldom investigated, yet poor estimates of strongly influential parameters may have large impacts on model performance. Therefore, investigation of modelled landings variability given input uncertainty and the identification of parameters that strongly influence model behaviour will enhance the quality of mixed fisheries products. This will provide confidence intervals around stock landings for each effort scenario and highlight the parameters that should be estimated with high confidence.

Here, three major sources of fleet dynamics uncertainty: (i) catchability of stocks by fleet metier, (ii) proportional effort-share among fleet metier, and (iii) proportional quota-share, or landings-share, of stocks across fleets, were investigated for an Fcube model for the Celtic Sea.

Uncertainty analysis, quantifying the variability of model outputs given input parameter uncertainty, was carried out by stochastically sampling input parameter values from a suitable probability distribution fitted to historical data (Thompson *et al.*, 1992). A total of 1000 stochastic replicates were sampled for each uncertainty scenario: catchability, effort-share, quota-share, and all uncertainty. Metier-stock catchability was drawn from a truncated multivariate normal distribution using the most recent four years of data to account for covariation in catchabilities among similar stocks for a given metier. Metier effort-share and stock quota-share are compositional data (see Aitchison, 1994); comprising a vector of elements – the proportional share – that sum to one. These were modelled using Dirichlet distributions (Maier, 2021) fitted to the most recent five years of data. Where a linear trend was detected in the historical period, a linear model was used to stochastically predict beyond the historically observed range.

Model output variability depended on the effort scenarios considered (Figure 3.1). For instance, the 'min' scenario, where fleet activity stops when the quota for any stock is consumed, has low variability because the presence of zero-catch advice for cod severely constrains fleet effort irrespective of catchability and effort-share. Moreover, the importance of catchability, effort-share and quota-share for landings variability depended on the stock as well as the effort scenario. As the predominant choke-stock, catchability uncertainty contributed to high cod landings variability in the `status quo effort`, `haddock` and `whiting` scenarios but not the `max` scenario. However, the variability of monkfish landings in the `haddock` and `whiting` scenarios largely depended on effort-share uncertainty, because a proportion of landings were derived from metiers with high specificity for this stock.

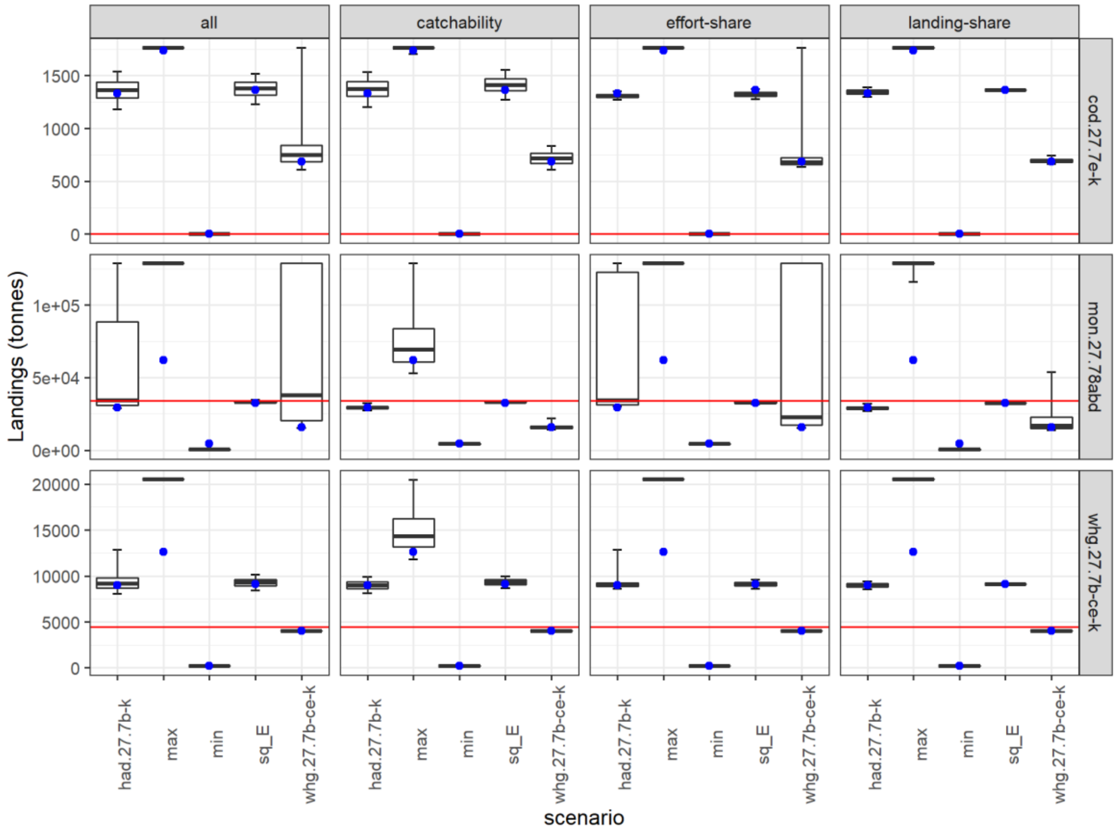


Figure 3.1. Variation in landings of cod, monkfish and whiting given uncertainty in metier-stock catchability, metier effort-share and fleet-stock landings-share under different effort scenarios. Boxes and whiskers span the 50% and 90% confidence intervals, respectively. Median values are shown as black tick-marks within boxes. Horizontal red line represents stock TAC.

Model sensitivity analysis was carried out using the Morris screening method (Morris, 1991). This is a computationally efficient global sensitivity analysis method that identifies influential and interacting parameters (Wu *et al.*, 2013). Fcube sensitivity to parameter variability depended on effort scenario and, following uncertainty analysis results, the landings of most stocks under the 'min' scenario were insensitive to parameter variability (Figure 3.2). Monkfish landings under the `min` scenario, which were not cod-limited, were most sensitive to metier effort-share and fleet quota-share. In contrast, landings of all stocks under `status quo effort` were highly sensitive to metier effort-share and relatively insensitive to both catchability and quota-share. The insensitivity to quota-share is expected given that variation in quota-share does not impact effort under the `status quo effort` scenario.

Uncertainty and sensitivity analyses of mixed fisheries models provide complementary information and should be integrated into future advice-products. Uncertainty analysis outputs may be integrated into headline advice to provide confidence intervals around mixed fisheries forecasts. Overall, sensitivity results suggest that high confidence in the parameterisation of effort-share and quota-share should be prioritised. Further methodological development is necessary to realistically condition future effort-share and quota-share with robust estimates of uncertainty.

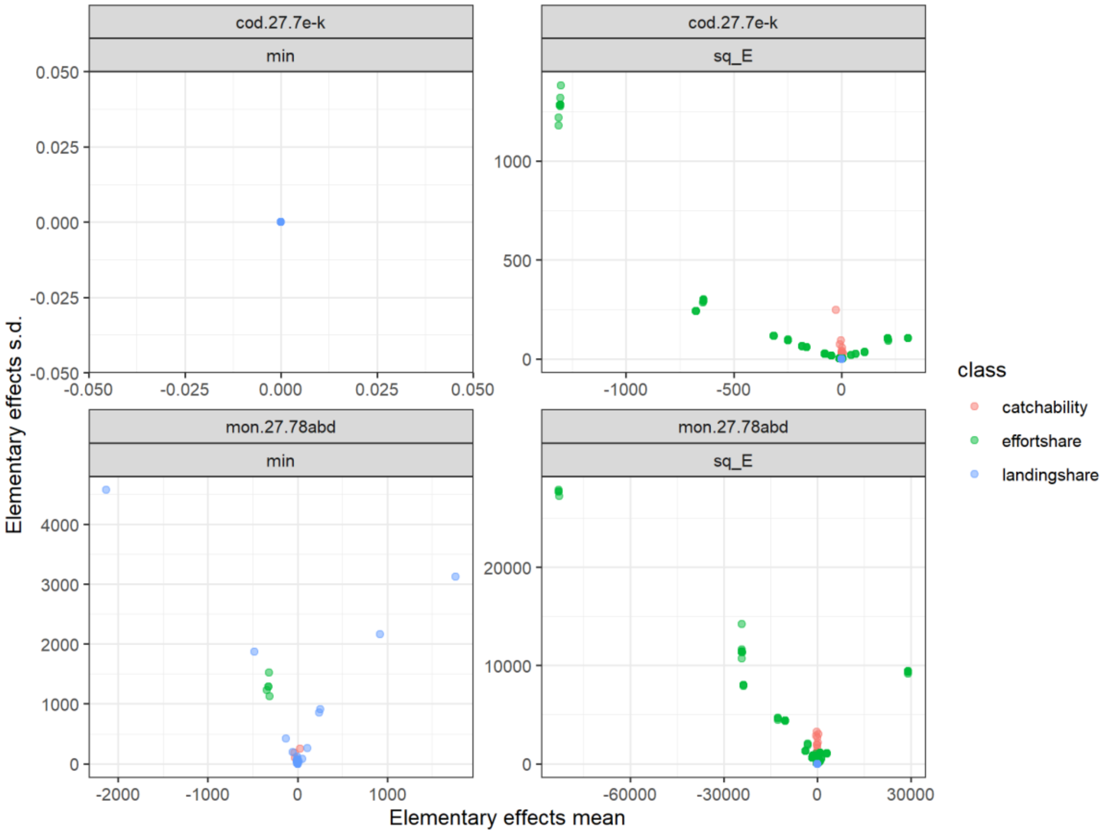


Figure 3.2. Sensitivity of modelled landings to metier-stock catchability, metier effort-share, and fleet-stock landings-share for cod and monkfish under minimum and status-quo effort scenarios. The mean effect of parameters on landings is plotted against the standard deviation of this effect. Values close to zero a limited effect on landings.

3.3 Web-based tools for advice communication

Point 2: Implement ways to communicate the layers of detail (stock level to fleet and individual métiers) through novel application of web-based tools; this allows managers and stakeholders to evaluate impact of different scenarios from different perspectives.

ICES is investing resources in transitioning from static advice product formats (pdf. Word etc.) to more interactive formats that could allow higher interactivity and direct access to visualisations and data by the users. During the past year ICES developed a new Shiny App for the single-stock advice. The app, presented during the meeting, is developed on top of existing ICES databases and web-services (SID, SAG, GIS, and Advice View). The single-stock advice is a fairly standardised product. However, the app, while maintaining the core standardised graphics of the pdf version, allows the user to inspect the plots more interactively, to test visually the effects of different scenarios, and most importantly, makes it easier to access correlated ICES products (for example: fishery overviews, ICES Vocab, SAG data, Advice View data). Furthermore, web-based applications like Shiny App provide increased flexibility in targeting a wider range of stakeholders, from managers and scientists to the general public.

The WKMIXFISH-METHODS participants can see how an interactive product of this type could benefit the presentation of WGMIXFISH scenarios, which are inherently less formally structured than the single-stock advice. During the meeting a few basic tests were conducted to display how the MIXFISH headline figure could work within a Shiny App format, giving the user the ability to choose which data to visualise and compare.

4 ToR C: Exploration of developments in methodology and advice

4.1 Quota share and choking (FIDES)

The common practice at WGMIXFISH is to assume that TACs in the coming year will be shared amongst countries and fleets with the same allocation as observed in the latest available landings data. This assumption has been challenged by the several stakeholders (in the North Sea) who claimed that their landings do not reflect their quota shares for some species, such as cod (the most frequent limiting stock in recent years), for which they generally under-use their quota (and sometimes also trade it for other species). In those instances, using an allocation based on recent landings could potentially lead to a wrong diagnostic on the choking effect of these stocks, as the actual quota share of these countries is higher than estimated based on their recent landings.

In an attempt to solve this problem, we considered using information on actual fishing quotas and exchanges to reflect the actual fishing opportunities of the countries instead of their recent fishing practices. This was done using the Fisheries Data Exchange System (FIDES) which is the official register of quotas and monitors quota exchanges in the European Union. It provides, on an annual basis, the initial quota (based on relative stability) and final quota (after exchanges and transfers) at the species and country level for all the species managed under a quota regime.

This data was first investigated by WGMIXFISH in 2018 (ICES, 2019) and used in FCube to deliver the mixed-fisheries advice in 2019 and 2020, but was then withdrawn in 2021. In this section, we revisit the potential use of this dataset to make assumption on future quota allocation in mixed-fisheries models.

Utilisation of the FIDES database

The data from FIDES contain annual quotas (initial and final) per country by species and for the different management areas of the different commercial species. The North Sea mixed fisheries model takes into account the fleets active in the North Sea (defined as covering ICES subarea 27.4 and divisions 27.7.d and 27.3.a) and also incorporates for each country. Some of the fleets have a “other” métier that is used to aggregate catches from smaller metiers of a country’s fleets. In addition, the mixed fisheries model also has a special fleet named “OTHER” that makes up any differences between MIXFISH data submission and the stock assessments; e.g. mainly catches of Norway (for which no detailed data is available to WGMIXFISH) and catches coming from outside the modelled areas.

A first step to the utilisation of FIDES in mixed-fisheries models consisted in selecting the quotas in the database that corresponded to the stocks modelled by WGMIXFISH, and to assign those of the countries for which the fleets are not explicitly modelled into the OTHER fleet. The aim is to extract data that corresponds to the structure of the FLEET object used in the model.

As there is not an exact overlap between management areas and stocks, the sum of the quotas selected from FIDES did not exactly match the TACs for the stocks modelled by WGMIXFISH (Figure 4.1).

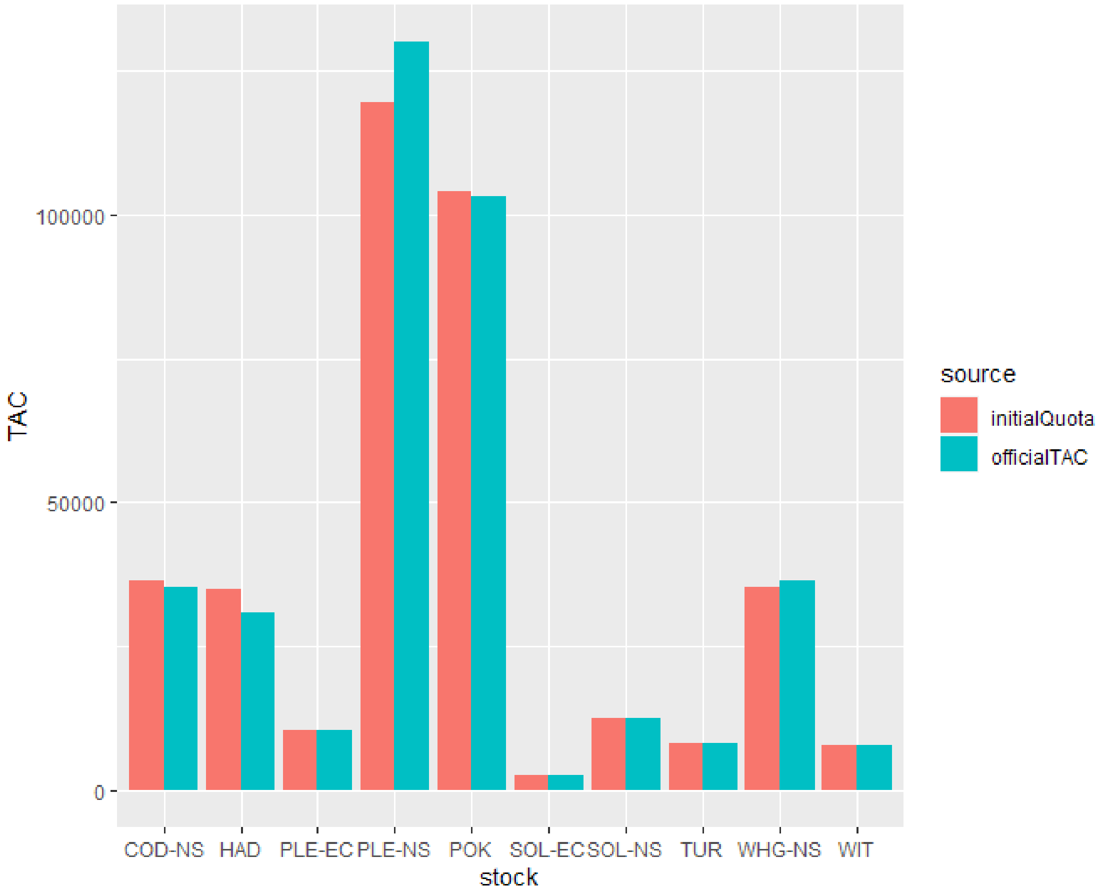


Figure 4.1. Sum of the quotas selected for the North Sea from FIDES and official TACs set for the year 2019.

Exploration of recent variations in quota share, quota exchange and quota consumption

In order to compute a country's initial and final shares of the TAC by stock, "Species.code" [species definition, without additional stock information] and "Area.description" [management area] columns in FIDES were aggregated by country and stock. Because management areas are quite complex to deal with and that management and assessment areas are not always consistent, some discrepancies might appear in Figure 4.2 (e.g. for whiting where the degree of variation in the quota share is inconsistent with the concept of relative stability), but it was consistent for most country/stocks. Figure 4.2 (left panel) shows that the initial quota shares (relative stability) were stable through time for most stocks and countries except for the last few years which shows the impact of the Brexit on quotas redistribution. However, the final share by country is not stable in time (Figure 4.2, right panel). For example, GBR shows an increase its share of COD-NS whereas that of HAD decreases over the period 2008-2020. It is apparent that some countries seem to hardly ever swap quota for some stocks (i.e. GBR for PLE-NS or FRA for COD-NS).

The differences between the initial vs final quotas at country/stock level are shown in Figure 4.3. These differences mostly result from quota swaps between countries but also potential result from spatial flexibility (exchanges between areas for some stocks). However, Figure 4.3 does not show a symmetrical distribution of positive/negative values, ending in a final TAC higher than the initial TAC. The group is currently unable to explain the mechanisms behind this result. Banking and borrowing mechanisms (inter-annual flexibility) may partially explain this but further investigation is needed to fully understand the different types of quota exchanges.

By combining the quotas allocation and landings by stock/country it is possible to assess quota consumption by stock/country. Given that initial and final quotas can be quite different, consumption were compared to both initial and final quota allocation (Figure 4.4). As shown in Figure 4.4, initial quotas are sometimes overshot, especially when quotas are low. However, in most cases, adapting the relative share of quotas (in addition to changes in fishing behaviour) better enables countries to keep consumption from overshooting their final quotas.

In many cases, decreasing trends can be observed in consumption when the catch opportunities increase. This is the case for example for the Dutch catching PLE-NS where the consumption is around 100% with catch opportunities around 20 000 tonnes, but less than 50% when the Dutch quota is above 40 000 tonnes.

Figure 4.2. Initial (left panel) and final (right panel) TAC share by country.

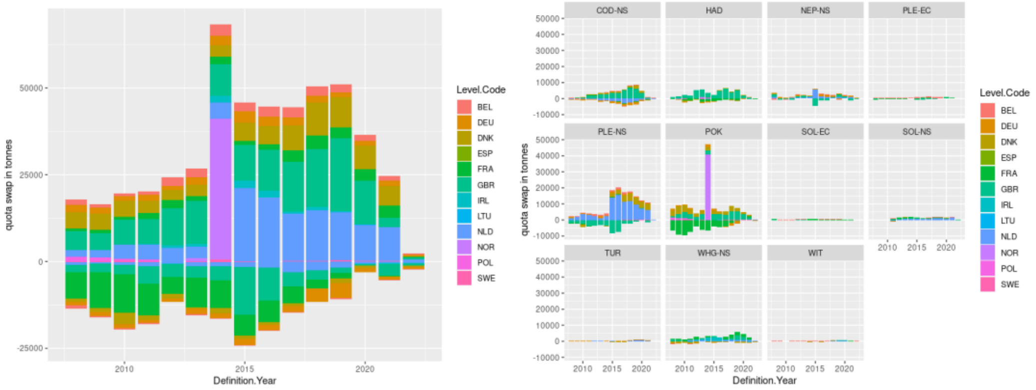


Figure 4.3. Quota swap at country level (left panel) and by stock (right panel).

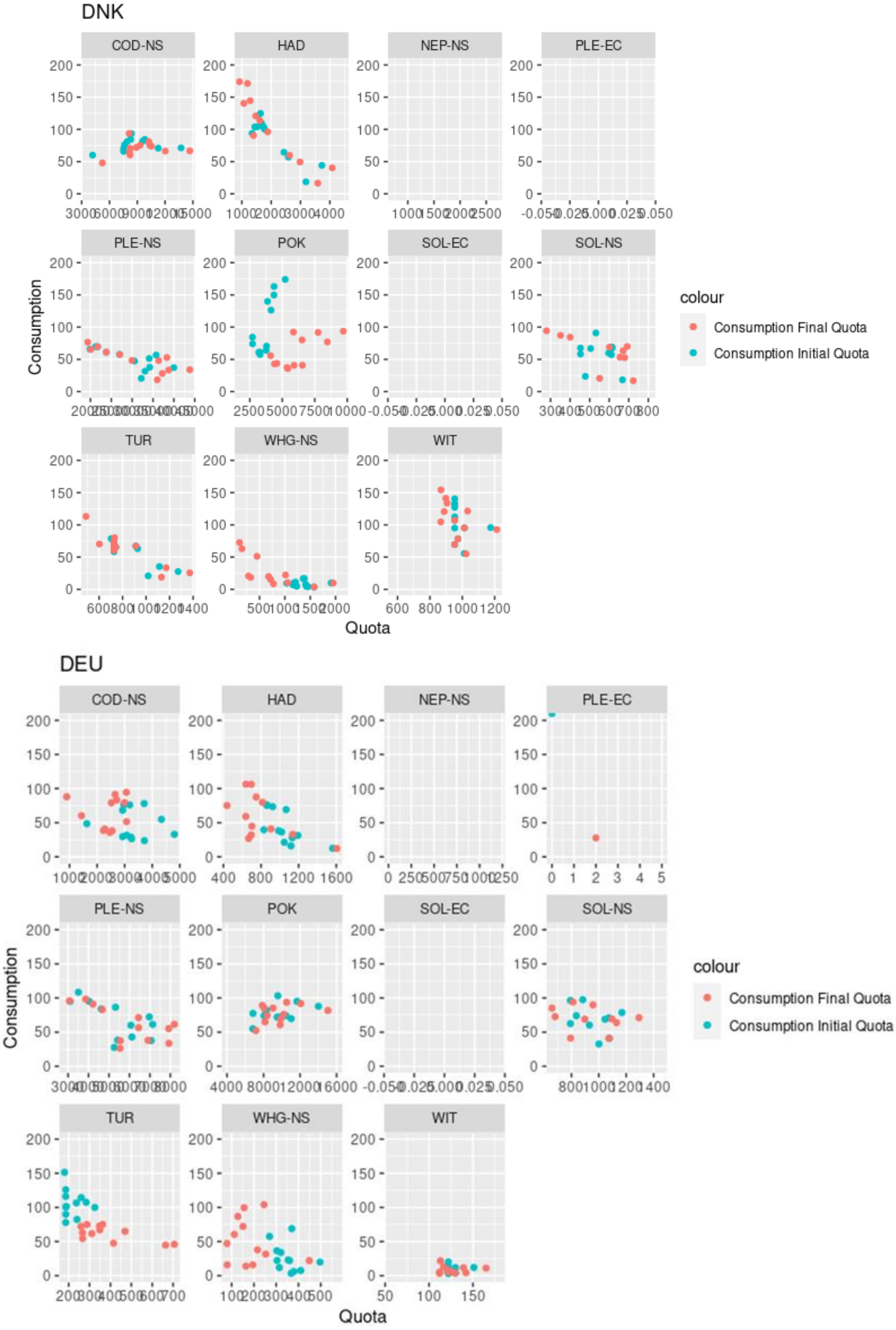


Figure 4.4. Consumption (landings in in percentage) by stock and country in function of initial/final quotas (2008-2021).

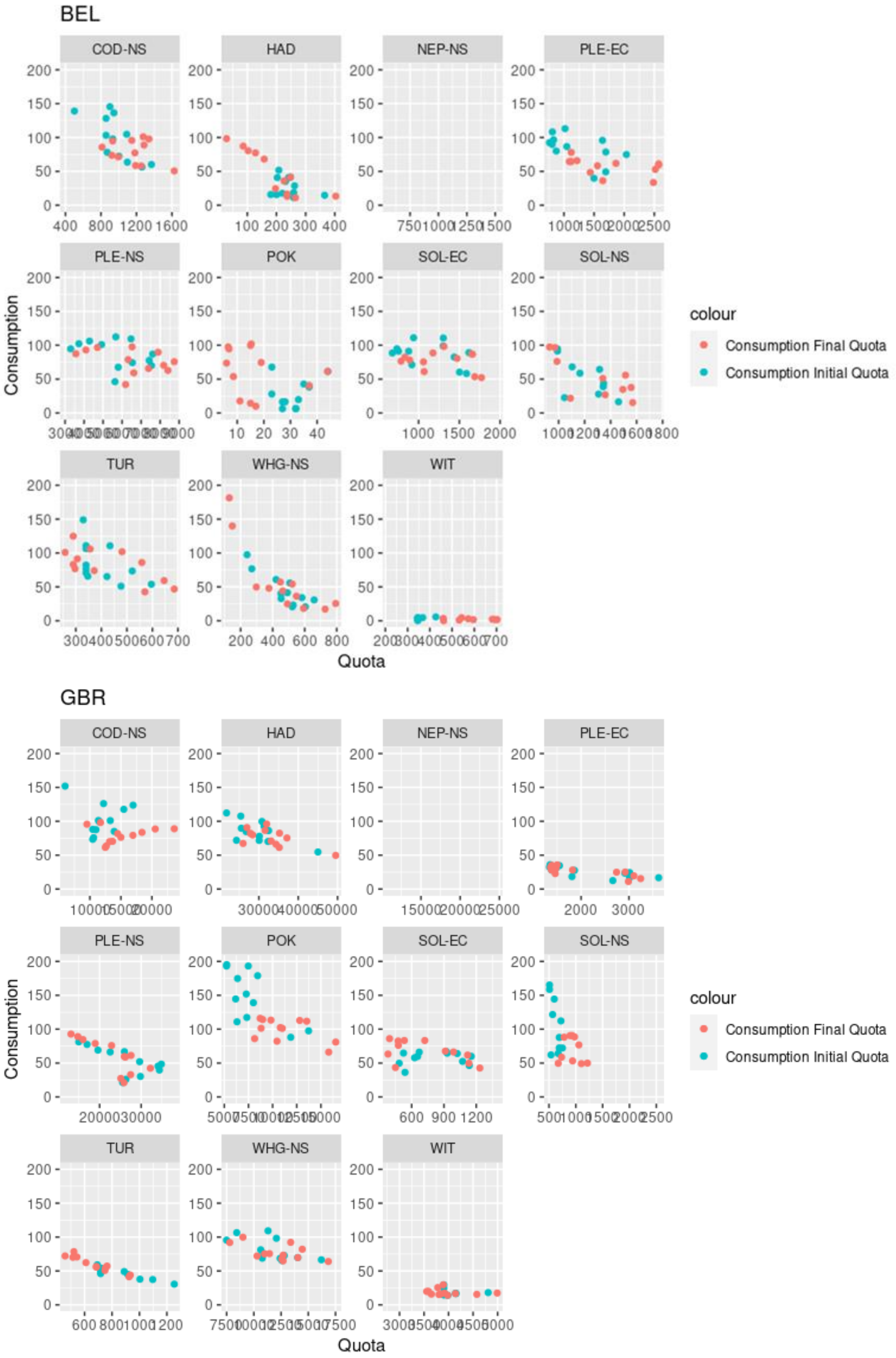
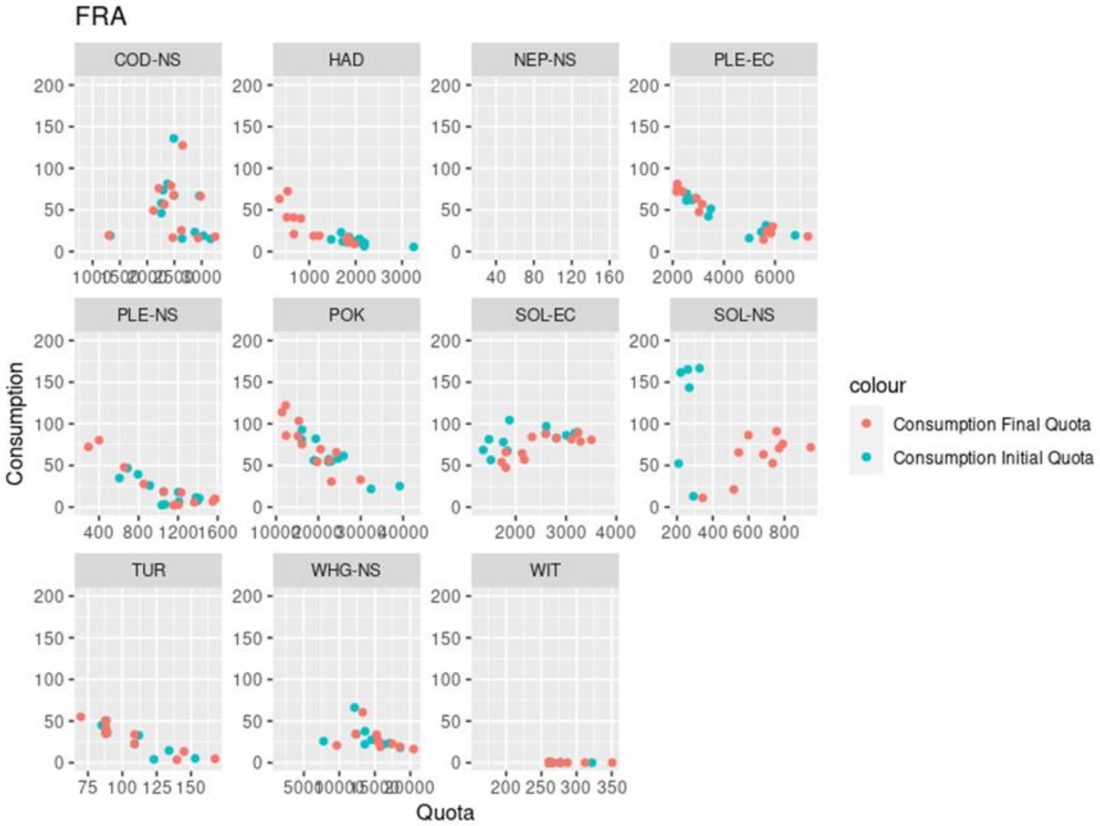
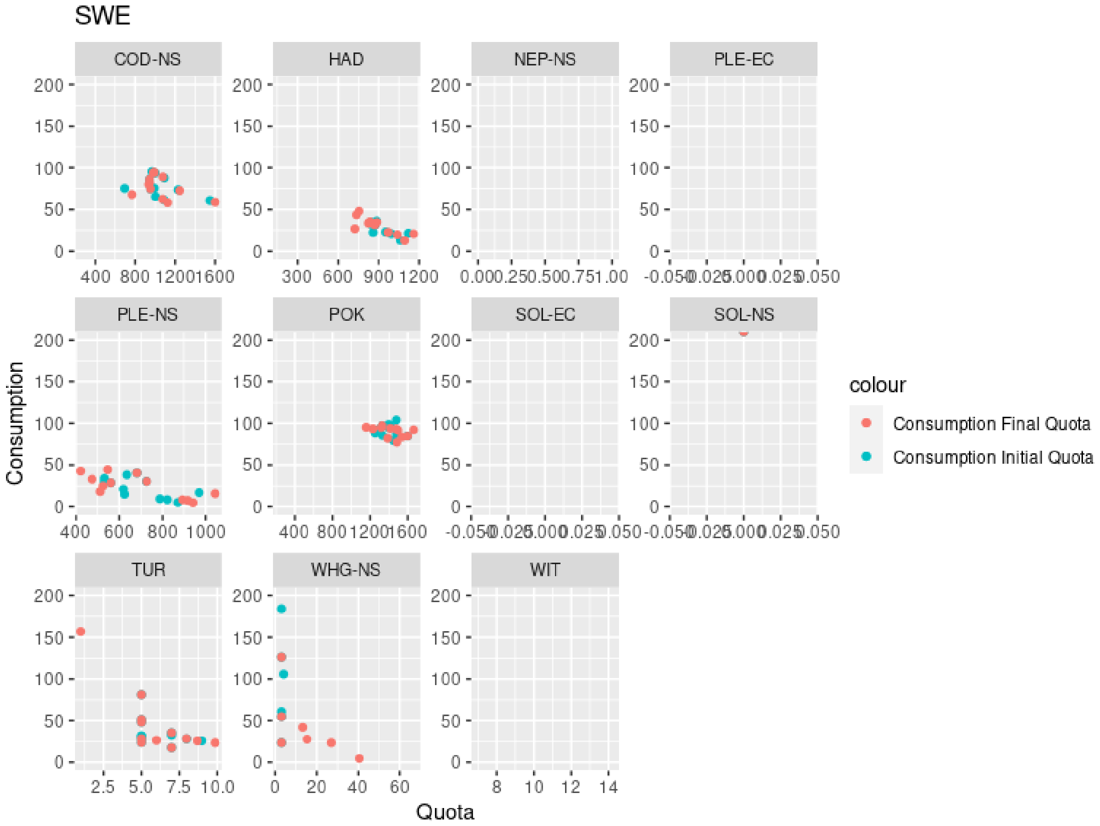


Figure 4.4. (cont) Consumption (landings in in percentage) by stock and country in function of initial/final quotas (2008-2021).


FRA
COD-NS
HAD
NEP-NS
PLE-EC
PLE-NS
POK
SOL-EC
SOL-NS
TUR
WHG-NS
WIT
Consumption
Quota
0
50
100
150
200
1000 2000 3000
40 80 120 160
2000 4000 6000
400 800 1200 1600
2000 3000 4000
200 400 600 800
75 100 125 150
200 250 300 350
colour
Consumption Final Quota
Consumption Initial Quota


SWE
COD-NS
HAD
NEP-NS
PLE-EC
PLE-NS
POK
SOL-EC
SOL-NS
TUR
WHG-NS
WIT
Consumption
Quota
0
50
100
150
200
400 800 1200 1600
300 600 900 1200
400 600 800 1000
2.5 5.0 7.5 10.0
0 20 40 60
8 10 12 14
colour
Consumption Final Quota
Consumption Initial Quota

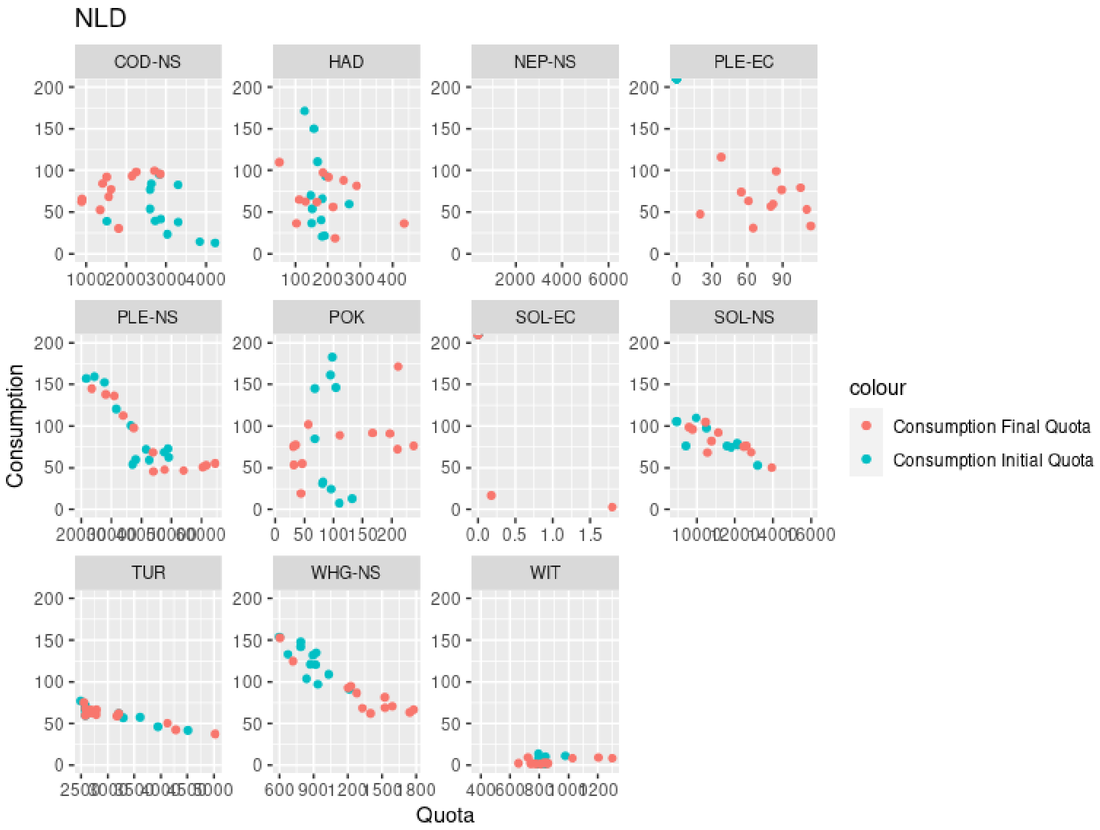


Figure 4.4. (cont) Consumption (landings in in percentage) by stock and country in function of initial/final quotas (2008-2021)s.

Explorations of alternative approaches to set future quota share based on FIDES data (using FCube)

Alternative approaches for the incorporation of the FIDES information in mixed fisheries forecasts

- The approach used for the 2019 and 2020 advice consisted in using the initial quotas from FIDES to compute quota shares per country corresponding to the relative stability allocation key. This national quota shares were then used to split the target F used to produce the TAC advice of each species into partial fishing mortalities of each country corresponding to the future TAC advice. This fishing mortality, Fnext, would be the expected fishing mortality of that country in the advice year, if it caught its official share of the quota:

$$Fnext_{country.stock} = quotashareFIDES_{country,stock} \times Ftarget_{stock}$$

On the other hand, making a status quo assumption, it is possible to get a first approximation of the actual partial fishing mortality of this country expected for next year, based on the past effort and catchabilites of its fleets:

$$Fpast_{country,stock} = \sum_{fleets} q_{2017-2019,fleet,stock} \times effort_{2017-2019,fleet,stock}$$

It can then be assumed that countries for which the partial fishing mortality corresponding to the recent activity of their fleets is lower than the partial fishing mortality corresponding to their fishing rights would in principle not be choked by the stock in question. In other words, for a given stock and a given country:

if($Fnext_{country,stock} \geq Fpast_{country,stock}$) {remove stock as possible choke for that country} else {keep stock as possible choke for that country}

The limiting stock then becomes the one that corresponds to the minimum effort for the fleets, and for which $Fnext < Fpast$. In this approach, the quota shares used to compute the efforts of the fleets remain based on the recent landing shares.

- Alternatively, instead of using the FIDES information to alter the list of potential choke species, it can be used to compute a quota allocation key between countries. This can be done on the basis of: 1. the initial quotas (i.e. the actual relative stability allocation keys) or, 2. the final quotas (which also reflect some potential agreements or usual practices on quota exchanges or transfers). Once the allocation key between countries is established based on the FIDES information, the proportional allocation of national quotas amongst its fleets can be done based on their recent landings shares.

The three approaches described above were implemented in FCube (using on the model from the WGMIXFISH 2020) and the outcome are compared below, with a focus on the outcome of the MIN scenario. The Figure 4.5 shows a comparison of the effort of each fleet in the 4 Fcube runs.

- Convential FCube vs. removing unlikely choke species (*qshare_landings* and *qshare_landings and FIDES rm choke* on Figure 4.5)

For the majority of the fleets, the effort is unchanged when unlikely choke species are removed (Figure 4.5). This corresponds to situations where the stock that is the most limiting with the standard FCube approach is not removed from the potential choke stocks (as $Fnext < Fpast$). For example, the Scottish otter trawlers (Figure 4.6) remain limited by their COD-NS quota, and the effort in the modified FCube run is the same as for the standard one.

However, for 3 countries (FR, GE, and NL), the effort is much higher (up to 2 to 3 times) when some stocks are removed from the potential choke stocks. These countries are the one for which recent landings of COD-NS have consistently been lower than their quota, even after trading part of it. Looking at the example of the Dutch beam trawlers (Figure 4.7), where COD-NS has been removed from the potential choke stocks, the fleet is limited by SOL-NS, for which the quota corresponds to a much higher effort, which is closer to the current effort.

In the standard FCube run, the realised fishing mortality for each stock is lower than the *Ftarget* from which the TAC advice was derived (Figure 4.8). As this is the MIN scenarios, the fleets deployed the effort corresponding to their most limiting quota, and the resulting *F* can only be smaller than the *Ftarget* (expect if all the fleet are limited by the same stock, which was almost the case of COD-North Sea in this particular run). When some stocks are removed from the list of potential choke stocks for each country, the effort in the MIN scenario can be higher than the minimum efforts. In the present case, as COD-NS is the main species removed from potential chokes, the effort are either equal or larger than the effort corresponding to the COD-NS quotas. This leads to a situation where the realised F for the COD-NS stock is higher than *Ftarget*, and therefore the TAC would be overshot, which, in principle, should not be the case in the MIN scenario.

- Future quota allocation based on initial quotas in FIDES
  - Basing quota shares on initial quotas leads to higher effort in the MIN scenario for the fleet of the countries that underuse their quota of COD-NS (the most limiting stock in the standard FCube run), and lower efforts for the fleets of the countries that normally tend to acquire additional quota (Figure 4.5). For the latter, such as England and Scotland, the difference in effort is in the range of -10%, corresponding to a more limiting COD-NS quota (Figure 4.5 and 4.6). For the countries normally not

    fishing their quota, the difference of effort can be substantial (e.g. +77% for the Dutch beam trawler fleet that is no longer limited by COD-NS but by WHG-NS, Figure 4.7). These differences of effort lead to a lower fishing mortality for COD-NS (Figure 4.8), as those countries that take most of the catch mainly result in decreased effort. Conversely, for the stocks that are targeted for those countries that have a markedly increased effort (flatfish for the Dutch and German fleets, saithe for France), the fishing mortality (and their TAC uptake) increase. For this run, fishing mortality is lower than the Ftarget for all stocks.

- Future quota allocation based on final quota in FIDES
    - Allocation based on final quotas lead to a slightly different situation compared to using initial quotas: for countries trading their COD-NS quota, the effort in the MIN scenario is slightly lower when allocation is based on final quotas, but remains (much) higher than when allocation is based on recent landings (as they trade part their quota, but generally underuse the remaining part). For the Dutch fleet taken as example, COD-NS becomes limiting again, but at a much higher effort than in the standard FCube run. For countries obtaining additional quota, the effort of their fleet is higher than when allocation is based on initial quotas, and often also higher than when the allocation is based on landings alone (as, they tend to get additional quota, but do not always exhaust it). For the Scottish fleet taken as example, COD-NS remain strongly limiting, at a slightly higher effort than in the standard run.

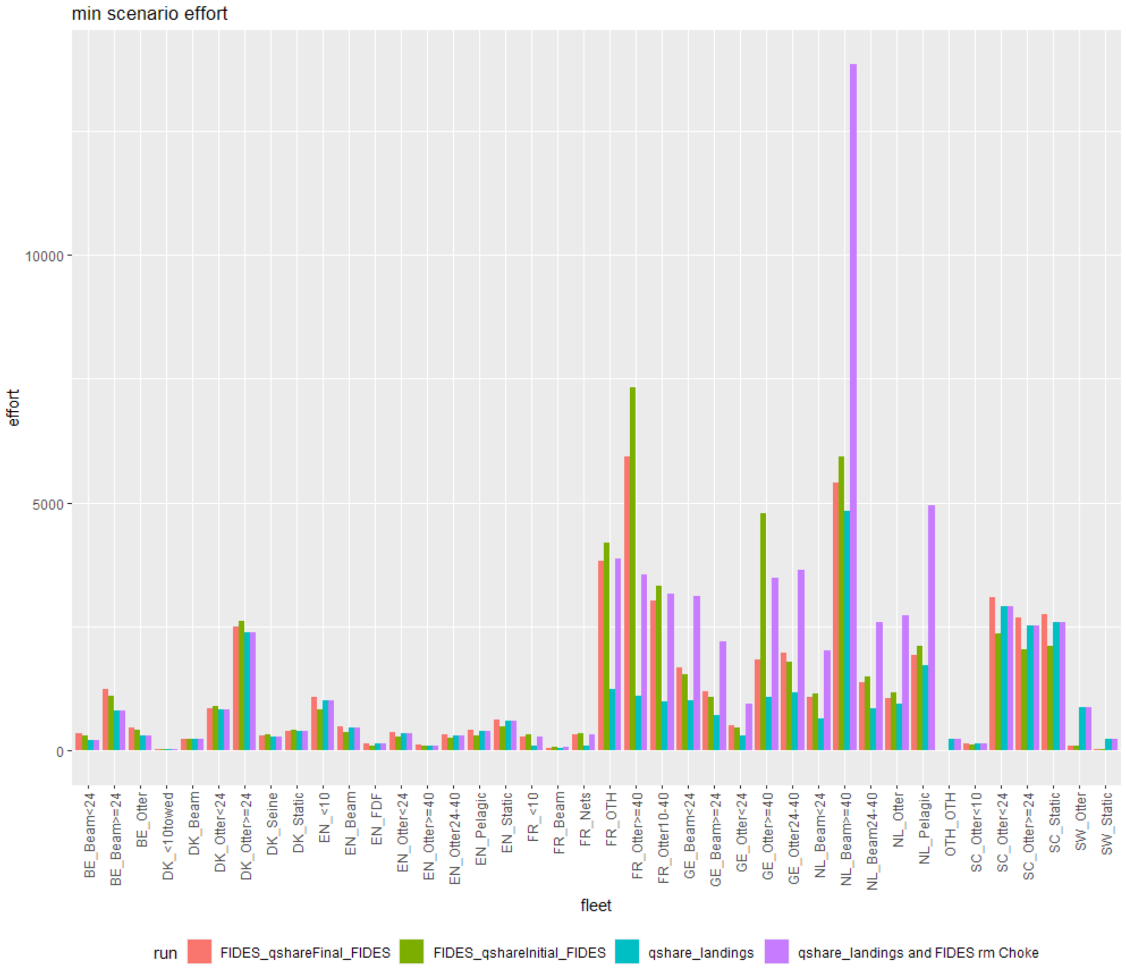


Figure 4.5. effort deployed by the fleets of the North Sea for the MIN mixed-fisheries scenario for 4 different FCube runs : qshare_landing = standard approach, with future quota share based on recent landings share, qshare_landing and FIDES rm Choke = similar to standard approach, but some stocks are removed from the potential choke species for each countries, based on the FIDES data, FIDES_qshareinitial and FIDES_qsharefinal : future quota shares are based on initial and final quotas respectively in the FIDES database.

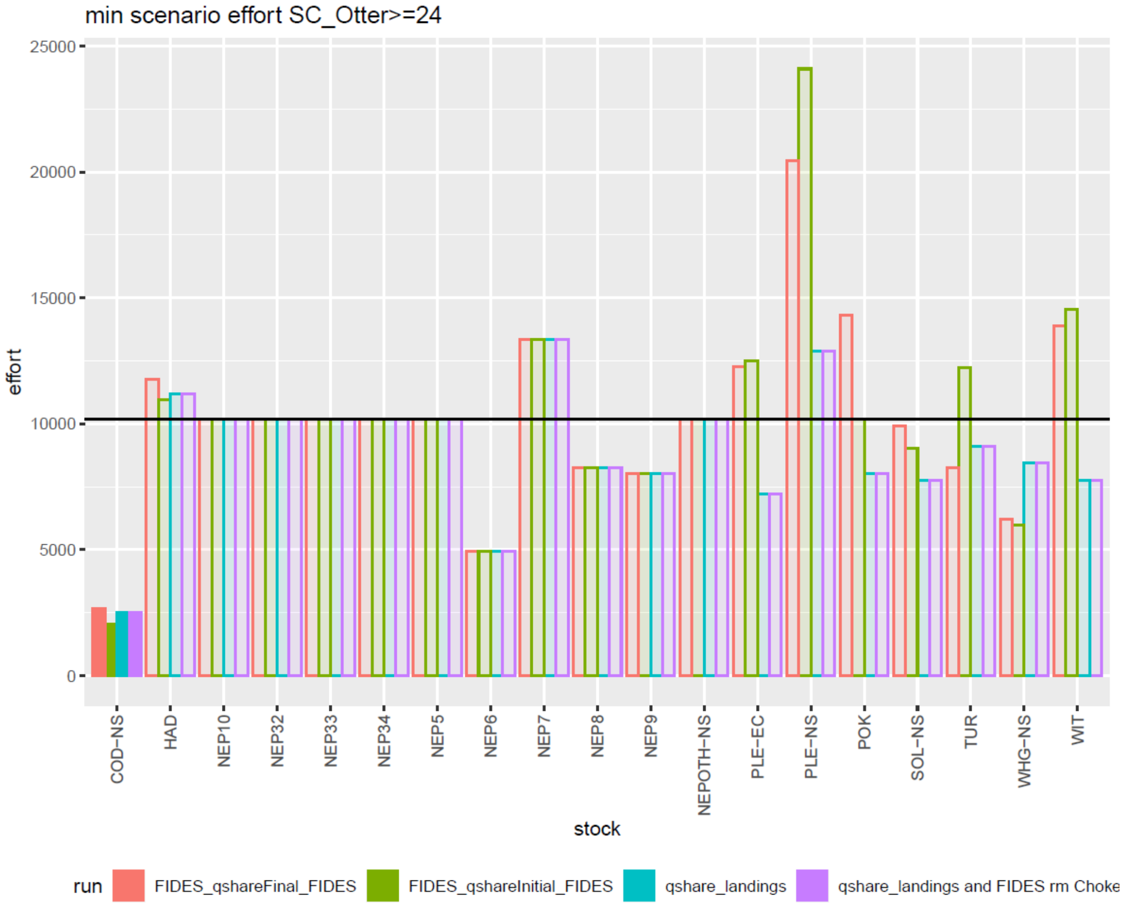


Figure 4.6. Effort corresponding to the quotas of each stock for the Scottish otter trawlers (larger than 24 m) for the 4 FCube runs (non-empty bars represent the most limiting species of each run, horizontal line represents status quo effort).

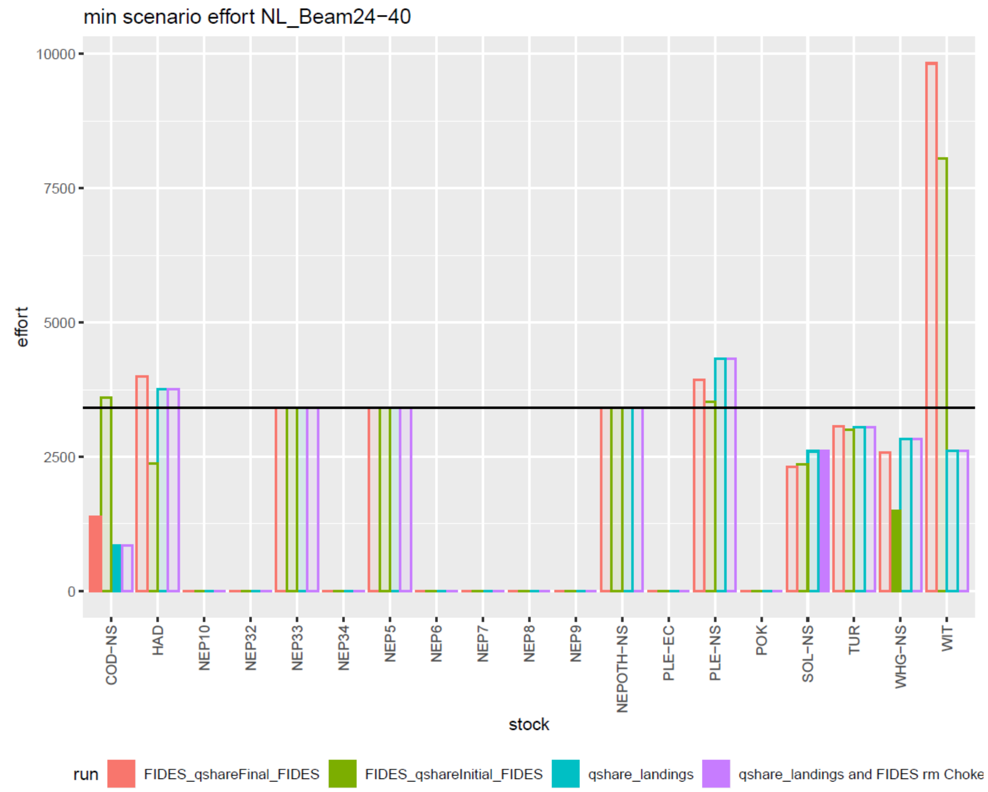


Figure 4.7. effort corresponding to the quotas of each stock for the Dutch beam trawlers (24-40 m) for the 4 FCube runs (non-empty bars represent the most limiting species of each run, horizontal line represents status quo effort).

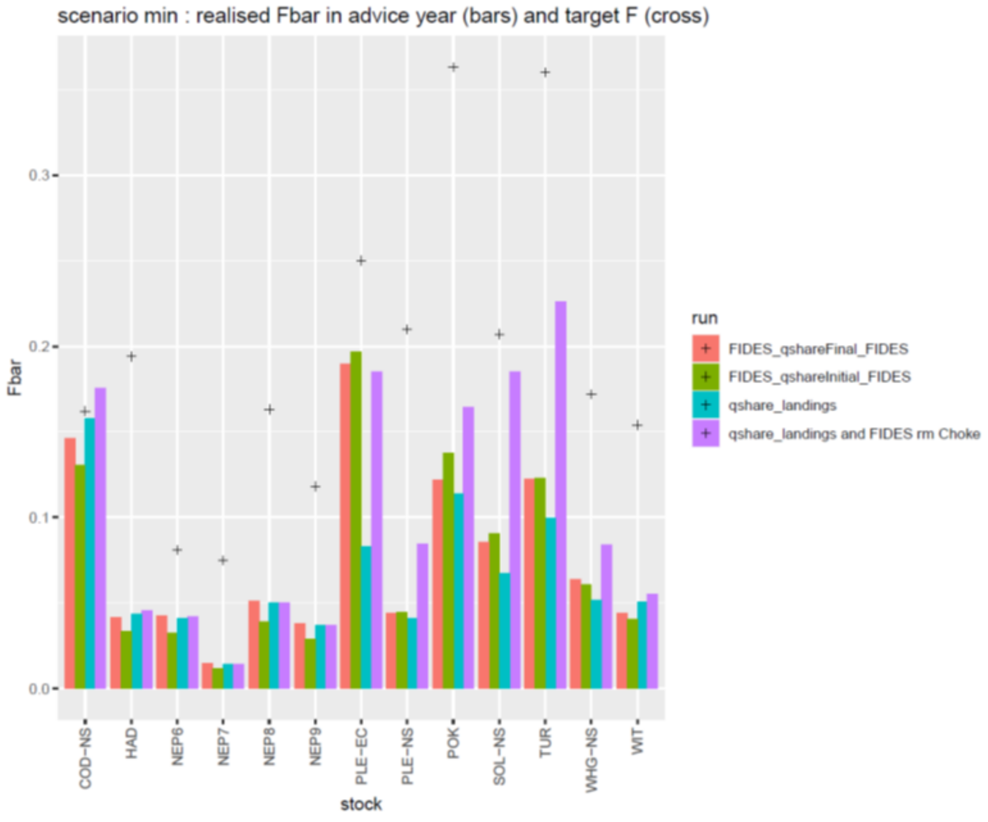


Figure 4.8. realised fishing mortality in the advice year for all stocks in the MIN scenario of the 4 FCube runs, crosses represent the Ftarget on which the TAC was based for each stock

Conclusions

Quotas, swaps consumption

Different strategies are observed with regard to quota trading. The French seem to keep all their COD-NS quota while the Dutch seem to be able to closely align their quota trading with their quota need (Figure 4.4). For countries that buy additional quota, different situations are found. For example, the UK are able to obtain additional quota for the different gadoids stocks, but their landings eventually exceed their initial quota only in the case of COD-North Sea, and there was clearly no need for additional quota for POK and WHG-NS.

Quota consumption is often higher than 100% when considering initial quota, but is normally lower than 100% when considering quota after exchanges, except in some cases, when the TAC (and subsequently quotas) is low. To the contrary, when TAC (and hence quotas) are high, quota consumption, even for target species, can be as low as 50%. Given that quota consumption appears to be rather variable, and the causes of these variations have not been studied yet, it seems difficult to make any assumption on future quota consumption that could be used in the mixed fisheries forecasts.

Pros and cons of the different approaches

The pros and cons of the different approaches tested here are summarised in Table 4.1.

Table 4.1. Summary of pros and cons of the different approaches restricting fishing effort in FCube:

	Pros	Cons
Standard procedure	Quota allocation based on last year's landings might be the best approximation of future landings shares, if the mixed fisheries constraints (i.e. which stock is limiting and by how much) do not change	When used in the MIN scenario, it can be expected that quota consumption and quota trading would differ from the status quo situation. In particular, for countries not fully using their quota for a given stock, they have the possibility to increase their future quotas share if a species is limiting in the MIN scenario. The standard procedure may therefore lead to wrong choke effects when countries are limited by stock for which they underuse their quota.
Removal of non-choking stocks using FIDES	Countries that under-utilize (and possibly trade) their quota of their by-catch stocks when catching their quota for their target species would not typically be choked by these by-catch stocks	Based on an assumption that q and effort do not change dramatically next year, which might be challenged in situation where fishing opportunities for the main target species of these countries would increase (but this can potentially be considered by using an "uncertainty buffer" as for example Fnext > 1.2 Fpast to remove a stock from the possible choke species) Decision made at the country level (so ignoring potential differences between fleets landing composition) Quota allocation still based on last year's landings, only removes stocks from potential chokes but do not alter quota shares. This can lead to situations where Frealised > Ftarget
Quota Allocation based on FIDES initial quotas	Possibly the most accurate representation of real allocation keys and seems therefore a good basis to compute effort in MIN scenario for country consistently under-using the quota for the overall most limiting stocks and therefore identify if they are choke species	For countries who are normally able to obtain additional quota, this approach results in over-constraining effort corresponding to the uptake of quotas for most-limiting stocks

	Pros	Cons
Quota Allocation based on FIDES final quotas	- Use of final quota share (FIDES) considers swaps that are likely to occur also in coming years	- Would not be appropriate if swapping practices suddenly change (e.g. by strong decrease in advised TAC)

Proposed approach for ADVICE

For the MIN scenario, considering that this scenario represents an extreme situation where the activity of each fleets would stop when they reach their most limiting quota, it would seem appropriate to assume that exchanges of quota would differ from the current practices. It seems unlikely that a country for which the fleets may be choked by a certain stock would still decide to trade their quota for this specific stock. Conversely, it is unlikely that it would be possible to acquire additional quota for the choke species. In that context, it seems that making no assumption on future quota exchange, and using a quota allocation based on the relative stability key (i.e. the initial quota from FIDES), represents the approach that is the most consistent with the philosophy of the MIN scenario.

Implementation in FLBEIA

The first necessary step towards producing again a MIXFISH advice that incorporate information from FIDES consisted in establishing the full list of quotas to be included for each of the North Sea stocks. This was achieved during this WGMIXFISH-METH.

The method used to incorporate the FIDES data in FCube for the 2019 and 2020 advice has already been implement and tested in FLBEIA (the same decision based on Fpast vs Fnext is made to restrict the list of potential choke species per country, and list is subsequently passed as an argument for fleet control object in FLBEIA).

Implementing the other approaches presented above (including the preferred one using initial quotas) would require minimal adjustments of the current FLBEIA code.

4.2 FLBEIA developments

A new version of FLBEIA has been released (v1.16), where a function written in C++ has been incorporated in order to improve running times, both in the conditioning process and in the simulation part. The new C++ function, called *fill_flcatches*, reads a FLFleet object, accesses to the indicated métier and stock and fills or updates all data slots needed for the FLCatch part, provided to the function. This function is now called by several FLBEIA functions, such as, *create.fleet.arrays* (fills data for each stock-métier-fleet) and *calculate.q.sel.flrObjs* (computes selectivity parameters) related to the conditioning process and *AgePop.CAA* (computes catches for each projection period), *BioPop.CAA* (computes catches for each projection period) and *CorrectCatch* (corrects catches when Catch > Population) that are used in the simulation part.

This update in the FLBEIA code, has been tested in two case studies; the *ONE* dataset (1 fleet, 1 stock, 1 iter) and BoB Demersal fishery (44 fleets, 28 stock, 1 iter), comparing running times for a 5-year projection simulation. For the ONE dataset, a 10% reduction was achieved, while for the multifleet demersal case study, more than a 70% of the running time was reduced (Table 4.2).

Table 4.2. 5 years projections' running times in seconds for two case studies.

Case study	Old version	New version	Reduction
ONE	3.9	3.5	10%
Demersal	655.5	188.7	71%

Concerning the conditioning running times, the BoB Demersal fishery case study was tested, obtaining more than a 90% reduction in the modified functions (Table 4.3).

Table 4.3. Modified conditioning functions running times in seconds for the BoB Demersal fishery case study.

Function	Old version	New version	Reduction
create.fleet.arrays	1689.6	81.6	95%
calculate.q.sel.flrObjs	2936.2	233.2	92%

The new FLBEIA version is available at https://github.com/flr/FLBEIA/releases/tag/v1.16.

4.3 Catch production model

Management Strategy Evaluation (MSE) simulation-tests the capacity for harvest strategies to deliver on management objectives and is a valuable tool to identify harvest strategies that are robust to a range of future environmental and fishery uncertainties (Butterworth, 2007). A key component in any MSE framework is the implementation of catch advice, accounting for constraints that may prevent perfect advice implementation. Therefore, realistic implementation of catch production is vital for projecting the impacts of dynamic catch advice on stocks. This is trivial in single-stock simulations. Using computationally efficient numerical methods, the fishing mortality required to achieve an advised catch may be rapidly and accurately estimated using the Baranov catch equation after accounting for any implementation error.

However, the implementation of catch advice in mixed fisheries is often constrained by the consumption of quota for a limiting stock that limits further harvesting of remaining stocks. Calculating the partial fishing mortality for a fleet to consume the quota for this limiting stock is challenging because the catch generated is dependent on the activity of all other fleets exploiting this stock. Hence, multi-stock and multi-fleet models typically either ignore fleet effort dynamics or use an analytically tractable discrete-time approximation to estimate catches (e.g. Garcia *et al.*, 2017; Punt *et al.*, 2022). In the latter case, the discrete-time fishing mortality is incompatible with the continuous-time mortality typically modelled with single-stock assessment models because harvesting is considered to occur instantaneously at a defined point in time.

We present a general approach (Figure 4.9) that allows for fishing-mortality-based harvesting in continuous time and is therefore more consistent with single-stock approaches. This approach could be implemented in any mixed fisheries framework and uses numerical optimisation to estimate the fishing effort, and hence partial fishing mortality, required for each fleet to fully consume the quota of the limiting stock.

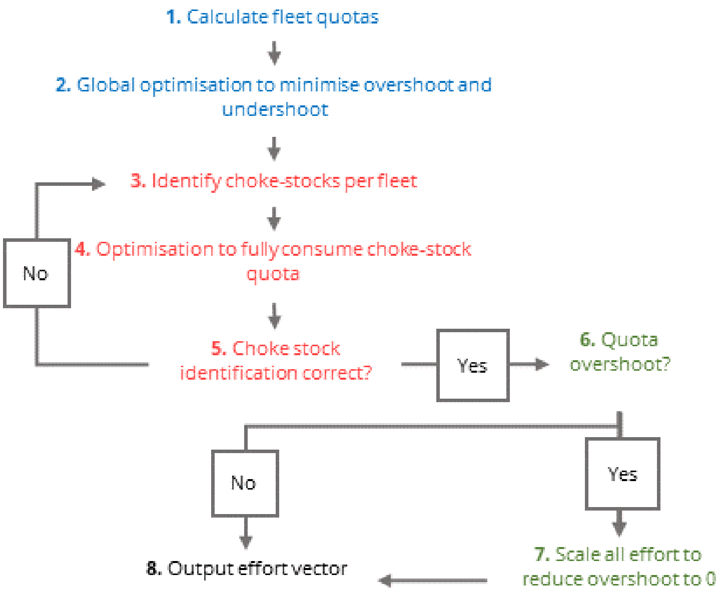


Figure 4.9. Schematic representation of the catch production algorithm, following the sequence: (blue) global optimisation to identify choke-stocks, (red) local optimisation of fleet effort, and (green) optional scaling of effort to reduce residual overshoot.

In essence, given estimates of fleet- and stock-specific quota and catchability, the limiting stock choking effort is first identified for each fleet. This is carried out by globally optimising fleet efforts to minimise both quota overshoot and undershoot, with greater weighting given to overshoot. Given the identified fleet choke-stocks, a second local optimisation is carried out to estimate the fleet effort required to fully consume choke-stock quota. Two checks are then carried out on local optimisation results before returning fleet efforts to the user. Firstly, if results show that the choke-stokes were mis-identified, local optimisation is re-run using updated choke-stocks. Secondly, an optional check of residual quota overshoot allows for a rescaling of overall efforts to reduce overshoot to zero.

Simulation experiments using synthetic data with differing numbers of stocks and fleets demonstrated that this approach satisfactorily optimised efforts for a wide range of fleet and stock combinations (Figure 4.10a). Optimisation quality declined slightly when numerous fleets exploited a small number of stocks, as well as when fleets were allocated a small quota for a stock for which they had high catchability. The runtime depended on the number of stocks and fleets in the optimisation problem. Although runtimes were <1 second for simulations with up to six fleets, these exceeded 12 seconds when 12 stocks and 30 fleets were present (Figure ure 4.10b). This may be prohibitive for complex mixed fisheries models with large iteration counts but could be suitable for both complex mixed fisheries models that are run deterministically and parsimonious mixed fisheries models with stochasticity.

Additional methodological development is required to refine trade-offs between runtime and optimisation quality and implement the method within the FLR environment for easier adoption for mixed fisheries analysis.

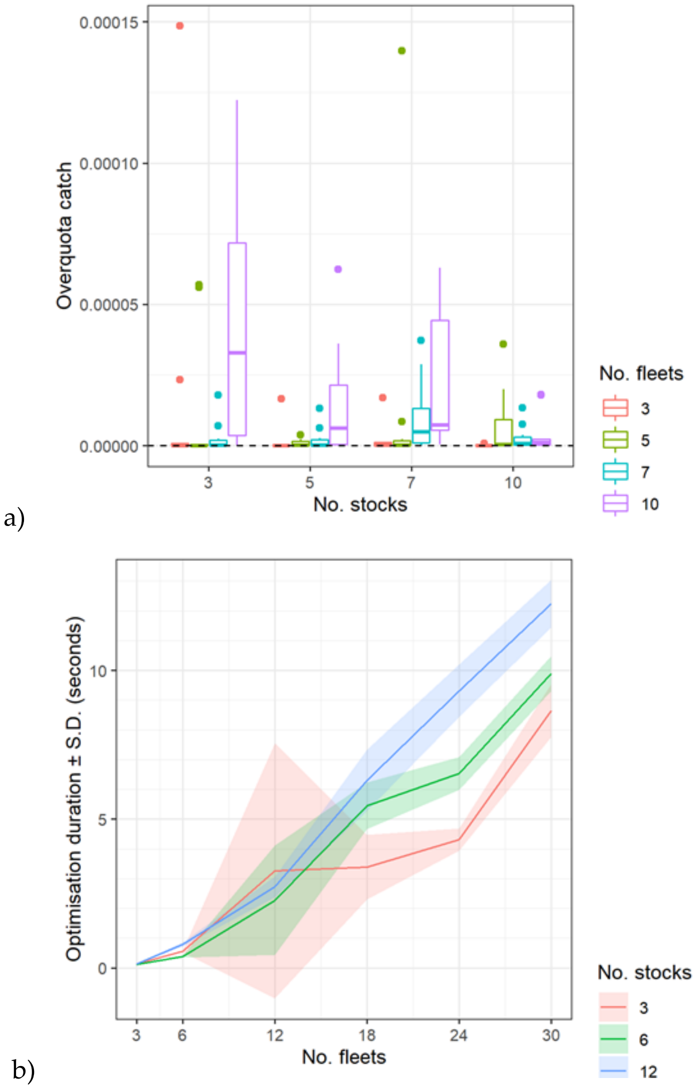


Figure 4.10. Simulation result summaries for synthetic data with different numbers of stocks and fleets showing: (a) residual over-quota catches (tonnes) following optimisation of fleet effort, and (b) algorithm runtime.

4.4 Incorporation of flexible environmentally-mediated stock-recruitment relationships (EMSRRs)

FLBEIA currently only allows to define types of stock-recruitment relationships (SRR) that are available within the FLR-framework. If one wants to include an SRR involving environmental information (environmental-mediated stock-recruitment relationship (EMSRR)) one is currently limited to use a Ricker-SRR involving one covariate (FLR-function: 'rickerCA'). Originating from the work done in the EU-project PANDORA a way to incorporate any EMSRR involving more than one covariate was presented. The procedure involves three steps: First one needs to define a function SR.predict(...) to predict recruitment as a FLQuant-object based on SSB and various covariates. Second, this function needs to be encased in wrapper-function SR.predict.wrapper(...), which is structured like the FLCore-based SR-functions e.g. bevholt or ricker returning the output of the model in a formula-like structure. At last, a call to this function needs to be included in the respective SRs$stock@model-slot of the SR-object and the covariates for future projections stored in the SRs$stock@covariate slot. The method was illustrated on a simple one-fleet/one-stock example involving the effect of two covariates on recruitment (for the whole methodology and a fully reproducible example see Annex 3).

4.5 SPiCT assessments

Several category 3 stocks are scheduled for benchmark assessment later this year using the surplus production model SPiCT (Pedersen and Berg, 2017):

- pol.27.67 Pollack Celtic Seas and the English Channel
- pol.27.89a Pollack Bay of Biscay and Atlantic Iberian waters
- whg.27.89a Whiting Bay of Biscay and Atlantic Iberian waters)
- boc.27.6-8 Boarfish Celtic Seas, English Channel, and Bay of Biscay
- mur.27.3a47d Striped red mullet North Sea, eastern English Channel, Skagerrak and Kattegat)
- bll.27.3a47de Brill (*Scophthalmus rhombus*) in Subarea 4 and divisions 3.a and 7.d-e (North Sea, Skagerrak and Kattegat, English Channel)
- ple.27.7fg Plaice (*Pleuronectes platessa*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea)
- ple.27.89a Plaice (*Pleuronectes platessa*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)
- rjc.27.8 Thornback ray (*Raja clavata*) in Subarea 8 (Bay of Biscay)
- whg.27.3a Whiting (*Merlangius merlangus*) in Division 3.a (Skagerrak and Kattegat)
- meg.27.8c9a Megrim (*Lepidorhombus whiffiagonis*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)
- pol.27.89a Pollack (*Pollachius pollachius*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)

As these stocks may potentially receive quota advice in the near future, it is in the interest of WGMIXFISH to begin consideration of their inclusion in future mixed fishery scenarios. Some examples already exist for translating SPiCT assessments into the FLR framework for use in WGMIXFISH operating models (FCube, FLBEIA). Annex 4 provides some resources for this translation that have been used in related mixed fisher explorations. Since SPiCT operates in continuous time, some degree of incompatibility with the discrete projections used by WGMIXFISH models is to be expected. Further work is still required to address these inconsistencies and likely consequences for forecasts done by WGMIXFISH.

4.6 Fleet and métier definitions and data led approaches

Evaluation of the sensitivity of projected catches under mixed fisheries scenarios to fleet and métier definition and resolution

There was a presentation on the main equations governing the technical interactions in FCube (Ulrich *et al*., 2011). The aim of the presentation was to answer the following questions, using the FCube modelling approach:

- Would the catch projections be any different if we had more or better differentiated métier?
- Would the catch projections be any different if we had more fleets, and under what conditions?

It was established that technical interactions in the model were occurring at the fleet level. This was determined by equation 4 of Ulrich *et al*. (2011):

$$q(Fl, St, Y+1) = \sum q(Fl, m, St, Y+1) \times Effshare(Fl, m, Y+1)$$

So, definitions of métier do not currently impact catch projections, as the fleet level catchabilities are the weighted average of the métier level catchabilities, which is in turn the fleet level catchabilities. Further, it was highlighted that under certain conditioning the scenarios produced by the model are insensitive to fleet definitions. This was particularly the case where assumptions around future share of fishing mortalities were based on past share. That leads to a constant scaling effect for each fleet, where the fleet catches a given stock. For example, if the most restrictive advice requires a 50% reduction in fishing mortality, then all fleets catching that stock require a 50% reduction in effort. Only certain conditions result in different outcomes based on altering fleet definitions. These were:

- Where the quota share is determined by the *landings* share but the choking effect determined by the *total catch*; here differences in fleet level discard rates can affect choking behaviour and therefore limiting stocks,
- Where the landings share for a fleet in a projection period is different to the past landings share (e.g. use the FIDES approach to define initial or adjusted quota allocations),
- where fleet definitions identify a fleet that does not catch a choke stock at all would it likely lead to different catch projections (but this was considered an unlikely outcome, as almost all demersal trawl fleets catch at least some of each of the stocks),
- Where there is dynamics in fishing patterns, either:
    - Where future catchabilities are not conditioned on past catchabilities,
    - Where future effort share is not based on past effort share,

Discussion focussed on the need to consider the impact of model conditioning on catch projections. Either through consideration of how quota shares might differ from past landings shares (e.g. the FIDES approach) or through uncertainty analyses being incorporated in the process of projecting catches. The latter may be a way forward to incorporate considerations around changes in fishing patterns and their impact on stock level catch projections, while acknowledging that we are not able to model fleet behaviour in response to the scenarios presented.

There was also discussion highlighting that appropriately defined fleet and métier were important both to understand and describe recent fleet and fishery dynamics and to potentially identify – with mangers - more informative scenarios based around limitations on certain métier to explore how this would affect stock level catch outcomes. The definition of scenarios was a topic that should be discussed at the future WKMIXFISH2 process, as it was a policy not a science question, so the group would need input into their definition.

Spatial patterns in retained catches in mixed fisheries

Single stock quota limits provide a particularly difficult challenge for mixed-fisheries management. The main issue is the overexploitation of fish when catches of species with available quota continue while species with low quota are discarded. With the introduction of the landing obligation (in force since 2019) all fish caught are counted against quota; this can constrain catch of the available quota, by producing a loss in productivity and economic value (a 'choke' effect). Reducing imbalance in catches of quota stocks in mixed-fisheries relies on the ability to describe the technical interactions between fleets, gears, and species to understand how exploitation of species caught together can be decoupled. Several studies undertaken for the Irish and the French fleets indicate the importance of capturing the right spatial and temporal scale in mixed-fisheries analyses. However, knowledge gaps are present on this type of analysis for the UK fleets.

We present a method to identifying spatial patterns in commercial landings data at a fine-scale by using VMS-linked logbooks data, along with a RShiny App called SPARC "Spatial Application of Retained Catches" developed as a way to visualise this information in a more interactive manner. Analysis was made by using a spatially references 'GeoFISH' database to get data for Beam and Bottom Trawls for UK vessels in 2018-2020 at a 3'*3' spatial scale. Principal Component Analysis (PCA) followed by spatial clustering analysis that takes account of spatial autocorrelation were applied to datasets separately for the West of Scotland, Northern North Sea, Southern North Sea and Eastern English Channel, Celtic Sea and Western Channel, and Irish Sea. Within the data we identified spatial distinct catch patterns in mixed-fisheries, that reflect more nuanced spatial behaviour by fishers.

Results showed a complex spatial structure in the species assemblage which differs by region around the UK, suggesting that there are several special distinct cases of mixed fisheries at UK level. This highlights the importance of analysing spatially resolved fisheries data to understand the complexity of mixed fisheries dynamics and the opportunities to decouple catches of species through changes in fishing patterns. Ultimately, this approach could be used as a tool to better define spatial aspects to fishing métier for incorporation in mixed-fishery management models and ultimately addressing the challenges of mixed-fisheries sustainability.

K means clustering of catch data

Clustering has previously been applied to fisheries data by Moore *et al.* (2019), using Hierarchical algometric clustering (HAC) and determined optimal clustering of fisheries data based on variables submitted as part of ICES data submission (Country, Year, ICES Division, Gear, Target spp., Mesh Size, Vessel Length). The study was able to successfully partitions the data, but points to limitations in the process: Inclusion of only TAC species, lack of spatial information and variation in sampling design and difference in the methods to define target species assemblage between Member States submitting data. A key problem is the spatial aggregation of data available to ICES, which combined with minor variations in national data submission may be masking true patterns of exploitation.

Here we have taken the processes one step further and applied K means clustering, a widely used machine learning algorithm for clustering data in ecology and bioinformatics and applied it to fisheries data at the national level. K means was used to investigate vessel level catch data for patterns or potential grouping naturally occurring based on catch composition. UK fleet data from the Celtic Sea for 2020 was grouped to the vessels unique RssNo for a year and aggregated to species and later species assemblage. The data was scaled and converted to a matrix to allow k means clustering to group the data. Where vessel did not catch a species a 0 value was substituted. Initial clustering based on all species caught within a year revealed no discernible pattern in the data (Figure 4.11)

The lack of any pattern when using all the data is likely a combination of too many species that individually do not drive the clustering, but due to their presence contribute to the muddying of the overall output and the introduction of too many zero values when a vessel does not catch a species present in the landings doing the same. The number of species was then reduced to the principal species included in the Celtic Sea mixed fisheries model, Cod, Haddock, Whiting, Sole, Megrim, Anglerfish, Monkfish, Hake and Nephrops. (Figure 4.12).

Reducing the number of species considered by the clustering functions improves the output, however while there is still a degree of overlap, some groups of vessels begin to emerge from the data. A custom version of the K means plotting function was used to overlay the WGMIXFISH fleet grouping that the individual vessels would normally be assigned to for comparison (Figure 4.13). Comparing and contrasting 4.12 and 4.13, shows that the current Celtics sea fleets do no match well with the underlying data and points towards county gear and vessels size not being sufficiently representative of the underlying pattern of behaviour exhibited in the catch. Rationally this makes sense as the model fleet definitions do not consider any kind of spatial component, and vessels size, while relevant for management consideration does not correlate to a specific pattern of fisheries exploitation. A further weakness of using only the Celtic Sea species is that a large amount of data is excluded, while Figure 4.11. was "messy" the underlying data should not be discounted out of hand, as it still drives vessels behaviour and exploitation of fisheries resources. Mixed fisheries have focused on the headline species requested in the considerations, this has led to the omission of landings data that is still driving vessel behaviour when constructing fleets. To reincorporate this into a usable format for cluster analysis the data was aggregated to species assemblage, PEL, DEF, MOL and CRU and plotted (Figure 4.14).

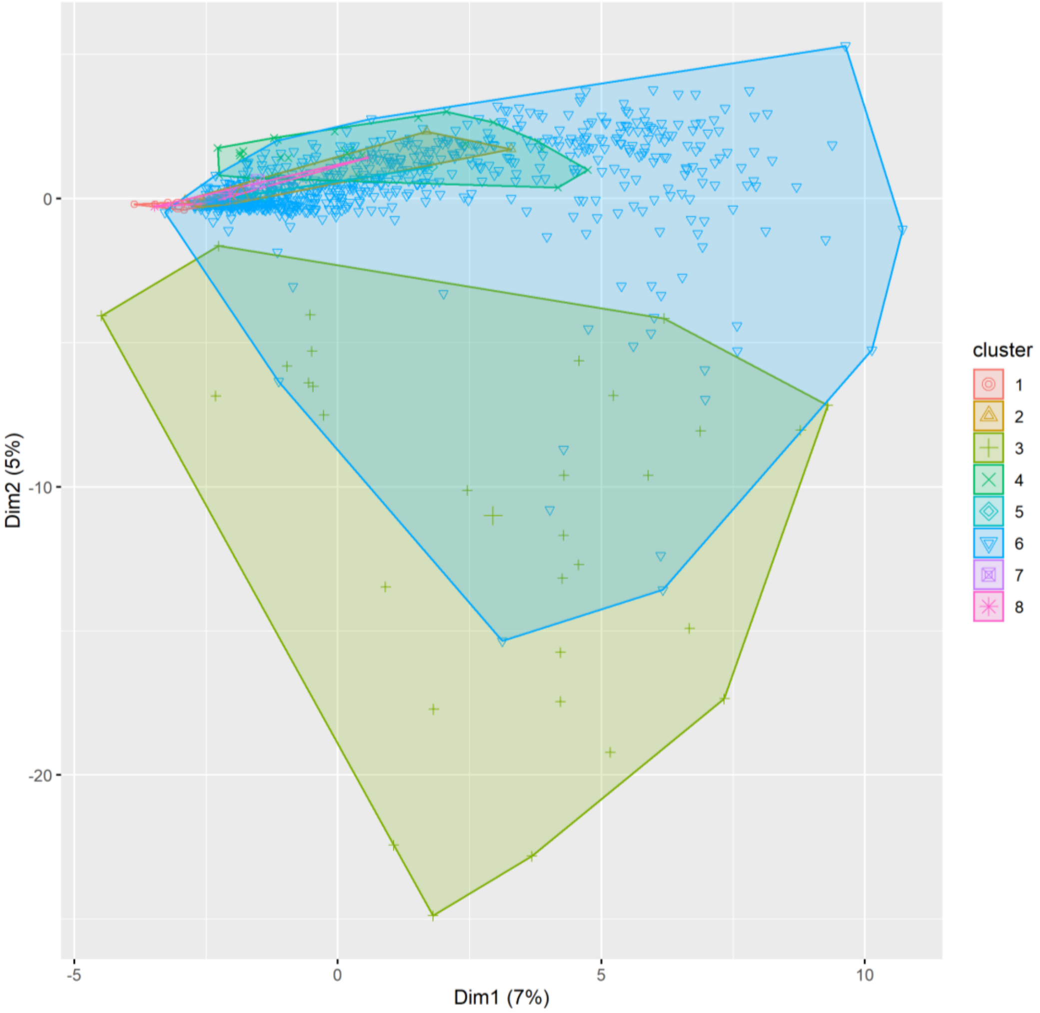


Figure 4.11. K means clustering of UK landings data for 2020, each point representing the summarised catch of 1 vessel for the year using all species (126) present in the data.

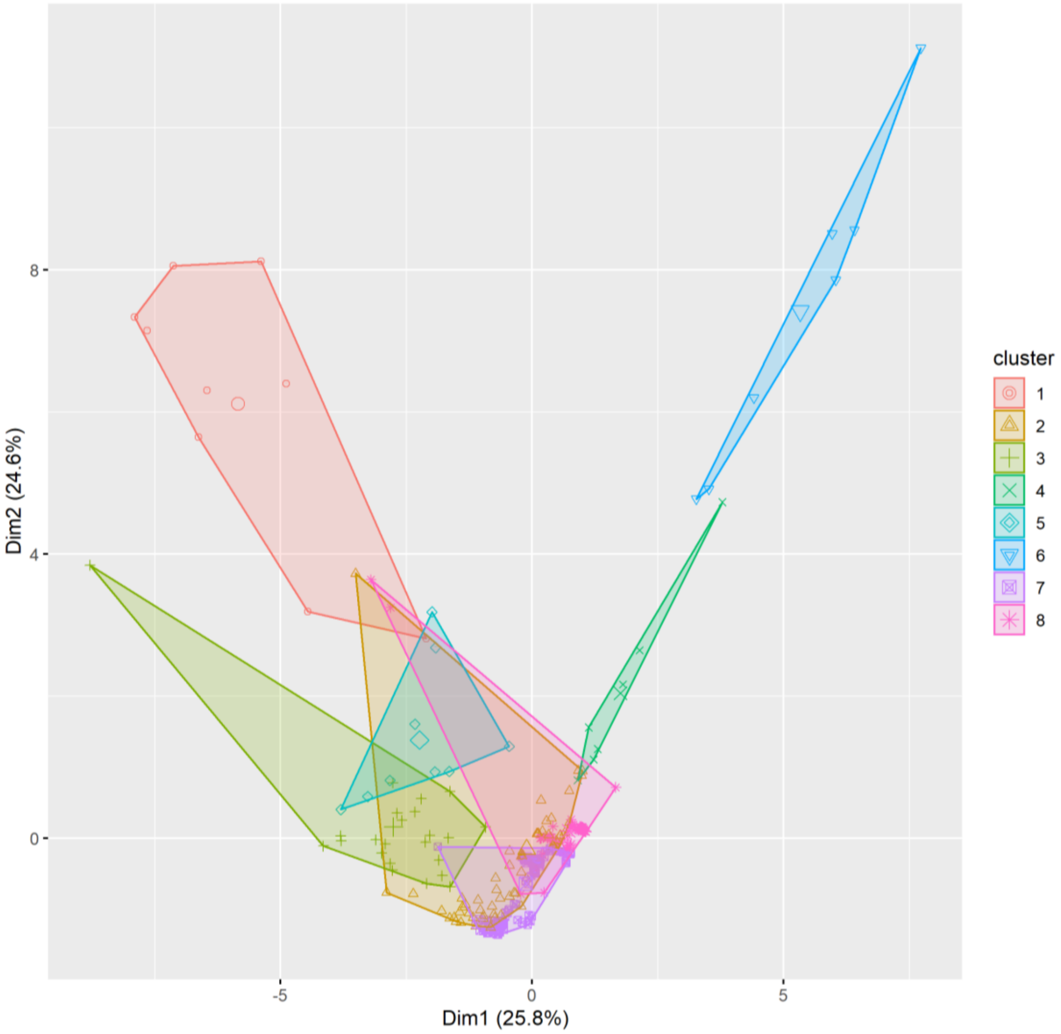


Figure 4.12. K means clustering of UK landings data for 2020, each point representing the summarised catch of 1 vessel for the year using specie present in the Celtic Sea mixed fishery model.

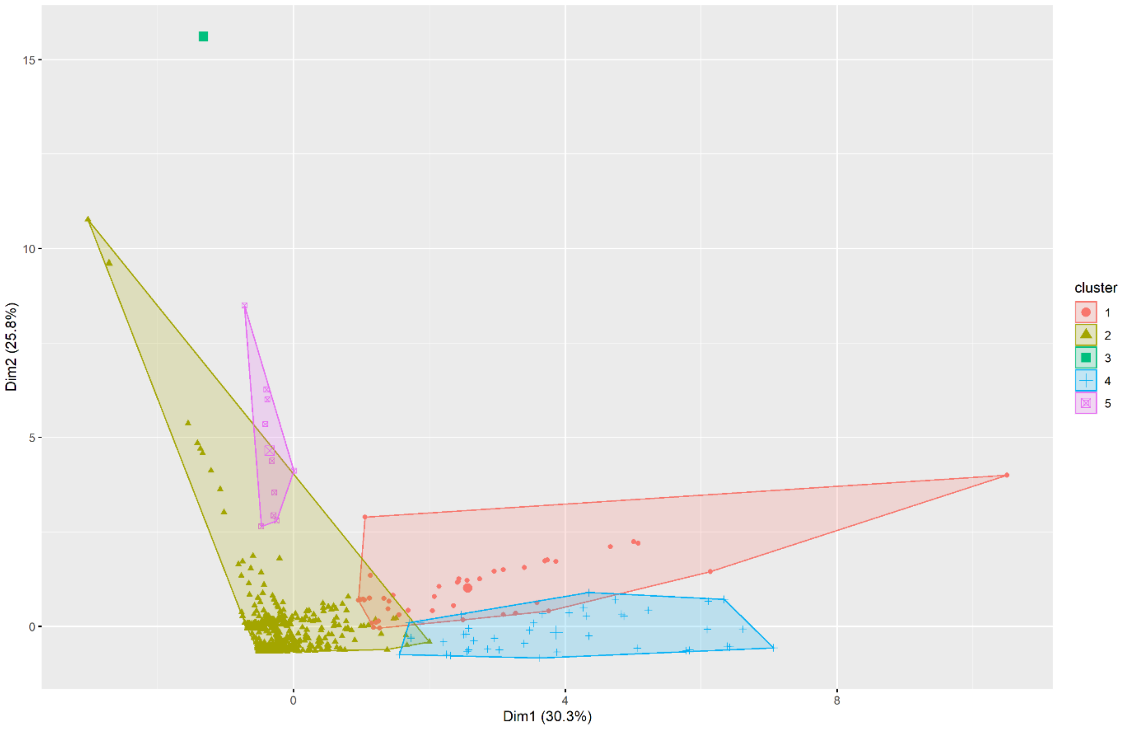


Figure 4.13. K means clustering of UK landings data for 2020, each point representing the summarised catch of 1 vessel for the year using specie present in the Celtic Sea mixed fishery model. The point shape represents the underlying cluster assigned by the function. The colours overlaid represent the assigned fleet for a given vessel based on the definitions used in the mixed fisheries model.

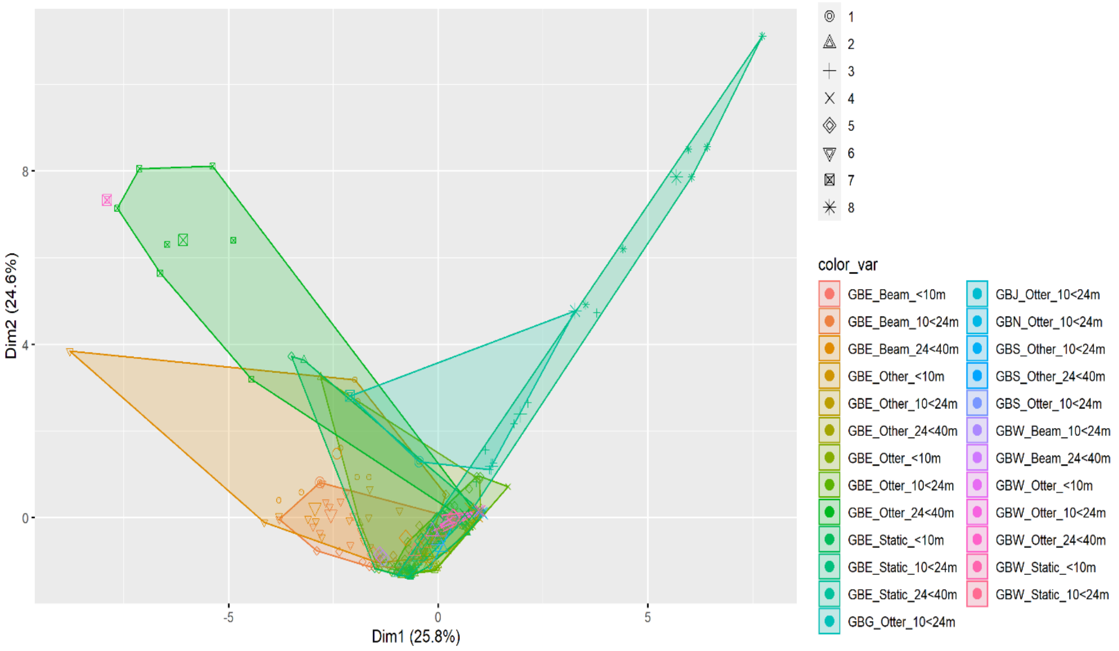


Figure 4.14. K means clustering of UK landings data for 2020, each point representing the summarised catch of 1 vessel for the year aggregated to species assemblage. The point shape and colour represent the underlying cluster assigned by the clustering.

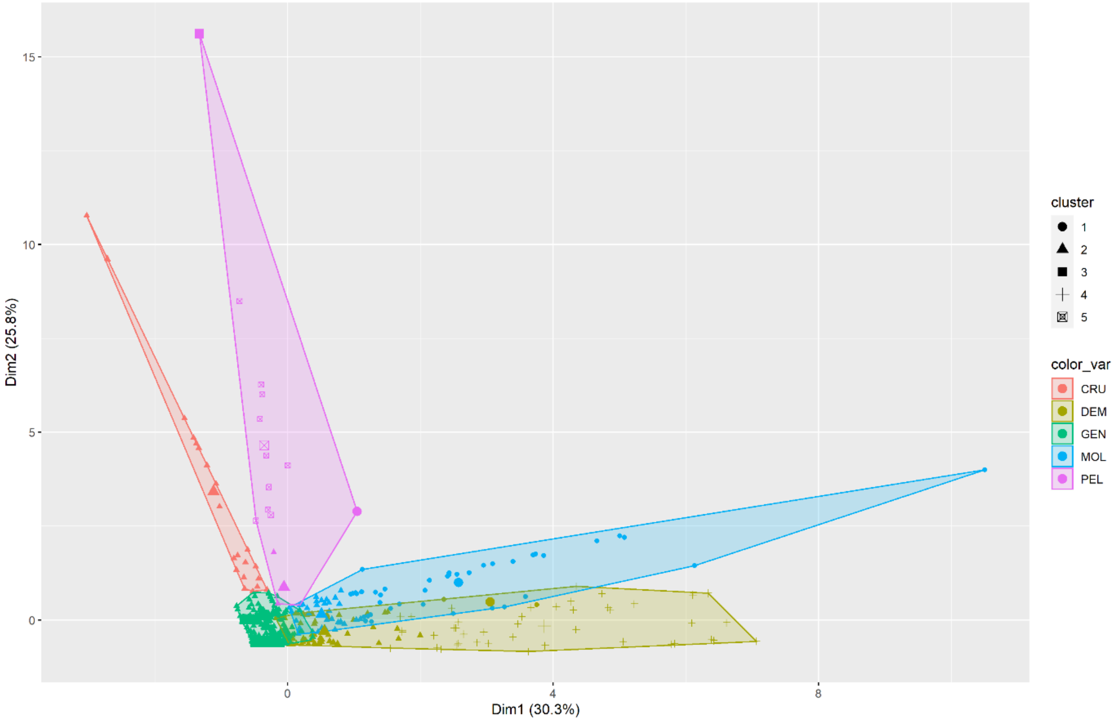


Figure 4.15. K means clustering of UK landings data for 2020, each point representing the summarised catch of 1 vessel for the year aggregated to species assemblage. The point shape and has been overlaid with manually assigned groups based on catch composition.

This greatly reduced the complexity of the data being clustered compared to using all species while still taking account of that data overall. Figure 3.14 displays much better clustering of the data and the emergence of 3 more defined groups can be seen in clusters 1, 4, and 5. Cluster 2 does overlap with all of these, but the picture is much clearer. In order to get some sense of how well these cluster line up with the underlying data the data was assigned to target assemblages based on an exclusion rule, taking the first quantile for each column in the analysis. A trip was assigned to either PEL, DEF, MOL, CRU or GEN for generalist if it was caught above the first quartile in one column or the highest value if above that in two or more columns Figure 3.15.

The manually assigned overlay corresponds relatively well to the clusters found in Figure 3.14, however they have included more vessels found closer to the 0, 0 mark on the graph. The clustering lines up quite well with the manually assigned groups but still has room for improvement. The GEN overlay also points to a group of vessels that catch something of everything but do not seem to have specialised in any one target assemblage. The clusters grouped to assemblage likely come closer to reflecting the underlying reality taking place compared to the mixed fisheries fleets as they currently stand.

The work points to a need to revaluate how fleets and metiers are constructed and to better understand the drivers behind their pattern of catch and effort and presents the mismatch between the aggregated view of vessel activity compared to the underlying realty of catch patterns. K means clustering could be employed as a method to resolve this, but would need to take place at a national level and a common methodology developed to do so. National data submitter would then be able to define vessel groupings under a unified framework on a more rationalised basis than the working group can. Further work is required to develop this methodology and to identify and incorporate factors such as time or spatial separation as well as identify suitable predictors. The group has suggested accompanying redundancy analysis (RDA) and principal component analysis (PCA) analysis to better explain the patterns being displayed.

5 ToR D: Respond to the outcomes and issues encountered during WGMIXFISH-Advice

The outcomes and issues encountered during the mixed fisheries advice production process were dealt with during this meeting. Details of these issues are given below, either as a case study specific issue or in individual sections due to the importance and wider implications.

5.1 Bay of Biscay

During WGMIXFISH-Advice 2021 (ICES, 2022, see Section 7), a series of future tasks were defined for the Bay of Biscay case study improvement. These are listed in Table 5.1.

Table 5.1. Planned future tasks for Bay of Biscay case study improvement and priority.

Task	Priority	Planned for WGMIXFISH-advice 2022-
Investigate the differences obtained in the short term forecast between that carried out for mixed fisheries advice and that of the assessment working groups, especially for seabass, mackerel and blue whiting.	2	yes
Improve fleet structure based on this year fleet configuration (e.g. consider removing some of them with low contribution to the catch, remove stocks that are only caught occasionally or where only caught in the past). Documenting and justifying the procedure.	1	yes
Analyse reported data for rays and decide on how to make assignments to the different species, given official catch data and information from surveys. Documenting and justifying the assumptions made.	7	no
Analyse stability of main model parameters (i.e. catchability, total effort, effort share and quota share). Based on the analysis consider the best way of conditioning the model at fleet/metier level, recent years average or last year value.	4	yes
Adapt the currently available code in the ICES-TAF repository (https://github.com/ices-taf) to follow the principles of TAF.	3	yes
Analyse the option of including fleet-dependent age structure in the conditioning of the model for some stocks.	6	no
Analyse the relevance of existing scenarios and identify new relevant ones. Need to review the status quo scenario assumptions for the pelagic fleets (status quo effort is considered appropriate for demersal)	5	yes

Additionally, the status quo effort scenario seems to be not appropriate for the pelagic species, because: (i) the pelagic vessels target them separately (i.e. one at a time), in contrast with the demersal ones that catch various of them at the same time; and (ii) constant catchability may be not appropriate for shoaling species. As a consequence, in the advice sheet (https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/2021/mix_BoB.pdf) it is stated that:

"This analysis includes some pelagic species which are mainly caught outside of the Bay of Biscay. The assumptions used in the SQ_E scenario may not be appropriate for the fleets which target these species; hence, this scenario should be interpreted with caution for horse mackerel and other pelagic species".

The majority of the changes were considered feasible prior to WGMIXFISH-Advice meeting (October 2022), so the group will work on implementation so that they can be incorporated for this year's advice.

The advances made during WGMIXFISH-Methods are detailed in the following subsections.

Short-term forecast

During WGMIXFISH-Advice 2021 (ICESc, 2021), there were some difficulties with reproducing the short term forecast for the northern hake stock (hke.27.3a46-8abd). Differences were larger than 10% (which is the defined advisable threshold) for the fishing mortality. These differences were attributed to the differences in population model used for the assessment (Stock Synthesis: seasonal length-based model) and short-term forecast and the one used in FLBEIA (annual age-based model). Additionally, the northern hake was benchmarked during 2022, and a new assessment has been accepted for the northern hake (Stock Synthesis: seasonal length-based and sex-disaggregated model with several fleets) and the short-term forecast was also run with Stock Synthesis.

In order to generate the FLR object required by the FLBEIA model to reproduce the stock dynamics (yearly age-structured dynamics all sexes), some simplifications should be made (see details in Table 5.2).

Table 5.2. Planned future tasks for Bay of Biscay case study improvements and priority.

Stock Synthesis model characteristics	Adaptation for FLBEIA
Length dynamics (although Stock Synthesis provides outputs for values at age). Quarterly time-steps.	Population at age were reported on 1 January and quarterly catches were collapsed to annual catches.
Recruitment occurs in two settlements (second and third quarter).	Recruitment (age 0) on 1 January was set as the sum of the recruitment in the two settlements and natural mortality for recruits was corrected accordingly.
Two sexes are modelled with different natural mortality and growth, and maturity ogive and consequently SSB is estimated only for females.	Maturity-at-age was reduced with the sex ratio-at-age to allow the resulting SSB to be comparable with SS female only SSB. M -at-age is the weighting mean of males and females (except for recruits).
Catches are estimated by quarter (where landings are quite accurate, but discards are underestimated). There are split in 9 pseudo fleets (with similar selectivity-at-length).	Catch-at-age for all fleets and quarters were collapsed in a yearly catch-at-age with landings and discards separated. Weight-at-age for landings and discards were estimated in a similar way to weight in the population.

Following this approach, the short-term forecast was replicated almost identically in terms of SSB and fishing mortality (Table 5.3). However, estimated discards by the FLBEIA model were considerably higher than those in the stock-specific short-term forecast.

Table 5.3. Results of the northern hake short-term forecast with FLBEIA relative to the stock-specific short-term forecast used for providing advice.

Year	F	SSB	catch	landings	discards
2021	0.99	NA	1.05	1.02	1.28
2022	0.95	0.97	1	0.95	1.71
2023	0.94	0.97	1	0.94	1.67
2024	NA	1.01	NA	NA	NA

Consequently, Bay of Biscay case study members plan to reproduce the short-term forecast with FLBEIA, but keeping the fleets modelled in the assessment, to evaluate if differences in discard estimates are reduced.

TAF repository

Bay of Biscay case study TAF repository for year 2022 now follows the TAF principles (see details in ToR A, Section 2.2) and is available at GitHub (https://github.com/ices-taf/2022_BoB_Mixed-FisheriesAdvice).

5.2 Celtic Sea

Inclusion of Northern Hake in FCube model

The northern stock of the European hake (hke.27.3a46-8abd) is not included in the Celtic Sea mixed-fisheries considerations. However, there is an interest to include it because around 40% of its total catches happened in the Celtic Sea.

Before including a stock in a mixed-fisheries considerations, it is necessary to be able to reproduce its single stock advice with the model used in the mixed-fisheries. In the Celtic Sea, the Fcube model is used to give the mixed fisheries advice. Thus, we tried to reproduce the single stock advice of the northern stock of the European hake with the Fcube model. For that, we used the latest stock assessment model outputs data. The data are disaggregated by sex (male and females), season (by quarter), morphs (four morphs related to four spawning periods), and fleets (seven fleets). However, the dimensions of the data were collapsed to one sex, one season, one morph and one fleet in order to apply the Fcube model in its simplest way.

The estimates of spawning stock biomass, fishing mortality and landings obtained with Fcube model varied less than 2% with respect to the single stock advice estimates. However, the estimates of discards obtained with Fcube model were 50% higher than in the single stock advice. The high difference found in discards estimates between the two approaches could be related to the dimensions of the input data. In the single stock advice, the data used were disaggregated by sex, season, morphs, and fleets whereas when we applied the Fcube model, we aggregate the data to one dimension. Thus, the aggregation of the input data dimensions must be further investigated. We cannot include the northern stock of the European hake in the Celtic Sea mixed-fisheries considerations until we are able to reproduce the single stock advice of the stock with Fcube model.

Treatment of *Nephrops* in FU16 (Porcupine bank)

Nephrops is assessed at the spatial resolution of Functional Unit (FU). However, *Nephrops* management, specifically TAC allocation, is at the level of ICES Subarea, with a TAC being provided for all of Subarea 27.7 (except FU16, which has its own '*of which*' quota since 2011). After some exploratory work, WGMIXFISH-METHODS 2020 (ICES, 2021) decided to split this TAC without taking into account the special condition of FU16, and thus the total TAC was firstly split between Celtic Sea and Irish Sea ecoregions based on long term landings proportions (average landings since 2000), and secondly split among different FUs based on previous year's landings proportions.

Now, in order take a more adequate and accurate approach, WGMIXFISH has decided to incorporate the special condition of FU16. Therefore, in future calculations, the '*of which*' limit will be subtracted from the total TAC of Subarea 7 first. After this new step, the resulting quota will be split as it was in the past: first between ecoregions, and second among FUs.

Although this new approach has the potential risk of reducing the available quota for the rest of Subarea 7 in our calculations, it is actually more realistic, as the Subarea 7 *Nephrops* TAC has never been fully caught since 2000, with an average of 76% of quota uptake, while the average '*of which*' quota uptake for FU16 since 2011 is 85%.

Improvements to code workflow

Celtic seas code has been continuously updated to streamline scripts, improve readability and reproducibility of outputs. However, like all other ecoregions the Celtic sea suffers from a multitude of setup options and stock specific options, that allow the subgroup to run specific scenarios, technical requests and customise stocks and fleets. While a concerted effort has been made standardise scripts, the multitude of options necessitated some means of differentiating outputs. This has previously been accomplished by appending the "options" into the file name of everything produced by the run. In the short term this has been an acceptable solution, but as the need to run multiple scenarios have increased, the output folder has become overpopulated with similarly named files. This can lead to some confusion as to what output corresponds to the final run or a specific run that has been requested as part of a technical request. A secondary issue to the scripts was the location of many of the "switches" present in the scripts, being as they are, spread throughout the scripts as they are implemented. When changing between model setups, this introduces an unnecessary amount of risk, where values needed to be altered in multiple scripts.

The current revision to the scripts has sought to remedy both these issues. Firstly, all control options have been moved to a single script "model_00_Setup_Options.R". Different model setups are controlled entirely off this script which is sourced by each successive script. This eliminates the need to edit each script in the process individually.

Secondly the output location for all the model scripts is now contained in a distinct folder with standardised names for all outputs inside said folder. The folder named supplied in the "model_00_Setup_Options.R" file. The differentiation between model setups is now done at the level of the folder name, to reduce the likelihood of overwriting a model run a versioning system has been incorporated into the folder naming code, with a specific overwrite flag needed to overwrite a previously created folder. The "model_00_Setup_Options.R"is also copied into the created folder as part of the processes, the concept being, edit the working "model_00_Setup_Options.R" as needed, with a copy always saved with the output of for those options. The actual model script files will therefore remain static between runs unless a specific development of that script is needed. This should reduce updates to these files to only those required for model development.

The decision to have all output names standardised between folders was made to facilitate any script or application for producing plots and graphs, for example the "FLFleets.RData" object is named the same and found in the same directory within the overarching model folder. Data and graphs can then be easily picked up with minimal need for editing complex files and file paths.

Progress in moving to FLBEIA

During the recent Inter-benchmark Procedure (ICES, 2021a) the Celtic Sea subgroup explored the use of FLBEIA for the provision of mixed fisheries advice for the region. While there were some problems with implementation due to inconsistencies in catches projected using the Cobb-Douglas production function in FLBEIA and those from single stock advice using the Baranov equation, there is still a desire to move from using FCube to using FLBEIA if the problems can be overcome.

The group had a brief discussion, and the intention is to move to using FLBEIA for the provision of advice from 2023. The steps needed to make this possible for the Celtic Sea are:

i. Implementation of the Baranov catch production function in FLBEIA – while technically challenging to do this at the fleet level, work presented elsewhere showed this was feasible in a generalizable way that could be incorporated in FLBEIA (ToR C, Section 4.3),
ii. Consideration of alternative conditioning of discarding projections in the model. At present several stocks in the Celtic Sea model have very low mean discard weights-at-age. Combined with the way FLBEIA projects discards, by estimating a total tonnage catch and converting this back to numbers based on quota limits and a discarded fraction, results in very high fishing mortality levels. Alternative approaches including conditioning over-quota discards based on the stock catch weight were considered more appropriate and should be explored.

These changes were considered feasible in the next 12 months, so the group will work on implementation so it can be reviewed ahead of the October 2023 advice meeting.

Consideration of zero TAC advice stocks

There was a brief discussion of the use of the Celtic Sea mixed fisheries model to address the EU standing technical request for estimates of catches for zero TAC advice stocks caught as part of mixed fisheries. The Celtic Sea model has been used to provide catch estimates for Celtic Sea cod in recent years based on a range of haddock and whiting limiting scenarios but may also be used to provide advice on other stocks in future.

In principle, bycatch quotas are intended to encourage avoidance or at least to reduce active targeting of depleted stocks. While the scenarios presented as part of the technical request are a best estimate of catches of each stock, they are conditioned on past behaviour which can include targeted fisheries. In future, consideration should be given to the effect this might have on projected catches, and whether alternative conditioning or information may be able to separate targeted catches from genuine bycatch. It was also highlighted that uncertainty in conditioning of future fishing patterns might also be used to provide a range of potential catches, rather than a point estimate, given the influence of targeting behaviour and changes in the fisheries on the project catch (see ToR B, Section 3.2).

5.3 Iberian Waters

Improve gear grouping of fleets used in mixed-fisheries scenarios

Fleet and métier categories used in the mixed-fisheries analysis are based on the EU Data Collection Framework (DCF) level 6 categories provided by Spain, Portugal and France. More than 40 métiers are reported, from these, the fleet groups used in the mixed-fisheries analysis, are defined combining the country, target assemblage and technical characteristics of the fishing métiers. As per last year there was a renaming of the gear groups used in the mixed fisheries analysis to improve harmonization with the other MIXFISH advice areas. The redefined group names and corresponding fishing gear, country of provenance, technical characteristics and target species are show in Table 5.4.

Table 5.4. Gear groups used to define fleets for mixed-fisheries analysis.

Old Mixed-fisheries groups	Gear / country	Mesh size / main target group	New Mixed-fisheries groups
CRU_>=55_0_0	Otter trawls / PT	≥ 55 mm Crustaceans	OT_CRU
DEF_>=100_0_0	Gillnets / SP	≥ 100 mm Demersal fish	GN1
DEF_>=65_0_0	Otter trawls / PT and SP	≥ 65 mm Demersal fish	OT_DEF
DEF_0_0_0	Longlines Gillnets, Trammelnets PT;SP	Any / Demersal fish	LL_GN_GT
DEF_60-79_0_0	Gillnets, Trammelnets SP	≥ 60 mm and < 79 mm Demersal fish	GN_GT
DEF_80-99_0_0	Gillnets SP	≥ 80 mm and < 99 mm Demersal fish	GN2
MCD_>=55_0_0	Otter trawls SP	≥ 55 mm Crustaceans, Demersal fish	OT_MCD
MPD_>=55_0_0	Otter and Pair trawls SP	≥ 55 mm Pelagic, Demersal fish	OT_PT_MPD
MIS_0_0_0_HC	Miscellaneous PT , SP	Any	MIS
OTH	Other gears PT, SP, FR	Any	OTH

The subgroup decided that some of the gear groupings currently used might not reflect the complex technical interactions in the area and could impact the quality of the model. Further work should be carried out in the country of provenance, fishing location, gear and the resulting composition of species catches to effectively describe the complex mixed fisheries scenarios being executed within the Iberian waters. It was recommended that the subgroup continues to explore this issue using the recent work and methods proposed by the MIXFISH-METHODS group and Moore *et al.* (2019).

Last year, Portugal provided a new series of effort and landings, which utilised a new algorithm for metier classification. Some outdated métiers who had no catches in the last years where removed in the new series.

Include hake as category 1

The southern Hake stock in divisions 8.c and 9.a was benchmarked in 2022 and is now in Category 1. The required adaptation of the FLBEIA model code, summary of results, tables and figures is currently undergoing in the TAF repository (https://github.com/ices-taf/2022_IW_Mixed-FisheriesAdvice).

The southern hake assessment is now performed using a seasonal length-based Stock Synthesis (SS) model with sex separated growth and natural mortality. A few simplifications had to be made to transform the stock data from SS to the required FLR format used in the FLBEIA model (age based, yearly, no sexes):

Southern hake SS model description:

- No age data are available for this stock. This is a length-based model although growth is estimated following a von Bertalanffy model and age results for population and catches can be provided by SS output system.
- The model has quarterly time steps. Catch are implemented quarterly and population dynamic follow also quarterly steps.
- Total landings and discards by quarter are estimated by the model. Landing estimation seems to be quite accurate although discards are underestimated (see Figure 5.1)
- Recruitment happens in two settlement assignments in January and July.
- There are two sexes with different natural mortality and growth (Figure 5.2)
- Maturity-at-length ogive and estimated SSB (1st Jan) is provided only from female data
- Catches are split in four pseudo fleets (groups of fleets with similar catch length distribution)
- Only the trawlers fleet group have discards in the model. Minor and partial discards are also available for other fleets although not implemented into their fleets in the SS model. All discards in weight are assigned to the trawlers fleet.
- Selectivity for the four fleets is estimated at length.

The FLR simplified approach to be used in the FLBEIA model

- Population-at-age are reported at 1st Jan and quarterly catches are collapsed to annual catches
- Recruitment (age 0) at 1st Jan is the sum of the recruitment in the two settlements (January and July). To keep consistency M at age 0 is corrected to deliver abundance at age 1 (1st Jan) equal the SS reported abundance.
- M-at-age is the weighting mean of males and females (except age zero. See previous point)
- Weight-at-age is the weighted mean of males and females.
- Maturity-at-age was reduced with the sex ratio-at-age to allow FLR SSB be comparable with SS female only SSB.
- Catch-at-age for all fleets and quarters are collapsed in a yearly catch-at-age with landings and discards separated.
- Weight-at-age for landings and discards are estimated in a similar way than weight in the population.

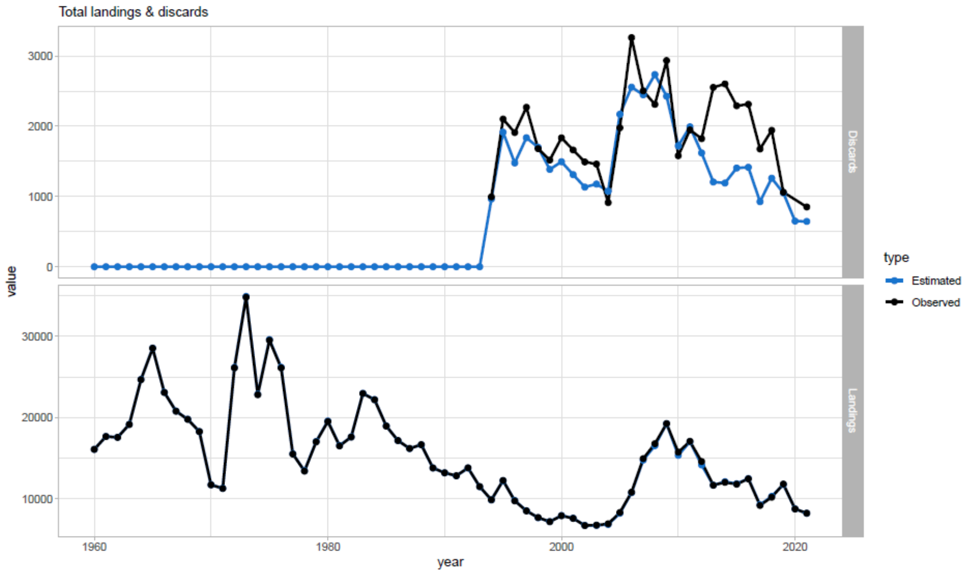


Figure 5.1. Observed (black) and estimated (blue) landings and discards.

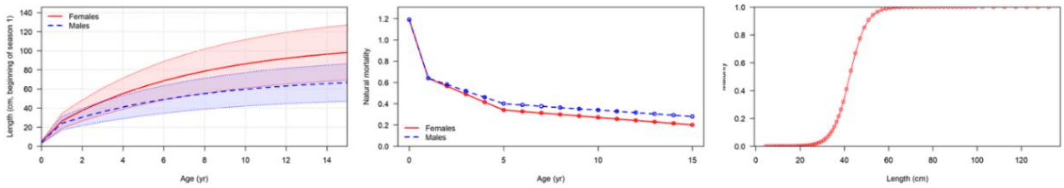


Figure 5.2. Growth, M and maturity at-age, for males (blue) and females (red).

Continued discussion for the inclusion of other stocks

There are not many Cat.1 and Cat.2 stocks in the area but several stocks were identified as potential candidates to be included in the Iberian Waters advice and all present some issues and challenges that should be followed in future work:

- Southern horse mackerel has a large uncertainty in the assessment model and undergoing a pre-benchmark process.
- The widely distributed stock *Scomber scombrus* is possible to be included in MIXFISH advice scenarios with the definition of a special fleet responsible for the catches outwith the Iberian Waters. This stock has its southernmost distribution in the area and only have some seasonal minor catches (compared with the bulk of the stock) and is not considered a target species for the fleets operating in the area.
- The widely distributed stock *Micromesistius poutassou* is also possible to be included in the advice scenarios with the definition of a special fleet responsible for the catches without the Iberian Waters. The stock has their southernmost distribution in the area and only have some minor catches (compared with the bulk of the stock). There are some fleet/hauls targeting this species in the area but interaction with other demersal species is minor.
- *Nephrops norvegicus* fisheries are relevant in the area. In recent years, the majority of Functional Units assessed with SPiCT have their fishery closed (TAC=0), with only a small catch in FU 31 (17 tonnes). This closure prevents from including this stock in the model in the short term

There are other stocks in the area that are not included in the mixed fisheries methodology and the current advice is probably missing some of the effort allocation and technical interactions in the area. Continued development for the inclusion of these and other species should be followed in the processes in this advice area.

5.4 North Sea

Different improvements where tackled during the advice meeting. These are no issues as such but will make the advice production smoother in October.

Developments of diagnostics for report and advice

Since the advice meeting in 2021, a single RMarkdown file that produces figures, tables and result extractions for both the advice sheet and the report exists. The file is regularly updated when new diagnostics or modifications are needed. Some improvements were made on the diagnostics during the Methods meeting. For instance, the summary figure that shows the stock projections for all scenarios now includes the results of the mixed fisheries version of the reproduce the advice scenario (Figure 5.3). New figures are also in progress as contribution to the Fisheries Overviews.

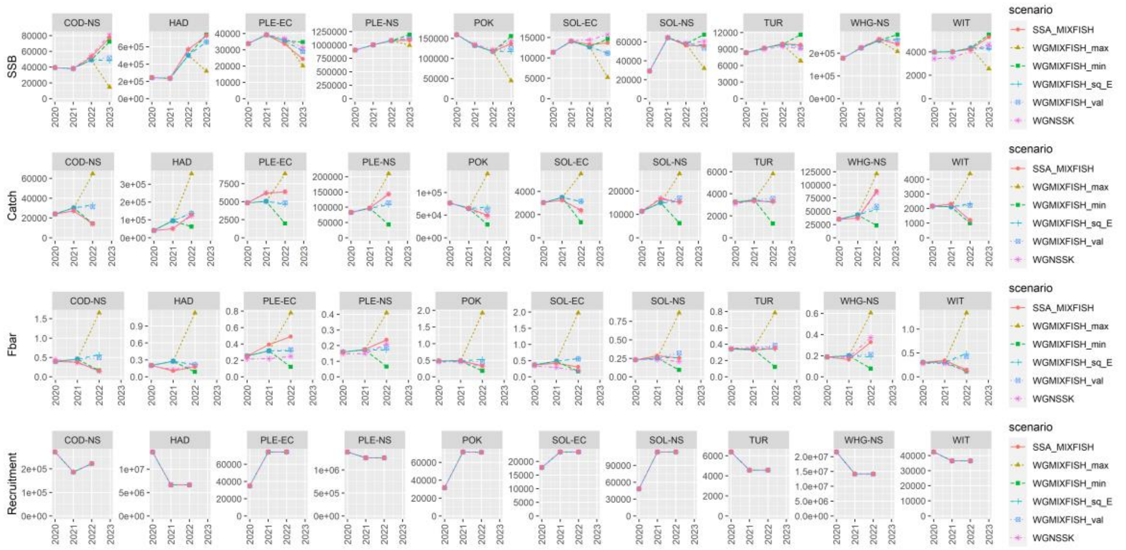


Figure 5.3. New summary figure that includes both reproduce the advice scenarios in single species (WGNSSK) and mixed fisheries (SSA_MIXFISH) context. Labelling will be improved in the future.

Observed vs. estimated catches in the FLStock objects

During the 2021 advice meeting, the North Sea group realized that some of the FLStock objects provided by the stock assessors included the observed catch values while others included the estimated catch values. Some discussion took place during the meeting to conclude on what are the best values to be provided to avoid data and model conflicts (see ToR A, Section 2.4).

While the observed catch is in accordance with the data provided in InterCatch (except if raising is done after extraction, which, should not be a problem for the North Sea case study), the single stock advice forecasts are based on estimated selectivity. In addition, while the other fleet (OTH-OTH) was created in the model to allow for disparity in the data, there is no process currently in place to scale down the catch if the total catch summed across fleets in FLBEIA is higher than the total observed catch. Notably, the OTH-OTH fleet mainly represented until now Norwegian catches that were not submitted, but this year Norwegian catches are submitted so the OTH-OTH fleet should represent a lower portion of the catch than in the previous years.

Script and updates in preparation for the 2022 advice

Given that FLBEIA is in constant development, some scripts needed to be modified following recent model improvements. Indeed, some functions in FLBEIA are not maintained anymore and this can create conflicts when updating R or R-packages. Notably, new conditioning functions now exist in FLBEIA that are coded partly in C++ for computing efficiency reasons (see ToR C, Section 4.2). As a result, some of the conditioning functions in the *model_02_FLBEIA_condition.R* script need to be updated to take advantage of these developments (*create.fleets.arrays()* and *create.biol.arrays()* instead of *create.fleets.data()* and *create.biols.data()*). These developments will carry on until the advice meeting in October.

Finally, the new 2022 advice TAF repository started to be updated in preparation for the 2022 advice (data and script updates). These updates will continue until the advice meeting.

6 ToR E: Develop mixed fisheries models for sea regions not currently covered in the mixed fisheries advice

6.1 Irish Sea

The Irish Sea FCube model now includes all demersal stocks managed by TACs in area 7a, namely: cod.27.7.a, had.27.7.a, ple.27.7.a, sol.27.7.a, whg.27.7.a, nep.fu.15, and nep.fu.14.

The aims of the Irish Sea subgroup within this methods meeting were to:

- Present the Irish Sea FCube model developed in the 2021 WGMIXFISH Advice Meeting and to discuss its suitability for the provision of advice scenarios.
- Discuss alternative scenarios for consideration based on alternative targets for whiting stocks in the Irish Sea
- Examine potential improvements to the fleet structures in the FCube model to best reflect Irish Sea fisheries practices and technical interactions

Presentation of the Irish Sea FCube model developed in the 2021 WGMIXFISH Advice Meeting

The results of the FCube model developed at the 2021 WGMIXFISH Advice Meeting were presented (see ICES, 2021b for model details), intersessional work in spring 2022 improved FCube forecasts and scenarios for plaice (ple.27.7a), and this stock was added to the other scenarios previously presented in the 2021 Advice Report (figures 1.1, 1.3, and 1.4).

On the basis of the work presented, the working group agreed that the Irish Sea FCube model is at a stage that further review should be conducted to determine its readiness for provision of mixed fishery advice for the Irish Sea in late 2022. A working group internal review is scheduled for late August 2022, with a view to conducting an external review in September 2022 (to be coordinated by ICES).

In preparation for these reviews, intersessional work will include the development of a model ‘key-run’ for the 2023 advice year integrating the new cod.27.7a category 1 assessment (previously, a category 3 assessment). *Nephrops* stocks will be included in this model by assuming a roll-over of the 2022 catch advice and stock sizes, as this information will not be available from the single-species advice process until autumn 2022 (as per usual ICES *Nephrops* advice schedule). These assumptions relating to *Nephrops* assessments are only for model testing purposes and will be updated when new estimates become available.

Alternative scenarios for consideration in the Irish Sea region based on alternative targets for whiting stocks

A key mixed fisheries issue in the Irish Sea is the continued low stock size of whiting (whg.27.7a) and cod (cod 27.7a), both of which are considered to have spawning stock biomasses below $B_{trigger,}$ B_{lim}, and B_{pa} (ICES, 2022b, 2021c). Zero catch advice has been issued for whg.27.7a in 2022 and 2023 (ICES, 2021c), and for co.27.7a in 2023. No directed fishery of cod or whiting is permitted the Irish Sea, and the current fishing opportunities for cod and whiting are set at 206 t and 721 t respectively to allow for by-catch from other fisheries (ICES, 2021d). However, despite the implementation of several technical measures which experimentally reduce whiting catches and the full implementation of the landings obligation in 2019, the discards of whiting remain high (1571 t in 2021). As a result, whiting is considered to be a 'choke species' for other fisheries in the Irish Sea region. This conclusion is supported by the Irish Sea FCube model (ICES, 2021b), which found that whiting was the most limiting stock for all fleets (i.e. all fleets caught whiting as by-catch). Hence, the whiting scenario is the same as the 'min scenario', and both resulted in a cessation of all fishing effort in order to meet the objective of all stocks being fished below F_{MSY} advice.

Here, we explore some alternative scenarios based on other whiting targets, to describe their expected implications for fleet effort and catches of other stocks in the region. These alternative targets represent a range of management scenarios for whiting and are based on those provided as part of the EU Technical Service for catch scenarios for zero-catch stocks (e.g. ICES, 2021d). Namely, the following advice targets for whiting were considered for 2022: zero catch (as per single-stock advice), SSB-stable (i.e. whiting SSB 2023 = 1326), SSB * 1.2 (i.e. whiting SSB 2023 = 1591), F_{MSY}*SSB/$B_{trigger}$ (whiting *F* 2022 = 0.0178; application of ICES Advice Rule, as per alternative cod.27.7e-k scenario in the Celtic Seas FCube model 2021). Under all scenarios the SSB is expected to remain considerably below the B_{lim} value of 10 000 t for this stock in 2023, and as such are not considered precautionary. In SSB based scenarios the SSB targets in 2023 were taken directly from the single-stock advice for comparability with other ICES advice products, slight differences would be observed if the FCube model estimates of SSB in the intermediate year had been used due to minor differences in intermediate year assumptions between the FCube model and the single-stock advice. Specifically, intermediate year assumptions in the FCube model are based on the mean fishing effort of the preceding three-year period, whilst the intermediate year assumption for the single stock advice for whiting is the mean *F* over the preceding 3-year period. Two further scenarios were investigated for comparison with the technical advice, the status quo effort scenario based on mean fleet effort (2018-2020), and the *Nephrops* FU 15 scenario (*Nephrops* 15 catch advice 2022 = 11785). The use of the *Nephrops* FU 15 scenario is based on the observed historic correlation between catches of these stocks (ICES, 2021d). In the period 2018–2020, 98% of the catches of whiting were attributed to *Nephrops* fisheries. These scenarios were run using the model settings described in the 2021 mixed fisheries advice report, with the exception of ple.27.7a for which minor changes were made to improve the match to the single-stock advice outputs. Scenarios presented below are subject to further refinement and for exploratory purposes only, and are based on the 2021 advice year.

The FCube model based on the zero-catch advice for whiting scenario indicated that catches for all stocks would be zero under this scenario as a result of whiting bycatch present in all fleets (Figure 5.1.; Table 6.1). The status quo scenario estimated whiting catches in 2022 of 1191 t, and is estimated to lead to an increase in whiting SSB in 2023 of 5% (Table 6.2). For comparison with the technical advice for whg.27.7a, this is between the *F* = Fsq scenario (based on F in 2021) of 1254 t, and the *Nephrops* bycatch scenario 967 t, which projected whiting SSB changes of -6.5% and +12% respectively (ICES, 2021d). The SSB-stable scenarios projected whiting catches marginally above the Status quo effort scenario (1273 t), and catches within the single stock advice for all other stocks except cod.27.7a for which predicted overshoot compared to advice. In the whiting SSB + 20% model the catches of whiting were lower than in that of F status quo model (955 t), suggesting that fishing effort would need to be reduced in order to increase whiting SSB by this amount by 2023. This model also showed an overshoot in cod 27.7a advice.

Table 6.1. Estimated catches of Irish Sea stocks based on alternative whiting scenarios in the Irish Sea FCube model.

Stocks	Fcube Scenarios						Advice 2022
	Status quo	NEP15	WHG-Zero	WHG-FMSY*SSB/Btrigger	WHG-SSB-Stable	WHG-SSB+20%	
had.27.7a	1676	2154	0	66	2126	1526	3038
ple.27.7a	1747	3883	0	55	1823	1297	2747
sol.27.7a	372	772	0	12	409	290	787
whg.27.7a	1191	1832	0	46	1273	955	0
nep.fu.14	245	332	0	6	194	136	835
nep.fu.15	8757	11679	0	329	11509	8064	11785
cod.27.7a*	236	380	0	9	305	214	74

* Cod.27.7a stock is based on the 2021 advice model. This stock changed from category 3 to category 1 advice in 2022.

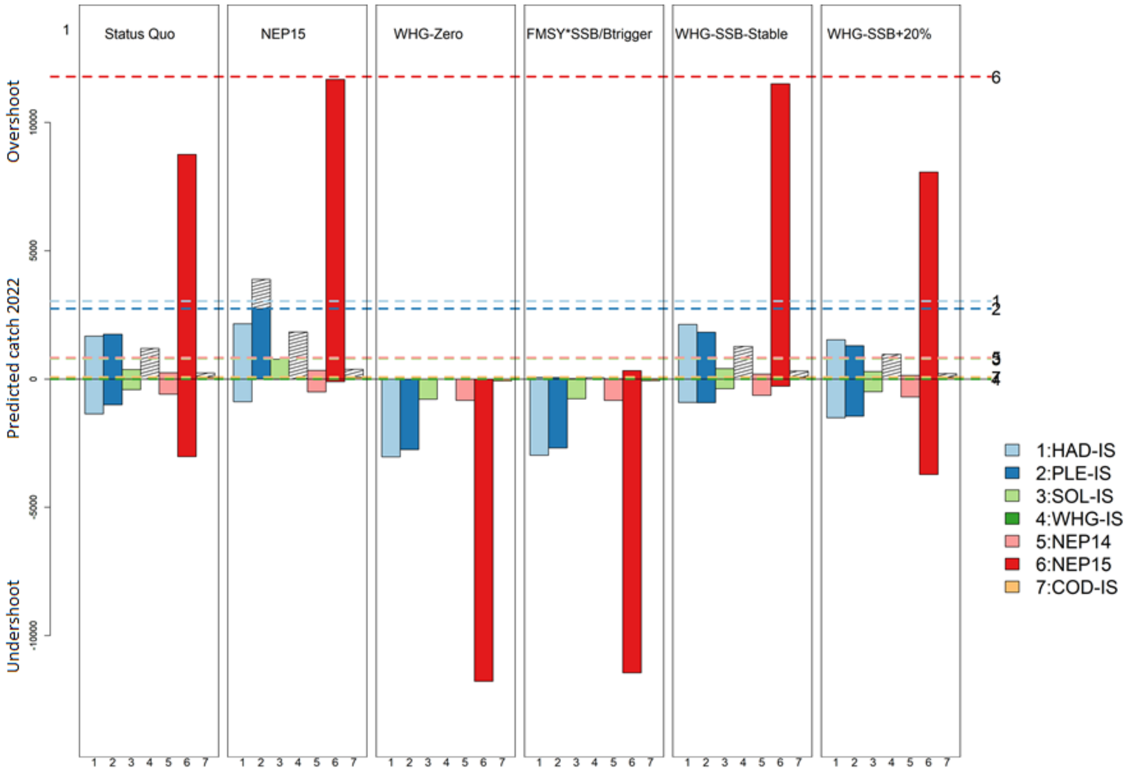


Figure 6.1. Irish Sea catch per stock under alternative FCube scenarios (2022). The ‘Status Quo’ scenario assumes mean fishing effort for the 2018-2020 period in 2022. ‘NEP15’ scenario is based on F_{MSY} advice for nep.fu.15 in 2022. ‘WHG-Zero’ scenario represents zero catch of whg.27.7a in 2022, and is equivalent to the mixed fisheries ‘min’ scenario in this case. ‘F_{MSY}*SSB/$B_{trigger}$’, ‘WHG-SSB-stable’ and ‘WHG-SSB+20%’ represent alternative advice targets for whg.27.7a (see main text above). Horizontal lines correspond to the single-stock catch advice for 2022 for each stock. Bars above the dashed lines are diagonally hashed to indicate an overshoot of the advised catch. Below the value of zero bars show undershoot (compared to the single-species advice) in cases where catches are predicted to be lower than the advice for that stock when applying the scenario.

Catches of nep.fu.15 under the nep.fu.15 advice scenario were considerably higher than in the status quo scenario (11 679 t, 8757 t respectively), this mismatch reflects the reality of the fishery which currently fishes below the F_{MSY} advice for the FU. This suggests that the single stock advice and TAC for nep.fu.15 are not the current limiting factor for this fishery, and this scenario that is unlikely to be realistic in the near future. However, it is still illustrative of the mixed fisheries interactions of the *Nephrops* fishery, and predicts that if the nep.fu.15 advice were realised then there would be likely to be overshoots of cod.27.7a, ple.27.7a and whg.27.7a as a result of bycatch. Under this scenario the FCube model projects whiting catches of 1 832 t and reduction of SSB of 33% in 2023 compared with 2022.

The FCube scenarios presented here are illustrative of likely outcomes for multiple stocks based on different management objectives. Whilst the specific results for individual stocks are expected to change slightly with model refinement, the current model demonstrates the utility of considering scenarios based on the management objectives for stocks of concern (e.g. those with SSB below B reference points, and/or F above reference points as a result of by-catch). The results of these scenarios are broadly comparable with those of the technical advice for whiting, but have the additional benefit of incorporating more fishing fleets and illustrating potential impacts on a broader suite of species. Of particular note here is that the SSB targets for whiting currently being considered are likely to overshoot the advice for cod27.7a based on the 2021 advice. In 2023, the catch advice for Cod 27.7a has been reduced to zero. This is due to the fact that, with the new category 1 single stock assessment, the SSB of cod.27.7a is estimated to be below B_{lim} and there are no catch scenarios that will rebuild the stock above B_{lim} by 2024. Thus, mixed fisheries models for the Irish Sea will need to consider illustrative and realistic scenarios for both of these stocks.

In contrast to single-stock advice there is no single advised catch level based on the mixed fishery approach, instead a range of scenarios are presented. These scenarios illustrate a range of options for the management of fishing opportunities. However, of the scenarios described here only the zero-catch advice for whiting would be considered to meet the objective of all stocks being fished at or below F_{MSY}. Any catch of whiting in 2022 is not considered precautionary as the stock is estimated to be and remain below B_{lim} (ICES, 2022b). The current analysis is based on the observed historical catch compositions of fleets and gears. Fishery managers may need to consider additional measures aimed at minimizing the potential misalignment between activity and stock shares for the fleets, such as changes in gear selectivity, spatiotemporal management measures, or reallocation of stock shares, if fishing opportunities are to be taken under a fully implemented Landing Obligation.

Table 6.2. Estimated catches in 2022 and SSB in 2023 of whiting (whg.27.7a), alternative scenarios in the Irish Sea FCube model. Change in SSB is shown relative to single stock advice SSB in 2022.

Scenarios	Whiting catch (2022)	Whiting SSB 2023 (t)	Change in whiting SSB (%)
Status Quo Effort	1191	1393	5
NEP15	1832	888	-33
WHG-Zero	0	2440	84
FMSY*SSB/Btrigger	46	2398	81
WHG-SSB-Stable	1273	1326	0
WHG-SSB+20%	955	1591	20

Potential improvements to the fleet structures in the Irish Sea FCube model

Fleets and métiers form the core structure of the FCube model and the decisions made in the allocation of métiers within fleets or the disaggregation of métiers into separate fleets will influence model outputs. In particular, 'choking' in the FCube model, whereby a fleet must stop fishing when it reaches its share of the landings quota occurs at the fleet rather than the métier level. Métiers within fleets are primarily descriptive of the catch composition of the fleet, and are used to compute catchabilities of each stock.

In the Irish Sea FCube model described in ICES (2021b) ten fleets were used in the model. These fleets reflected the main nations fishing in the area and fishing gears employed by each; namely Northern Irish otter trawls, Irish otter trawls, Irish seine nets, Irish beam trawls, English beam trawls, English otter trawls, Belgian beam trawls, Northern Ireland other gears and Irish other gears. A further fleet called 'OTH_OTH' was used aggregating all fisheries which landed < 1% of any stocks in the model. Within each fleet, métiers were defined based on the Technical Regulation (TR) classes methodology (outlined in the long-term plan for cod stocks and the fisheries exploiting those stocks, see ICES (2021b) for details). However, the result of this process was that multiple gears with different target species were be grouped within the same fleet. For example, the Northern Irish otter fleet contained otter trawl métiers with mesh sizes between 70-99 mm which mainly target *Nephrops* and otter trawl métiers with a larger mesh size >100 mm which typically target whitefish such as haddock. The result of this in the FCube model is that when either of these métiers reach the limit of their landings share under a given scenario, then that fleet stops fishing. This model behaviour may be unrealistic if the catch compositions of the métiers within a fleet are sufficiently different. In such a case, if one métier reached the limit of its landings share of a 'choke species', another métier could in reality (but not in the model) continue to operate without targeting the 'choke' species. In order to allow for this kind of métier switching within in FCube it is currently necessary to define separate fleets for the each of the contrasting métier.

In order to investigate the impact of nesting métiers with differing mesh-sizes (and target species) on the outputs of the FCube model, we constructed a new version of the 2021 model with an alternative fleet structure. This new structure increased the number of fleets in the model to thirteen including the 'OTH_OTH' fleet. This was done by separating the otter trawls into separate fleets targeting crustaceans (mesh size 70-99), demersal fish species (mesh size >100) and pelagic species (mesh size 32-69). Beam trawl fleets were unchanged. Landings and discards of each new fleet for are shown in Figure 6.2 below. Full R code and model outputs are available at: https://github.com/ices-taf/2022_IrS_MixedFisheriesAdvice

When compared with the previous model outputs across all scenarios the results of the model with the new fleet structures were broadly similar (Figure 6.3 and Figure 6.4, below). However, reductions were noted in the overshoot of *Nephrops* FU 15 in the haddock and plaice scenarios (Figure 6.4), indicated that increased catches of demersal fish could be realised with lower by-catch of *Nephrops.* This model behaviour is considered to be more realistic in terms of the potential for fleets to separately target *Nephrops* and demersal fish, and will be maintained in further Irish mixed fisheries models.

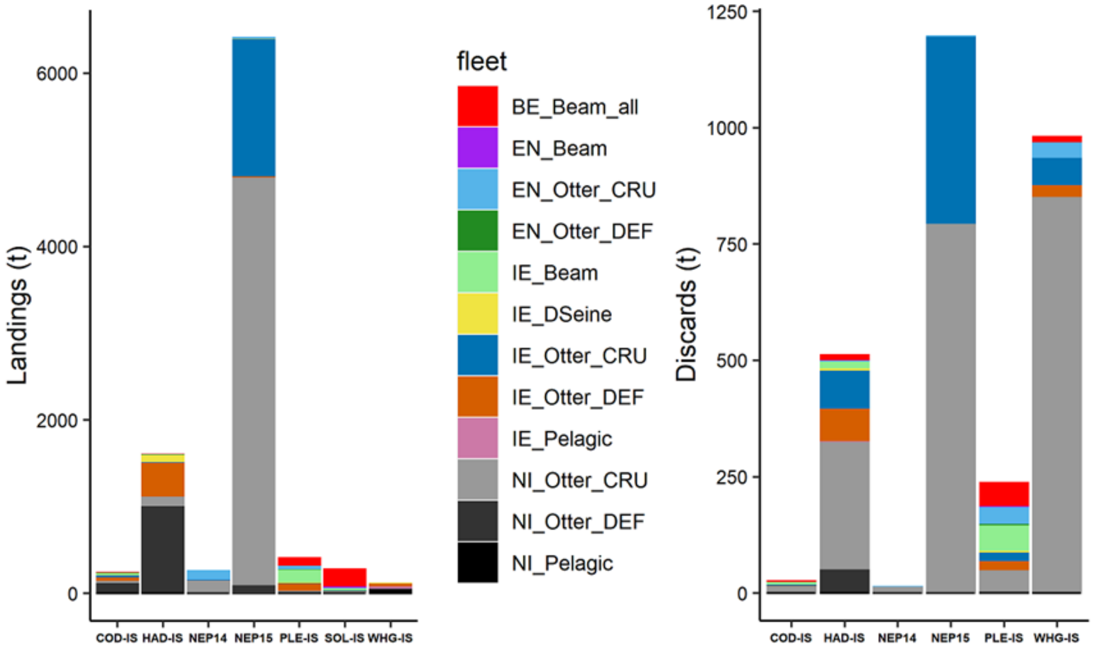


Figure 6.2. Landings and discards of stocks included in the new FCube model by fleet, landings and discards (mean of 2018-2020). Y-axis scale differs between plots. Plaice discards are 'dead discards' only, calculated at the 40% survival rate as per the single species assessment. Sole discards are not included as these are not included in the FCube model as per single species stock assessment, and are instead calculated as 10% of catch by weight after the model forecast.

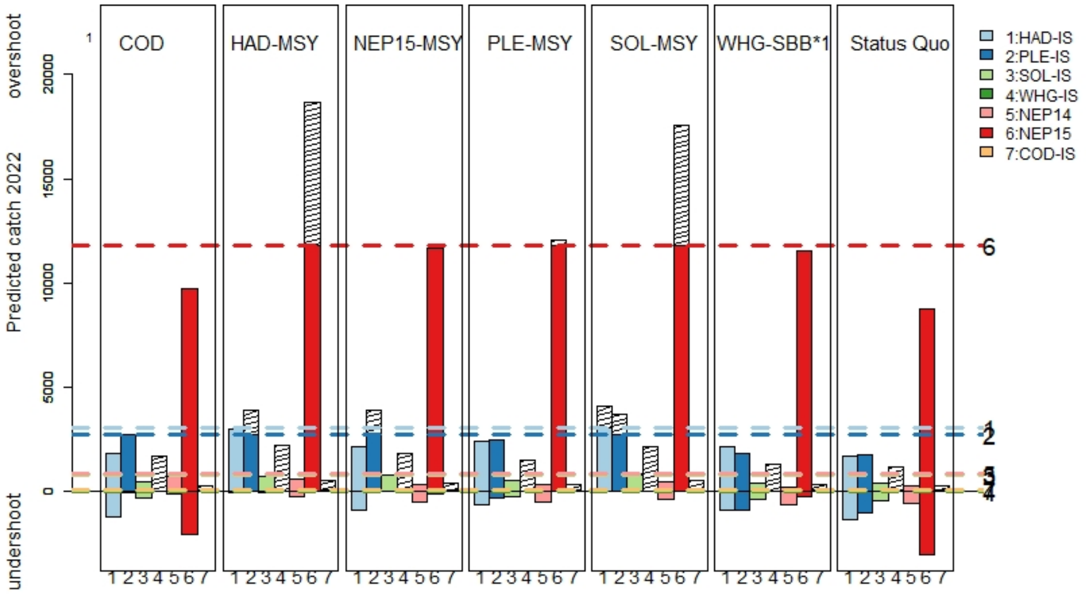


Figure 6.3. Irish Sea catch in 2022 per stock for mixed fisheries scenarios using original ten fleets from the 2021 advice meeting model (see text above for details). The 'Status Quo' scenario assumes mean fishing effort for the 2018-2020 period in 2022. Stock specific scenarios are based on the fishing to the advice limit for the named stock in 2022. Horizontal lines correspond to the single-stock catch advice for 2022 for each stock.

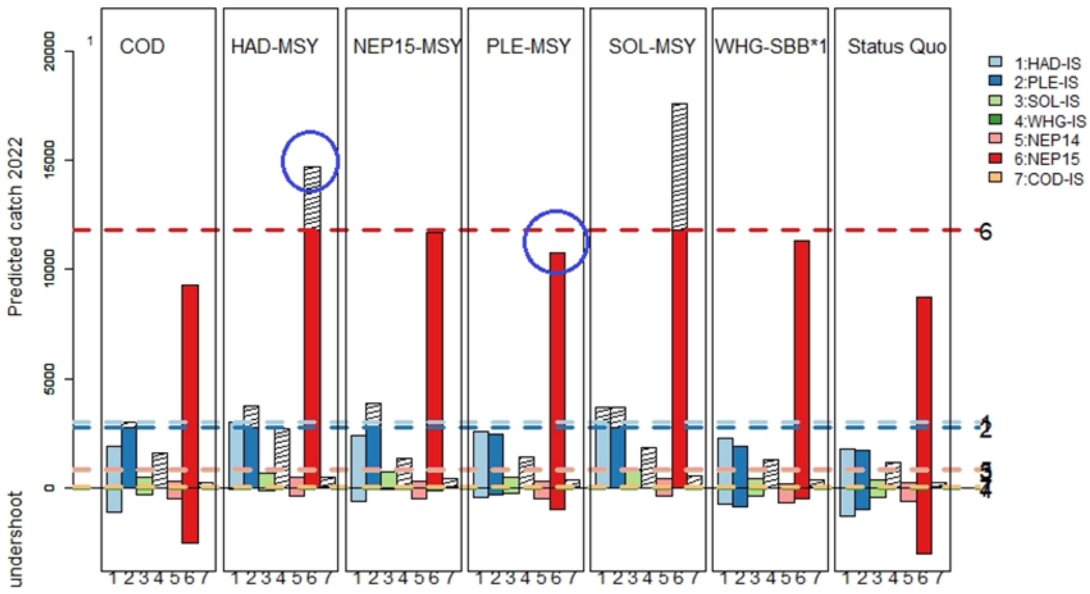


Figure 6.4. Irish Sea catch in 2022 per stock for mixed fisheries scenarios using new fleet structure separating otter trawl fleets based métier mesh-sizes (see text above for details). The 'Status Quo' scenario assumes mean fishing effort for the 2018-2020 period in 2022. Stock specific scenarios are based on the fishing to the advice limit for the named stock in 2022. Horizontal lines correspond to the single-stock catch advice for 2022 for each stock. Blue circles highlight in reductions in the catch estimates for *Nephrops* FU 15 in the haddock and plaice scenarios, likely due to the disaggregation of métiers targeting crustaceans and demersal fish in the model fleet objects.

Conclusion

The developed Irish Sea FCube model is at an advanced stage, incorporating all demersal stocks managed by TAC in the region. Scenario explorations above demonstrate the utility of the model for exploring alternative advice scenarios for zero-advice stocks such as whg.27.7a, and the potential advantages of further disaggregation of the fleet objects based on métier mesh-sizes. Further model refinement will focus on the incorporation of the new cod.27.7a assessment into the model, and updating the model with the most recent year's data for other stocks. A detailed internal review of the model will be conducted by WGMIXFISH in late August 2022, with a view to providing advice scenarios for the region at WGMIXFISH-ADVICE.

6.2 Baltic Sea

Following a request from ACOM to consider developing mixed fisheries advice for the Baltic Sea an exploration of WGMIXFISH data covering this ecoregion was conducted. WGMIXFISH has previously explored data for the Kattegat to address zero TAC advice issues for Kattegat cod in a mixed fisheries context.

The Baltic Sea ecoregion is shown in Figure 6.5 and covers ICES subdivisions 22-32. There are 17 stocks, listed in Table 6.3, assessed by ICES at the Baltic Fisheries Assessment Working Group (WGBAFS). Of these stocks, 13 are demersal fish stocks and only 6 have full analytical assessments. Herring and sprat account for the majority of landings in the Baltic Sea (Figure 6.6) with cod and flounder accounting for the largest demersal landings. Some of these stocks extend beyond the extent of the ecoregion into the Kattegat (Subdivision 21) and 1 stock also extends to the Skagerrak (Subdivision 20).

Figure 14 from the Baltic Sea Fisheries Overview (ICES, 2021e) (Figure 6.7) indicates that there is a high degree of mixing between sprat and herring and also between cod and flounder. The Fisheries Overview also states that the degree of mixing in the pelagic fishery varies between subdivisions and shows a north-south spatial trend.

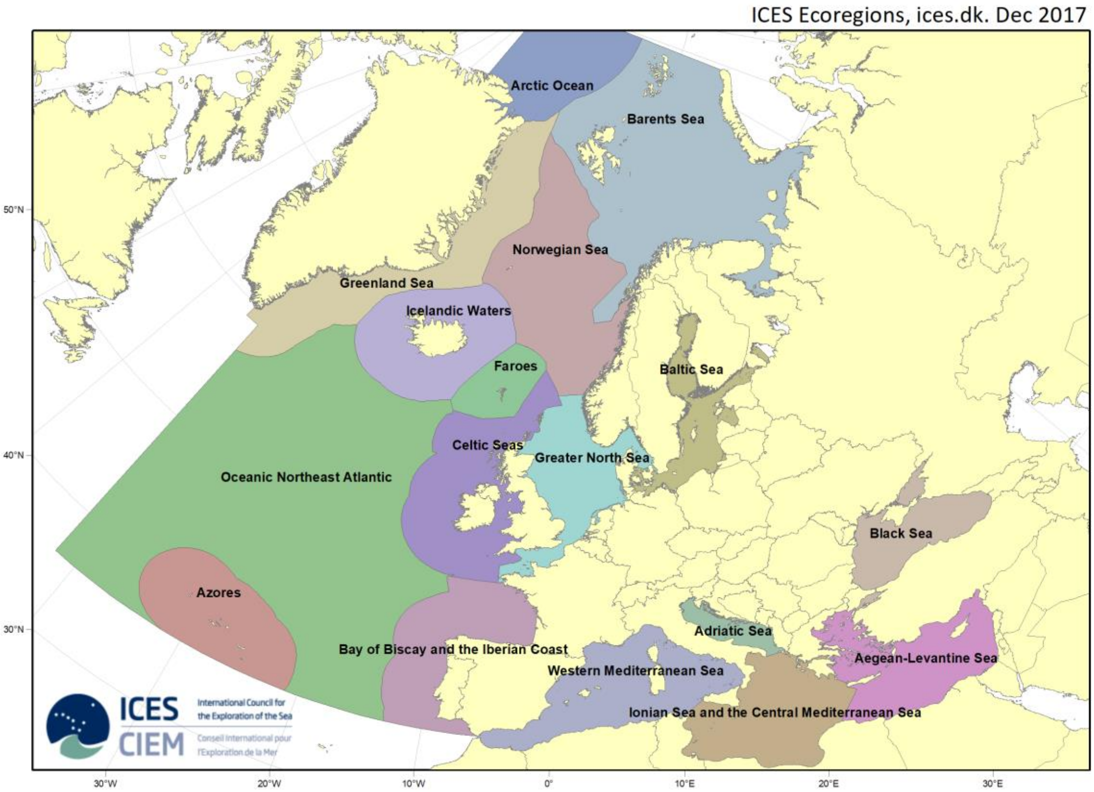


Figure 6.5. Map showing ICES ecoregions

Table 6.3. Baltic Sea stocks assessed by WGBFAS.

Stock	Assessment type
Brill 22-32	Trends based
Cod 21	Trends based
Cod 22-24	Analytical
Cod 25-32	Analytical
Dab 22-32	Trends based
Flounder 22-23	Trends based
Flounder 24-25	Trends based
Flounder 26+28	Trends based
Flounder 27+29-32	Trends based
Herring 25-27, 28.2, 29, 32	Analytical
Herring 28.1	Analytical

Stock	Assessment type
Herring 30-31	Trends based
Plaice 21-23	Trends based
Plaice 24-32	Trends based
Sole 20-24	Analytical
Sprat 22-32	Analytical
Turbot 22-32	Trends based

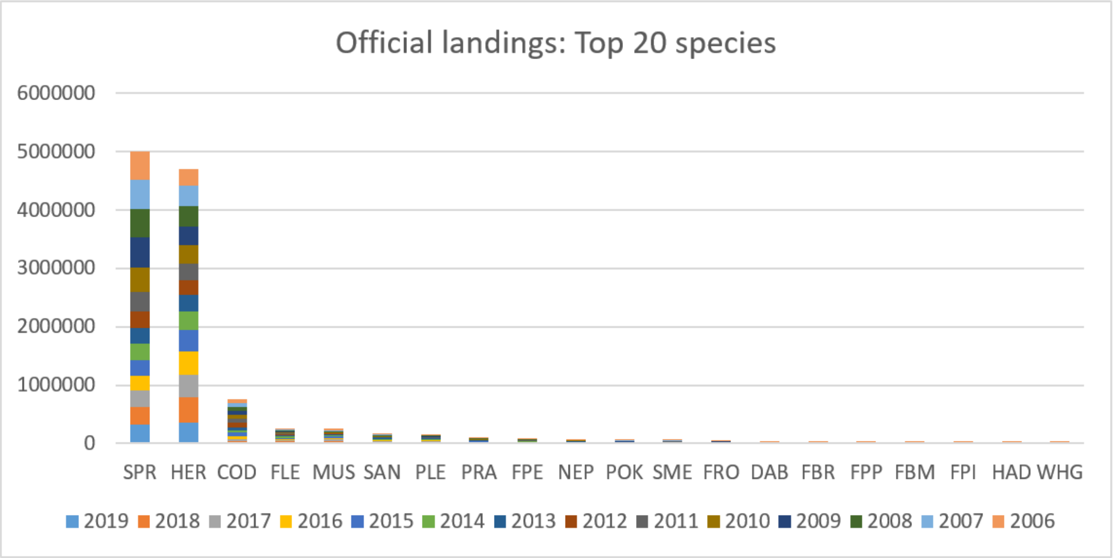


Figure 6.6. Official landings, 2006-2019 in descending order, for the top 20 species caught in the Baltic Sea.

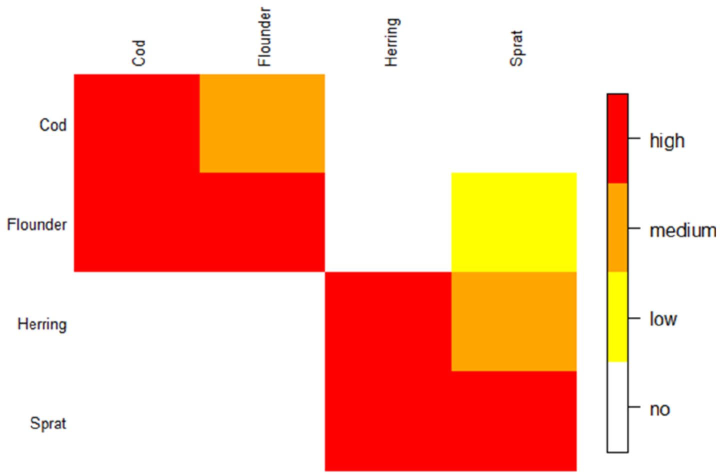


Figure 14 Technical interactions between the four most important stocks in the Baltic Sea. The rows illustrate the fisheries where the species A was caught. The red cells indicate the species B which the A species are frequently caught together with; the orange cells indicate medium interactions; the yellow cells indicate weak interactions. The columns show the degree of mixing in fisheries where species B accounts for at least 5% of the total landings. A more detailed explanation of Figure 14 is provided in the text.

Figure 6.7. Figure 14 taken from the ICES Fisheries Overview for the Baltic Sea showing the strength of technical interactions between different species caught in the Baltic Sea. The data source for this figure is most likely STECF data.

ICES subdivisions covering the Baltic have been listed on the WGMIXFISH data call for a number of years and data have been provided by all Baltic nations (except Russia) and for all stocks assessed by WGBFAS. To begin initial exploration of the accessions data currently submitted, a QC report was drafted for the Baltic ecoregion (all countries together). The length of the time-series covers 12 years (2009–2020) and the number of records each year was found to be fairly consistent through time. Some minor issues were found with non-standard codes present in the data (i.e. submitted codes do not match those requested in the data call). The submission of non-standard codes is an issue routinely identified by our annual QC procedure and correction requests are provided to data submitters as part of this process. This has proven to be an effective method for improving the consistency of the accessions data. Overall, the consistency between the effort and catch datasets was high with a low percentage of unmatched metiers (~5%).

Outstanding issues requiring resubmission:

- Finland have only 1 year of data (2020). Data for 2009-2019 need to be submitted.
- Some effort total (subdivisions 27.3.c.22 and 27.3.d.24 in 2017) look unusually high and need to be checked with data submitters.
- Vessel codes are missing for some catch records from Germany between 2009-2011.
- There were several thousand occurrences of duplicate records. In some cases, this is due to identical records being reported in multiple files and needs to be corrected by data submitters. In other cases, the duplicate records come from data resubmissions and can be addressed through our data collation procedure.

Most of the catches provided to WGMIXFISH are reported as either “active” (mostly trawls) or “passive” (mostly gillnets) metier codes. It is assumed that data submitted to InterCatch will match these metiers. However, this low diversity of reported metiers may explain the high level of consistency between the catch and effort datasets. This may also give a false impression of the strength of technical interactions, especially between demersal and pelagic species, as the high-level aggregation of metiers makes it appear that many species are being caught together when in reality they would be being caught with different gear types and mesh sizes. This is demonstrated by comparing the landing compositions where many metiers are reported (Figure 6.8) to the catch compositions where only the “active” and “passive” metiers are reported (Figure 6.9). This high level of aggregation across metiers hinders our ability to properly characterise the technical interactions. Furthermore, more understanding of the mixed fishery issues that advice requesters want to be addressed is needed to inform on the exact data requirements for this ecoregion.

To progress work on the Baltic Sea discussions with experts from WGBFAS will be needed to gain a better understanding of the mixed fisheries issues for this ecoregion (such as 0 TAC advice, pelagic-demersal mixing, mixing of pelagic stocks). This information will be used to design a Baltic specific data call to ensure that WGMIXFISH receive mixed fisheries data in the most appropriate format to address these issues. This revised data format may diverge from the Baltic metier definitions currently submitted to InterCatch and so this should be accounted for in the design of the data call. Once the data are received an initial data analysis can be conducted to characterise the technical interactions that are relevant to the mixed fisheries issues in the Baltic. However, for this work to be completed 1-2 Baltic fisheries experts will need to join WGMIXFISH for 1-2 years. Furthermore, the longer-term development of mixed fisheries work for this ecoregion is wholly dependent on the permanent recruitment of experts on the Baltic fisheries to WGMIXFISH.

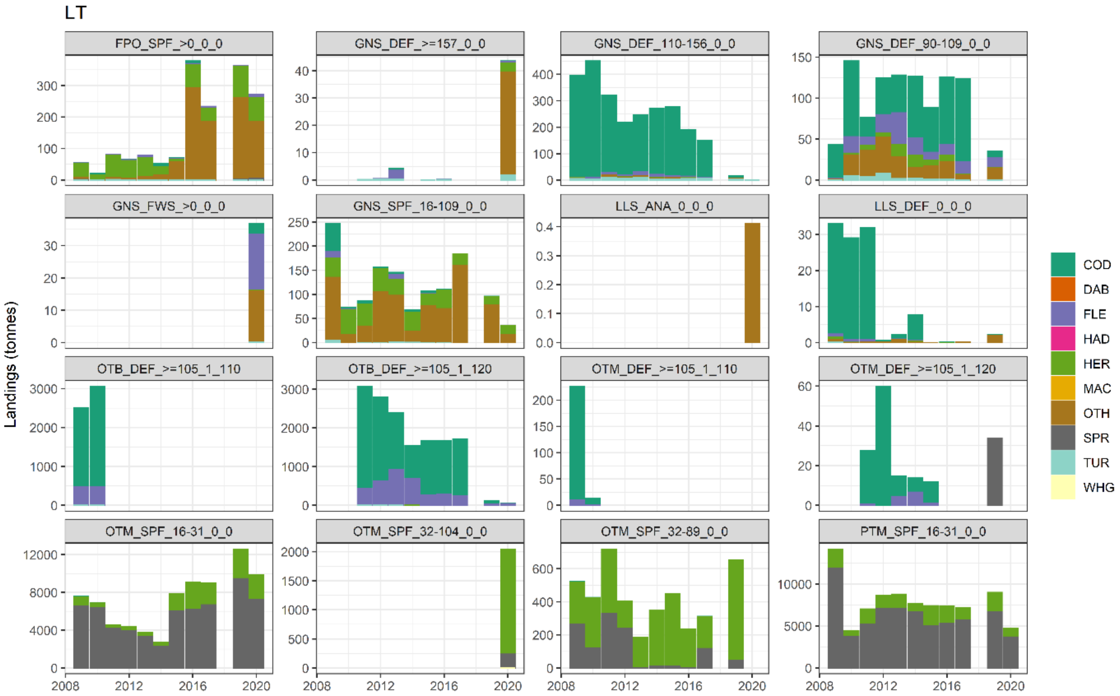


Figure 6.8. Landings per species by métier (2009-2021). An example where data has been submitted under multiple métiers.

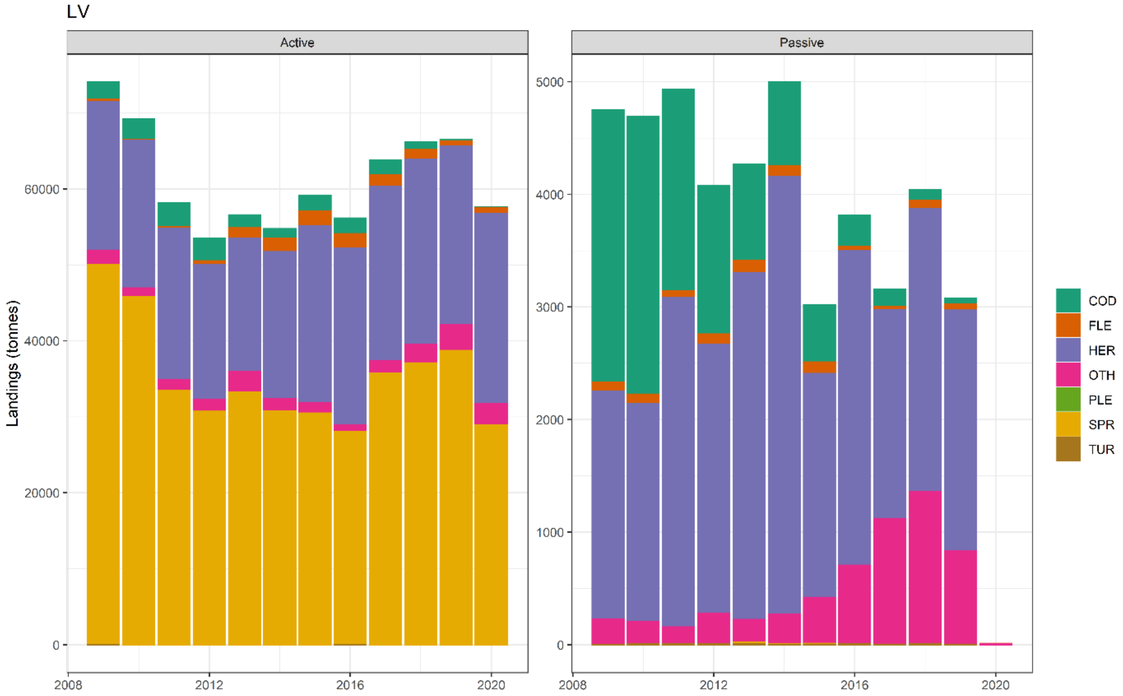


Figure 6.9. Landings per species by metier (2009-2021). An example where data has been submitted under just 2 métiers; “active” and “passive”.

7 ToR F: Plan a second scoping workshop to present developments made since WKMIXFISH and to close the remaining knowledge gaps on the use and value of mixed fisheries advice

The WKMIXFISH scoping workshop, held in March 2020, offered an opportunity to review progress and the scientific advisory capacity of ICES to support the management of mixed fisheries. The workshop had several aims (ICES, 2021f). Firstly, to review current methods and approaches used to deliver mixed fisheries considerations with particular attention on the understanding and interpretability from managers and stakeholders. Secondly, to identify new ways of presenting the many layers of information available from mixed fisheries analyses and finally, to review recent scientific developments that informed on the management challenges caused by mixed fisheries interactions.

Several key issues were identified at WKMIXFISH and through subsequent interactions with stakeholders/advice requesters. It was clear that - while there was strong support for advice that addressed mixed fisheries interactions - the current level of understanding of mixed fisheries outputs and methodologies amongst managers and stakeholders was low. In general, there was more interest in scenarios than catch advice based on specific objectives. More recently, concerns were raised by the European Commission on the realism of the current scenarios especially at fleet level concerning choking effects and future fishing patterns and overall confidence in model performance (see Annex 5). These issues can be resolved through using simpler and more intuitive plots and text in the mixed fisheries considerations, designing new tools (i.e. online advice) to enable user-specific access to data and model outputs and addressing specific concerns on realism by reviewing the assumptions used in the mixed fisheries models.

Some advances have been made to resolve these issues though disruption from national lockdowns during the Covid-19 pandemic has slowed progress. In addition, significant knowledge gaps still exist between WGMIXFISH and users of mixed fisheries considerations on the use and value of our products. As a result, a second scoping workshop (WKMIXFISH2) is proposed.

One aim of this second workshop would be to seek direct feedback on the improvements made so far to address the issues identified at WKMIXFISH, and to understand the primary purpose and expected outputs from the scenarios. This includes changes made to the current plots produced, improvements to characterising uncertainty in model assumptions/conditioning, the design of web-based tools for advice, the presentation of fleet-based information and the reporting of model performance metrics to improve confidence.

Another aim would be, with the involvement of stakeholders, to further develop the current scenarios or design new mixed fisheries products. Possible topics to consider would be the operational use of F_{MSY} ranges, evaluating new gears/selectivity changes in a mixed fisheries context, incorporating economic data, modelling changes in fisher behaviour in response to changing advice and including information of bycatch and protected, endangers and threatened (PET) species. It is likely that WGMIXFISH would need support from external groups with expertise on economics, spatial fishing data, gear technology and social science. The ideas gathered during the scoping meeting would then be developed further before seeking direct feedback from stakeholders. Due to the scope of work planned, it is likely that this second scoping workshop will need to take place in two parts.

Further planning of WKMIXFISH2 will take place later in 2022 to identify exact timescales, select a chair and refine the aims and objectives.

8 ToR G: Review the contribution of mixed fisheries advice to the fisheries overviews and propose alternatives, to provide valuable fleet level information to stakeholders and raise awareness of the work done by WGMIXFISH

Mixed fisheries information is currently presented in all Fisheries Overviews but WGMIXFISH provides information for the Baltic Sea, Celtic Seas, Greater North Sea and Bay of Biscay and Iberian Coast. However, the mixed fisheries contributions are produced from a wide variety of dataset and are inconsistently presented across the ecoregions.

During the meeting a review of the mixed fisheries information currently presented in the Fisheries Overviews was conducted. This is summarised in Table 8.1.

Table 8.1. Summary of mixed fisheries information presented in the Fisheries Overview

FO section	Information presented	Baltic Sea	Bay of Biscay and Iberian Coast	Celtic Seas	Greater North Sea
Who is fishing	Plot: Total effort by country	Data source: STECF	Data source: STECF	Data source: STECF	Data source: STECF
Who is fishing	Plot: Total effort by gear type	Data source: STECF	Data source: STECF	Data source: STECF	Data source: STECF
Description of the fisheries	Plot: Spatial distribution of average fishing effort by gear type	Data source: VMS	Data source: VMS	Data source: VMS	Data source: VMS
Description of the fisheries	Plot: Spatial distribution of landings of main species	-	-	Data source: STECF	-
Mixed fisheries	Text: Summary of latest MF considerations	-	Present	Present	Present
Mixed fisheries	Text: Description of main fleets/technical interactions/storytelling	Present. Based on technical interaction matrix plot	Present. Based on catch composition plot	Present. Based on catch composition plot	Present. Based on technical interaction matrix plot
Mixed fisheries	Plot: Catch compositions	-	Data source: WGMIXFISH	Data source: WGMIXFISH	-
Mixed fisheries	Technical interaction matrix	Data source: STECF	-	-	Data source: STECF

FO section	**Information presented**	**Baltic Sea**	**Bay of Biscay and Iberian Coast**	**Celtic Seas**	**Greater North Sea**
Mixed fisheries	Reported spatial variation in mixing of pelagic fisheries	Data source: unknown	-	-	-

Following this review, it is proposed that WGMIXFISH reproduce the plots currently presented in the Fisheries Overviews, where possible, using WGMIXFISH datasets. The plots presented and accompanying text should also be standardised across the different ecoregions. As mixed fisheries considerations are now removed from the FO document and are provided as a standalone document, WGMIXFISH was asked to provide a figure/table summarising the main message of mixed fisheries analyses in the Fisheries Overviews. A proposal was to introduce a new plot to present information on effort by fleet resulting from stock-specific scenario runs from the mixed fisheries models (i.e. the effort by fleet resulting from the full utilisation of the TAC for a specified stock (see Figure 8.1). It was also proposed that the technical interaction matrix plot might be updated when the RDBES is available. Having information at trip/fishing operation level will makes that matrix relevant as technical interaction are occurring at that level. These updates should be completed in time for review at WGMIXFISH-ADVICE 2022 in October.

Proposals for additional mixed fisheries contributions will be discussed and reviewed at WGMIXFISH-METH 2023. Such additions could include a description of the major fleets/metiers in the ecoregion, a description of and storytelling around the main technical interactions and the expansion on existing plots or text into presenting information on pelagic fisheries. Further ahead, the launch of RDBES may provide opportunities to provide information in a spatial context.

Figure 8.1. Relative change in the assessment year from status quo effort resulting from stock-specific scenarios run in the Bay of Biscay mixed fisheries model.

To facilitate standardisation between different case studies in the fisheries overviews a graph showing the catch composition per métier originating from the Celtic Sea case study was adapted for the North Sea (Figure 8.2). However, as the amount of detail on métier level would be likely too much for the North Sea, a first version only showing details on the fleet level was produced and added to the "report.rmd" file in the TAF-github repository.

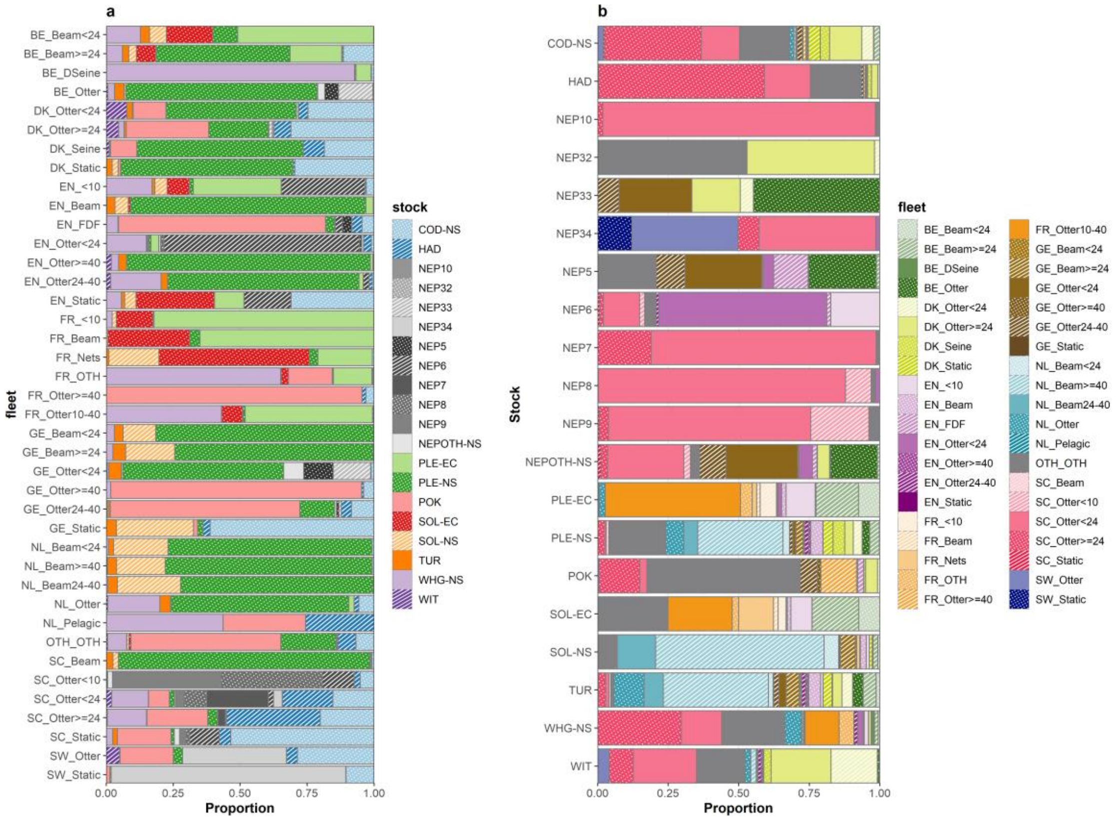


Figure 8.2. Description of technical interactions in the mixed fisheries of the North Sea showing a) the catch composition of each fleet and b) which fleet contributes to the catch of each stock in 2019. The fleet-label incorporates the country code, main gear and length class.

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Annex 1: List of participants

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Annex 2: Draft resolution 2023

WGMIXFISH-METHODS - Working Group on Mixed Fisheries Advice Methodology

The Working Group on Mixed Fisheries Advice Methodology (WGMIXFISH-METHODS), chaired by Marc Taylor, Germany, and Harriet Cole, UK, will hold a hybrid meeting in San Sebastián, Spain, on 19–23 June 2023, to:

a. Continue the improvement of WGMIXFISH-ADVICE data call, data processing, workflow, auditing, updating associated documentation and increasing transparency;
b. Respond to the outcomes of the Mixed Fisheries Scoping Meeting;
c. Exploration of developments in methodology and advice;
d. Respond to the outcomes and issues encountered during WGMIXFISH-Advice;
e. Develop mixed fisheries models for sea regions not currently covered in the mixed fisheries advice;

WGMIXFISH-METHODS will report by 29 July 2023 for the attention of ACOM.

Only experts appointed by national Delegates or appointed in consultation with the national Delegates of the expert's country can attend this Expert Group.

Supporting information

Priority:	The work is essential to ICES to progress in the development of its capacity to provide advice on multispecies fisheries. Such advice is necessary to fulfil the requirements stipulated in the MoUs between ICES and its client commissions.
Scientific justification and relation to action plan:	The issue of providing advice for mixed fisheries remains an important one for ICES. The Aframe project, which started on 1 April 2007 and finished on 31 march 2009 developed further methodologies for mixed fisheries forecasts. The work under this project included the development and testing of the FCube approach to modelling and forecasts. In 2008, SGMIXMAN produced an outline of a possible advisory format that included mixed fisheries forecasts. Subsequently, WKMIXFISH was tasked with investigating the application of this to North Sea advice for 2010. AGMIXNS further developed the approach when it met in November 2009 and produced a draft template for mixed fisheries advice. WGMIXFISH has continued this work since 2010.
Resource requirements:	No specific resource requirements, beyond the need for members to prepare for and participate in the meeting.
Participants:	Experts with qualifications regarding mixed fisheries aspects, fisheries management and modelling based on limited and uncertain data.
Secretariat facilities:	Meeting facilities, production of report.

Financial:	None
Linkages to advisory committee:	ACOM
Linkages to other committees or groups:	SCICOM through the WGMG. Strong link to STECF.
Linkages to other organizations:	This work serves as a mechanism in fulfilment of the MoU with EC and fisheries commissions. It is also linked with STECF work on mixed fisheries.

Annex 3: Incorporation of flexible environmentally-mediated stock-recruitment relationships in FLBEIA

Prepare a one Stock/one fleet example

```
library(FLCore)
library(FLBEIA)
library(dplyr)
library(mgcv)
```

Create an artificial population driven by two environmental covariates

To illustrate the problem, we simulate a simple one-stock, one fleet system, where recruitment is driven by two environmental covariates (one with a positive trend having a negative effect on recruitment and the other one showing a quadratic relationship with recruitment) and spawning stock biomass (SSB).

```
# example with artificial data
set.seed(27)
N = 200

# a 12 age population
n.stages = 12
pop.def = list(ages = c(1:n.stages), weights = 100 *
  (tanh(((2 * pi * scale(1:n.stages, 1, n.stages -
    1) - pi))) + 1)/2, fertility = c(rep(0, floor(0.2 *
  n.stages)), rep(1, ceiling((1 - 0.2) * n.stages))),
  m = c(rep(0.4, floor(0.4 * n.stages)), rep(0.2,
    ceiling((1 - 0.4) * n.stages))), selectivity = c(0.1,
    0.2, 0.5, rep(1, n.stages - 3)))
start.pop = 1e+05 * exp(-0.2 * (1:n.stages))

# environmental variable with trend and positive
# autocorrelation
env1 = seq(0.1, 12, length.out = N) + arima.sim(n = N,
  model = list(order = c(1, 0, 0), ar = 0.7, sd = 0.1))
# environmental variable with negative
# autocorrelation
env2 = arima.sim(n = N, model = list(order = c(1, 0,
  0), ar = -0.5, sd = 2))

# population parameters
n = 100

# create a time series of fishing mortality
ts = cumsum(arima.sim(n = n, model = list(order = c(1,
  0, 0), ar = 0.4, sd = 0.005)))
F_ts = as.numeric(0.5 * scale(ts, min(ts), max(ts) -
  min(ts)))

ssb = rep(NA, n)
ssb[1] = sum(start.pop * pop.def$fertility * pop.def$weights)
age0 = rec = rep(NA, n)
```

```r
ages = catch = data.frame(matrix(NA, nrow = n, ncol = length(pop.def$ages)))
ages[1, ] = start.pop
for (i in 2:n) {
  age0[i - 1] = exp(1.1 * log(min(c(ssb[i - 1], 1e+12))) -
    0.4 * env1[i - 1] + 0.3 * (env2[i - 1])^2 +
    rnorm(1, 0, 0.7))
  for (j in 1:ncol(ages)) {
    if (j == 1) {
      # assuming an initial natural mort of
      # 0.4 in the first yr (before rec.
      # happen)
      ages[i, j] = rec[i] = age0[i - 1] * exp(-0.4)
    } else if (j > 1 & j < ncol(ages)) {
      Z = pop.def$m[j - 1] + F_ts[i - 1] * pop.def$selectivity[j -
        1]
      ages[i, j] = ages[i - 1, j - 1] * exp(-Z)
      catch[i, j] = ((F_ts[i - 1] * pop.def$selectivity[j -
        1])/Z) * ages[i - 1, j - 1] * (1 -
        exp(-Z))
    } else if (j == ncol(ages)) {
      Z = pop.def$m[j] + F_ts[i - 1] * pop.def$selectivity[j]
      ages[i, j] = ages[i - 1, j] * exp(-Z)
      catch[i, j] = ((F_ts[i - 1] * pop.def$selectivity[j])/Z) *
        ages[i - 1, j] * (1 - exp(-Z))
    }
  }
  ssb[i] = sum(ages[i, ] * pop.def$fertility * pop.def$weights)

}

# remove burn-in phase (first 50 data points)
ssb = ssb[-(1:50)]
rec = rec[-(1:50)]
env1 = env1[-(1:50)]
env2 = env2[-(1:50)]
ages = ages[-(1:50), ]
catch = catch[-(1:50), ]
F_ts = F_ts[-(1:50)]
year = (1:n)[-(1:50)]

df = data.frame(year = year, rec = rec, ssb = ssb,
  env1 = env1[1:(n - 50)], env2 = env2[1:(n - 50)])

# calc lagged versions of the time series

x.lagged = data.frame(apply(df[, c("ssb", "env1", "env2")],
  2, function(x) dplyr::lag(x = x, n = 1)))
names(x.lagged) = paste(names(df[, c("ssb", "env1",
  "env2")]), "lag1", sep = "_")
rec.df = df[, c("year", "rec"), drop = F]
df_lagged = data.frame(rec.df, x.lagged)
df_lagged = df_lagged[complete.cases(df_lagged), ]

# plot SSB & covars
par(mfrow = c(1, 3), mar = c(4, 2, 2, 1))
plot(1960:(1960 + nrow(df) - 1), df$ssb, type = "l",
  xlab = "year", ylab = "")
title("SSB", adj = 0, line = 0.5)
plot(1960:(1960 + nrow(df) - 1), df$env1, type = "l",
  xlab = "year", ylab = "")
title("Covar1", adj = 0, line = 0.5)
plot(1960:(1960 + nrow(df) - 1), df$env2, type = "l",
  xlab = "year", ylab = "")
title("Covar2", adj = 0, line = 0.5)
```

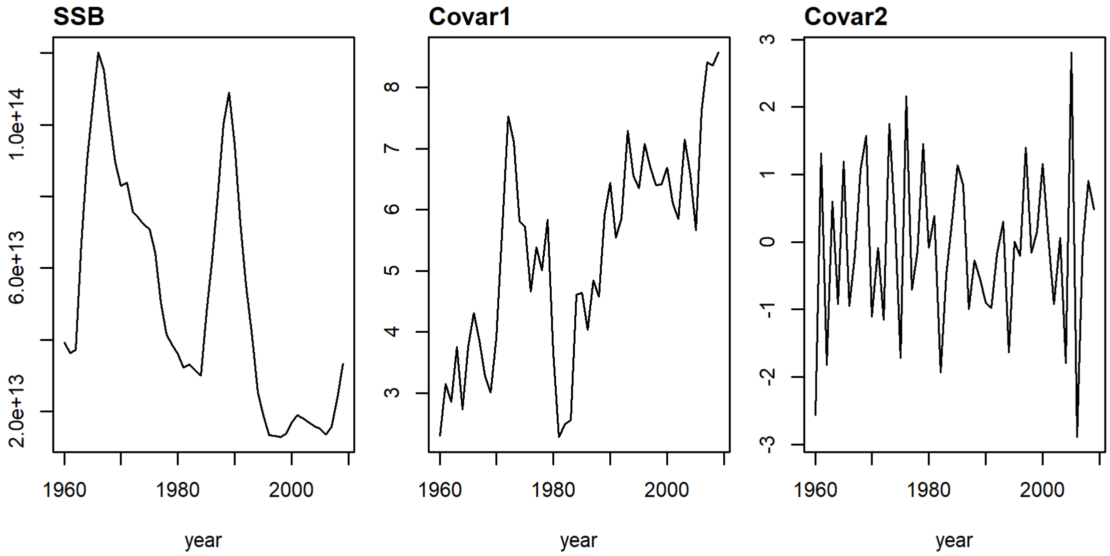

Fig 1. Time-series of SSB, Covar1 and Covar2 for the simulated stock

```
# plot Recruitment and SSB
par(mfrow = c(1, 2), mar = c(4, 4, 2, 0.5))
plot(1960:(1960 + nrow(df) - 1), df$rec, type = "l",
  xlab = "year", ylab = "")
title("Rec", adj = 0, line = 0.5)
plot(df$ssb[-1], df$rec[-nrow(df)], ylim = c(0, max(df$rec)),
  xlim = c(0, max(df$ssb)), xlab = expression("SSB"[t -
    1]), ylab = "Rec")
title("Stock-rec. Rel", adj = 0, line = 0.5)
```

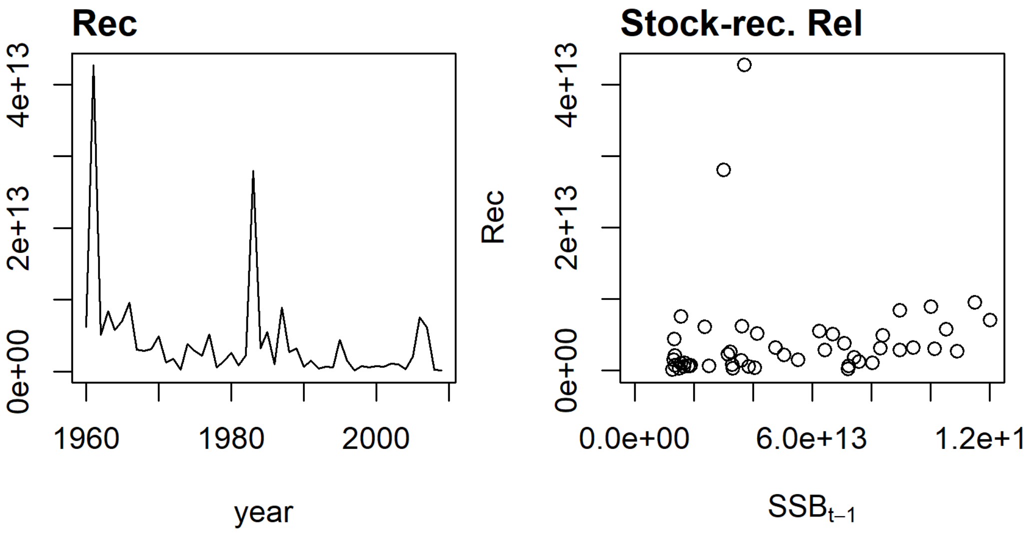

Fig 2. Time-series of recruitment and the Stock-recruitment relationship for the simulated stock

```
# model with a gam
dat = data.frame(rec = df_lagged$rec, ssb = df_lagged$ssb_lag1,
  covar1 = df_lagged$env1_lag1, covar2 = df_lagged$env2_lag1)
```

```
# fitting the EMSRR
gam.fit = gam(rec ~ s(ssb, k = 4, bs = "tp") + s(covar1,
  k = 4, bs = "tp") + s(covar2, k = 4, bs = "tp"),
  data = dat, family = gaussian(link = "log"))

summary(gam.fit)

##
## Family: gaussian
## Link function: log
##
## Formula:
## rec ~ s(ssb, k = 4, bs = "tp") + s(covar1, k = 4, bs = "tp") +
##   s(covar2, k = 4, bs = "tp")
##
## Parametric coefficients:
##       Estimate Std. Error t value Pr(>|t|)
## (Intercept)  28.50    0.15   190  <2e-16 ***
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##       edf Ref.df   F p-value
## s(ssb)  1.167 1.312 0.063  0.819
## s(covar1) 1.000 1.000 59.194 <2e-16 ***
## s(covar2) 2.642 2.904 41.932 <2e-16 ***
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) = 0.877  Deviance explained = 88.9%
## GCV = 7.0986e+24 Scale est. = 6.2571e+24 n = 49

# plot the gam fit
par(mfrow = c(1, 3), mar = c(4, 4, 3, 1), oma = c(0,
  0, 1, 0))
for (i in 1:3) {
  plot(gam.fit, select = i)
  title(c("SSB", "Covar1", "Covar2")[i], adj = 0,
    cex.main = 0.7, line = 0.6)
}
par(mfrow = c(1, 1))
mtext("Partial effects GAM", adj = 0.5, font = 2, line = -0.5,
  outer = T)
```

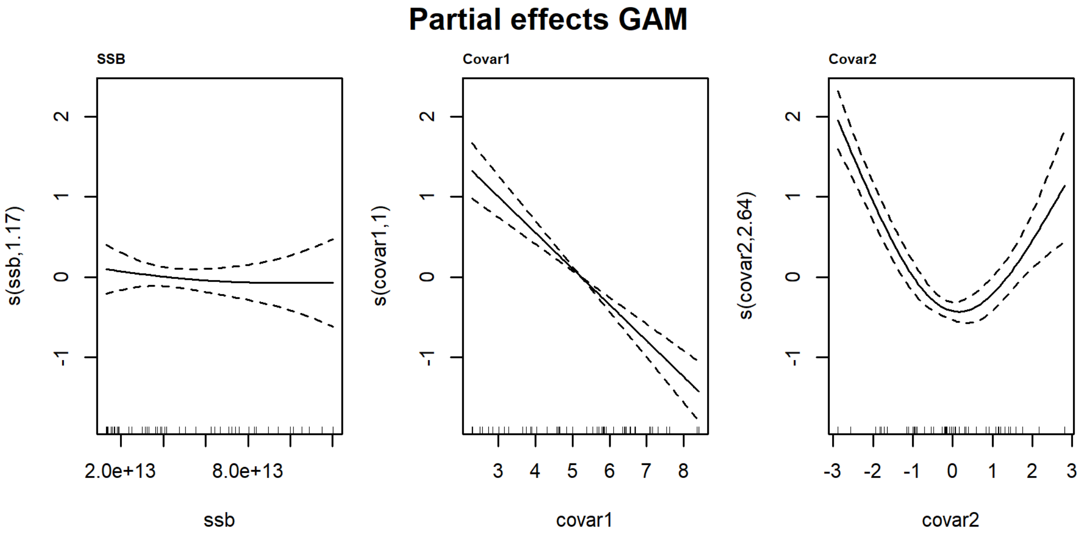

Figure 3. Partial effects for SSB, Covar1 and Covar2 in the GAM-stock-recruitment model.

Conditioning the FLBEIA model

```
first.yr = 2010 - 50 # first year of the simulation
proj.yr = 2010 # first year of the projection period
last.yr = 2060 # last year of the projection period (and the whole simulation)
yrs = c(first.yr = first.yr, proj.yr = proj.yr, last.yr = last.yr)
hist.yrs = first.yr:(proj.yr - 1)

# Set names, age, dimensions

fls = c("fl1") # name of the fleets

stks = c("stk1") # name of the stocks

fl1.mets = c("met1") # declare the names of the metiers
fl1.met1.stks = c("stk1") # declare the names of the stocks

# all stocks the same

ni = 1 # nr. of iterations
it = 1:ni #
ns = 1 # nr. of seasons

# stock stk1
stk1.age.min = 1
stk1.age.max = 12 # number of age classes
stk1.unit = 1

# ----------------------------------- # Data:
# stk1_n.flq, m, spwn, fec, wt
# ----------------------------------- #

# stock stk1

# numbers
a = matrix(as.numeric(t(as.matrix(ages))), ncol = nrow(ages),
  nrow = ncol(ages))
stk1_n.flq = FLQuant(a, dim = c(n.stages, ncol(a),
  1, 1, 1, 1), quant = "age", units = "NA", iter = 1)
attributes(stk1_n.flq)$dimnames$year = seq(first.yr,
```

```
  proj.yr - 1)

# mortality
stk1_m.flq = FLQuant(pop.def$m, dim = c(n.stages, ncol(a),
  1, 1, 1, 1), quant = "age", units = "NA", iter = 1)
attributes(stk1_m.flq)$dimnames$year = seq(first.yr,
  proj.yr - 1)

# spawning mortality
stk1_spwn.flq = FLQuant(0, dim = c(n.stages, ncol(a),
  1, 1, 1, 1), quant = "age", units = "NA", iter = 1)
attributes(stk1_spwn.flq)$dimnames$year = seq(first.yr,
  proj.yr - 1)

# maturity at age
stk1_mat.flq = FLQuant(pop.def$fertility, dim = c(n.stages,
  ncol(a), 1, 1, 1, 1), quant = "age", units = "NA",
  iter = 1)
attributes(stk1_mat.flq)$dimnames$year = seq(first.yr,
  proj.yr - 1)
# fecundity
stk1_fec.flq = stk1_mat.flq

# weights
stk1_wt.flq = FLQuant(pop.def$weights, dim = c(n.stages,
  ncol(a), 1, 1, 1, 1), quant = "age", units = "NA",
  iter = 1)
attributes(stk1_wt.flq)$dimnames$year = seq(first.yr,
  proj.yr - 1)

stk1_range.min = 1
stk1_range.max = n.stages
stk1_range.plusgroup = n.stages
stk1_range.minyear = first.yr
stk1_range.minfbar = 4
stk1_range.maxfbar = 9

# Projection biols: weight,fecundity,mortality
# and spawning

stk1_biol.proj.avg.yrs = c(2007:2009)

# Create the object
stks.data = list(stk1 = ls(pattern = "^stk1"))
biols = create.biols.data(yrs, ns, ni, stks.data)

# -------------------------------------------- #
# Data: SRs - fit segmented regression to data
# -------------------------------------------- #

# historical data on SSB & rec (for model
# fitting)
ssb = FLCore::ssb(biols[[1]])[, as.character(first.yr:(proj.yr -
  2)), 1, 1]
rec = biols[[1]]@n[1, as.character((first.yr + 1):(proj.yr -
  1)), ]

# Fit the model given historical data
sr.segreg = fmle(FLSR(model = "segreg", ssb = ssb,
  rec = rec))

# fill slots
stk1_sr.model = "segreg"
stk1_params.n = 2
a = sr.segreg@params["a"]
b = sr.segreg@params["b"]
```

```
params = array(c(a, b), dim = c(2, length(first.yr:last.yr),
  1, 1), dimnames = list(param = c("a", "b"), year = as.character(first.yr:last.yr),
  season = 1, iter = 1))

stk1_params.array = params
stk1_params.name = c("a", "b")

# recruitment object

stk1_ssb.flq = FLCore::ssb(biols[[1]])[, ac(first.yr:(proj.yr -
  1)), ]
stk1_rec.flq = biols[[1]]@n[1, ac(first.yr:(proj.yr -
  1)), ]
stk1_uncertainty.flq = FLQuant(1, dim = c(1, length(first.yr:last.yr),
  1, 1, 1, 1), quant = "season", units = "NA", iter = 1)
attributes(stk1_uncertainty.flq)$dimnames$year = first.yr:last.yr
stk1_proportion.flq = FLQuant(1, dim = c(1, length(first.yr:last.yr),
  1, 1, 1, 1), quant = "season", units = "NA", iter = 1)
attributes(stk1_proportion.flq)$dimnames$year = first.yr:last.yr
stk1_prop.avg.yrs = ac(2006:2008)
stk1_timelag.matrix = matrix(c(1, 1), nrow = 2, ncol = 1,
  dimnames = list(c("year", "season"), "all"))

# FLBEIA input object: SRs
stks.data = list(stk1 = ls(pattern = "^stk1"))

SRs = create.SRs.data(yrs, ns, ni, stks.data)

# -------------------------------------------------
# # create Fleets object

# Data per fleet effort, crewshare, fcost,
# capacity Data per fleet and metier effshare,
# vcost Data per fleet, metier and stock
# landings.n, discards.n,landings.wt,
# discards.wt, landings, discards, landings.sel,
# discards.sel, price

# fleet lvl
fl1_effort.flq = as.FLQuant(80000 * F_ts, quant = "age")
attributes(fl1_effort.flq)$dimnames$year = hist.yrs
fl1_capacity.flq = as.FLQuant(1.5 * max(fl1_effort.flq),
  dim = c(1, length(hist.yrs), 1, 1, 1, 1))
attributes(fl1_capacity.flq)$dimnames$year = hist.yrs
fl1_fcost.flq = as.FLQuant(500, dim = c(1, length(hist.yrs),
  1, 1, 1, 1))
attributes(fl1_fcost.flq)$dimnames$year = hist.yrs
fl1_crewshare.flq = as.FLQuant(0.25, dim = c(1, length(hist.yrs),
  1, 1, 1, 1))
attributes(fl1_crewshare.flq)$dimnames$year = hist.yrs

# metier lvl
fl1.met1_effshare.flq = as.FLQuant(1, dim = c(1, length(hist.yrs),
  1, 1, 1, 1))
attributes(fl1.met1_effshare.flq)$dimnames$year = hist.yrs

cc = matrix(as.numeric(t(as.matrix(catch))), ncol = nrow(catch),
  nrow = ncol(catch))
cc[is.na(cc)] = 0
fl1.met1.stk1_landings.n.flq = FLQuant(cc, dim = c(n.stages,
  ncol(cc), 1, 1, 1, 1), quant = "age", units = "NA",
  iter = 1)
attributes(fl1.met1.stk1_landings.n.flq)$dimnames$year = hist.yrs

fl1.met1.stk1_discards.n.flq = FLQuant(0, dim = c(n.stages,
  ncol(cc), 1, 1, 1, 1), quant = "age", units = "t",
```

```
  iter = 1)
attributes(fl1.met1.stk1_discards.n.flq)$dimnames$year = hist.yrs

# Projection fleets: fl1
fl1_proj.avg.yrs = c(2008:2009)
fl1.met1_proj.avg.yrs = c(2008:2009)
fl1.met1.stk1_proj.avg.yrs = c(2006:2008)

# create fleets object

fls.data = list(fl1 = ls(pattern = "^fl1"))

fleets = create.fleets.data(yrs, ns, ni, fls.data,
  stks.data)

# --------------------
# create Advice object

# advice:TAC/TAE/quota.share

stk1_advice.TAC.flq = as.FLQuant(0.9 * fleets$fl1@metiers$met1@catches$stk1@landings,
  quant = "stock")
attributes(stk1_advice.TAC.flq)$dimnames$stock = "stk1"
stk1_advice.quota.share.flq = FLQuant(1, dim = c(1,
  length(first.yr:last.yr), 1, 1, 1, 1), quant = "fleet",
  units = "NA", iter = 1)
attributes(stk1_advice.quota.share.flq)$dimnames$year = first.yr:last.yr
attributes(stk1_advice.quota.share.flq)$dimnames$fleet = "fl1"

stk1_advice.avg.yrs = c(2000:2008)

# create advice object
stks.data = list(stk1 = ls(pattern = "^stk1"))

advice = create.advice.data(yrs, ns, ni, stks.data,
  fleets)

# --------------------
# indices

# no index
indices = NULL

# --------------------
# create ctrls:
# Biols.ctrl - fleet-ctrl - obs.ctrl -
# Assessment.ctrl - advice.ctrl - main.ctrl

# biols ctrl
growth.model = c("ASPG")
biols.ctrl = create.biols.ctrl(stksnames = stks, growth.model = growth.model)

# fleet ctrl
n.fls.stks = 1
fls.stksnames = "stk1"
effort.models = "SMFB"
effort.restr.fl1 = "stk1"
restriction.fl1 = "catch"
catch.models = "CobbDouglasAge"
capital.models = "fixedCapital"
flq.stk1 = FLQuant(dimnames = list(age = "all", year = first.yr:last.yr,
  unit = stk1.unit, season = 1:ns, iter = 1:ni))

fleets.ctrl = create.fleets.ctrl(fls = fls, n.fls.stks = n.fls.stks,
  fls.stksnames = fls.stksnames, effort.models = effort.models,
  catch.models = catch.models, capital.models = capital.models,
```

```
  flq = flq.stk1, effort.restr.fl1 = effort.restr.fl1,
  restriction.fl1 = restriction.fl1)

fleets.ctrl$fl1$stk1$discard.TAC.OS = FALSE

# obs. ctrl
stkObs.models = "perfectObs"
flq.stk1 = FLQuant(dimnames = list(age = "all", year = first.yr:last.yr,
  unit = stk1.unit, season = 1:ns, iter = 1:ni))

obs.ctrl = create.obs.ctrl(stksnames = stks, stkObs.models = stkObs.models,
  flq.stk1 = flq.stk1)

# Assessment ctrl
assess.models = "NoAssessment"
assess.ctrl = create.assess.ctrl(stksnames = stks,
  assess.models = assess.models)
assess.ctrl[["stk1"]]$work_w_Iter = TRUE

# advice ctrl
HCR.models = c("IcesHCR")
ref.pts.stk1 = matrix(rep(c(1e+13, 2.3e+13, quantile(F_ts,
  0.3)), 3), 3, ni, dimnames = list(c("Blim", "Btrigger",
  "Fmsy"), 1:ni))
advice.ctrl = create.advice.ctrl(stksnames = stks,
  HCR.models = HCR.models, ref.pts.stk1 = ref.pts.stk1,
  first.yr = first.yr, last.yr = last.yr)

advice.ctrl[["stk1"]][["sr"]] = list()
advice.ctrl[["stk1"]][["sr"]][["model"]] = "geomean"
advice.ctrl[["stk1"]][["sr"]][["years"]] = c(y.rm = 2,
  num.years = 10)
advice.ctrl$stk1$AdvCatch = rep(TRUE, length(first.yr:last.yr))
names(advice.ctrl$stk1$AdvCatch) = as.character((first.yr:last.yr))

# main ctrl
main.ctrl = list()
main.ctrl$sim.years = c(initial = proj.yr, final = last.yr)
```

Run FLBEIA model

First we simulate recruitment with a simple Hockey-stick relationship not taking into account any environmental effects.

```
ex1 = FLBEIA(biols = biols, SRs = SRs, BDs = NULL,
  fleets = fleets, covars = NULL, indices = NULL,
  advice = advice, main.ctrl = main.ctrl, biols.ctrl = biols.ctrl,
  fleets.ctrl = fleets.ctrl, covars.ctrl = NULL,
  obs.ctrl = obs.ctrl, assess.ctrl = assess.ctrl,
  advice.ctrl = advice.ctrl)

plot(ex1$stocks[[1]])
```

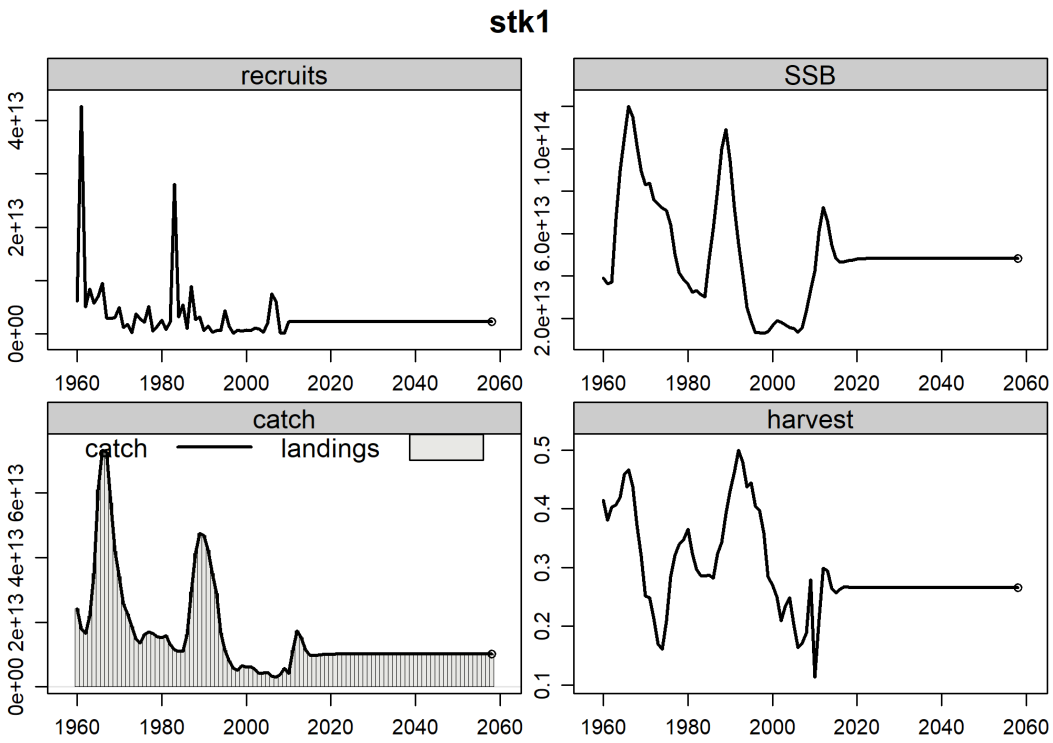

Fig 4. Quick summary plot of the FLBEIA output (with a simple Hockeystick recruitment) showing recruitment, SSB, catch and fishing mortality.

Incorporation of a flexible EMSRR

Now we try to incorporate the GAM-model with SSB and 2 covariates, we fitted earlier, into the FLBEIA model. Including a user-defined SR-relationship in FLBEIA is done in three steps: First one needs to define a function `SR.predict(...)` to predict recruitment as a FLQuant-object based on SSB and various covariates. Second, this function needs to be encased in wrapper-function `SR.predict.wrapper(...)`, which is structured like the FLCore-based SR-functions e.g. `bevholt` or `ricker`. At last, a call to this function needs to be included in the respective `SR$stock@model`-slot of the SR-object and the covariates for future projections stored in the `SR$stock@covariate` slot.

```
# use the GAM-model defined earlier
EMSRR.model_stk1 = gam.fit
```

SR.predict(...)

In our example, this function predicts recruitment based on SSB and 2 covariates and returns a prediction stored in the form of a FLQuant-object. Contrary to the classic Beverton-Holt function, which requires additional parameters to be specified, a nonparametric model like a GAM requires no further parameters passed to the function. However, FLBEIA requires the explicit definition of parameters related to the SR-model (e.g. "a" and "b" in the case of Beverton-Holt), otherwise it will throw an error. To circumvent this problem we add a dummy-parameter to the function call of `SR.predict(...)`, which has no effect on the prediction. Note that this dummy-parameter needs to be later referred to in the `SRs$stock$params` slot.

```
# create a function to make preditions

SR.predict = function(ssb, covar1, covar2, dummy.param) {
  stopifnot(require(mgcv))
  # convert to vector
  new.data = data.frame(ssb = as.vector(ssb), covar1 = as.vector(covar1),
    covar2 = as.vector(covar2))
  # predict
  new.rec = predict(EMSRR.model_stk1, newdata = new.data,
    type = "response")

  # convert back to FLQuant-obj
  new.rec = FLQuant(as.vector(new.rec))
  return(new.rec)
}
```

SR.predict.wrapper(…)

This wrapper-function needs to be matched to the characteristic structure of the built-in SR-functions from FLCore. It requires no input and returns three output-objects stored in a list specifying the loglikelihood for optimisation `logl` in the first slot, the `model` of class formula in the second and optional starting parameters for the model fitting **`initial`** in the third. The FLBEIA-routine accesses the second slot `model`, where we need to call our own SR-function `SR.predict(...)`.

```
# SR predict wrapper function

SR.predict.wrapper = function() {
  logl = NA
  initial = NA
  model = as.formula(rec ~ SR.predict(ssb, covar1,
    covar2, dummy.param))
  return(list(logl = logl, model = model, initial = initial))
}
```

Changes in the SRs-object

The following changes need to be done to the `SRs-object`, which stores the stock-recruitment related information, in order for the simulation routine to find the user-defined SR-model as well as all relevant input variables. A FLQuant-object containing the dummy parameter needs to be assigned to the slot `SRs$stock@params` and the name of the SR-model, in this case `SR.predict.wrapper(...)` needs to be stored in the model slot `SRs$stock@model`. At last a FLQuants-list containing the covariates as FLQuant-objects needs to be assigned to the `SRs$stock@covar` slot.

```
# load environmental covariates (organised as data.frame)

df.covars = data.frame(year = 1960:(1960 + length(env1) -
  1), covar1 = env1, covar2 = env2)

# dummy parameter
dummy.params = array(0, dim = c(1, length(first.yr:last.yr),
  1, 1), dimnames = list(param = c("dummy.param"),
  year = as.character(first.yr:last.yr), season = 1,
  iter = 1))

SRs_emsrr = SRs
SRs_emsrr[["stk1"]]@params = dummy.params
```

```
# SR-relationship
SRs_emsrr[["stk1"]]@model = "SR.predict.wrapper"

# covar can only be included AFTER SR is already
# defined!
covar.flq = FLQuants(covar1 = FLQuant(df.covars$covar1[df.covars$year %in%
  ac(first.yr:last.yr)], dimnames = list(year = ac(first.yr:last.yr))),
  covar2 = FLQuant(df.covars$covar2[df.covars$year %in%
    ac(first.yr:last.yr)], dimnames = list(year = ac(first.yr:last.yr))))

SRs_emsrr[["stk1"]]@covar = covar.flq
```

Run FLBEIA with newly defined EMSRR

Now we run FLBEIA with the newly defined EMSRR and compare the output with a baseline model, where we simulated recruitment with a simple Hockeystick function.

```
ex2 = FLBEIA(biols = biols, SRs = SRs_emsrr, BDs = NULL,
  fleets = fleets, covars = NULL, indices = NULL,
  advice = advice, main.ctrl = main.ctrl, biols.ctrl = biols.ctrl,
  fleets.ctrl = fleets.ctrl, covars.ctrl = NULL,
  obs.ctrl = obs.ctrl, assess.ctrl = assess.ctrl,
  advice.ctrl = advice.ctrl)

plot(ex2$stocks[[1]])
```

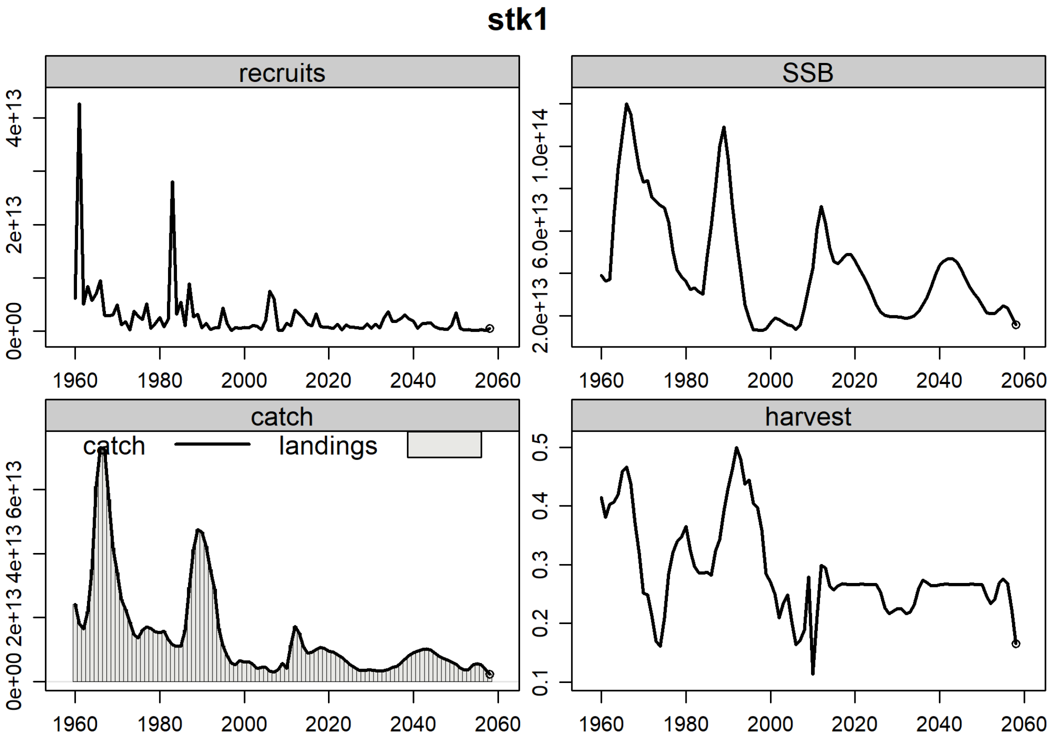

Fig 5. Quick summary plot of the FLBEIA output (with the environmentally-mediated SRR) showing recruitment, SSB, catch and fishing mortality.

Compare Scenarios

```
output = rbind(bioSum(obj = ex1, scenario = "Hockeystick with no Covar",
  long = T), bioSum(obj = ex2, scenario = "flexible EMSRR",
  long = T))

ind = c("rec", "ssb", "catch", "f")
output.ind = output[output$indicator %in% ind, ]
output.ind$indicator = factor(output.ind$indicator,
  levels = ind)

ggplot(output.ind, aes(x = year, y = value)) + geom_line(aes(col = scenario),
  lwd = 1.1) + geom_vline(xintercept = proj.yr, lty = "dashed") +
  ylab("") + facet_wrap(~indicator, scales = "free_y") +
  theme_bw() + theme(strip.text.x = element_text(size = 10))
```

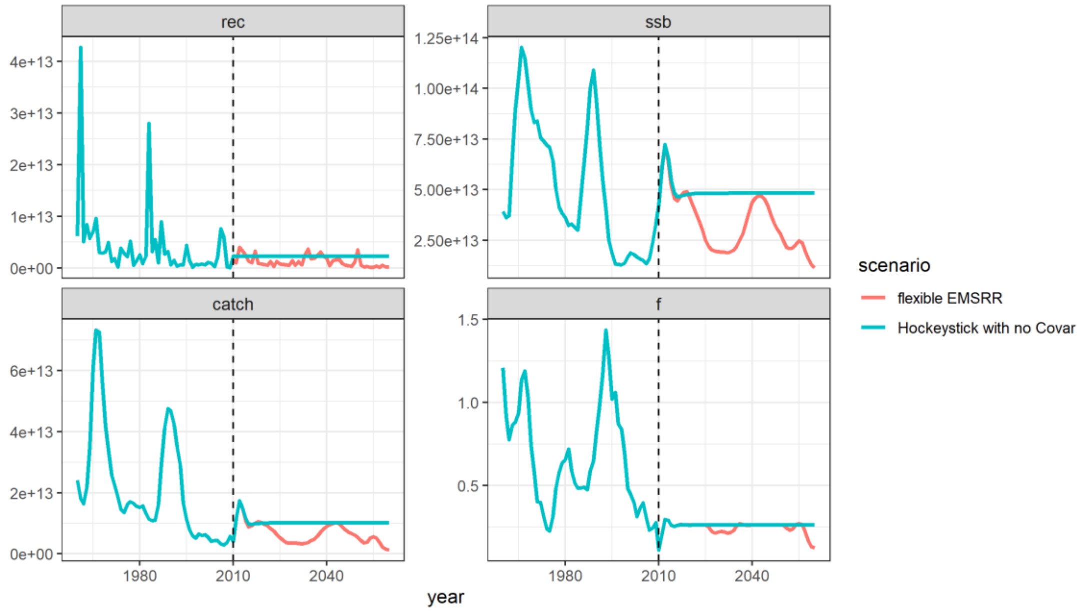

Fig 6. Comparison of the two simulations for recruitment, SSB, catch and fishing mortality.

A Word of caution

For this example, I just fitted a statistical stock-recruitment relationship not paying any special attention to the SSB-Rec relationship in the model. Since the model relationship with SSB was more-or-less flat and not passing through the origin (as every SRR should theoretically), you might run into troubles if the management procedure within FLBEIA leads to very low/high SSBs outside the historical range (extrapolation). In this case recruitment might be heavily over/underestimated. So always keep in mind checking the SSB-Rec relationship and if it does not to seem stable or output unreasonable recruitment values in the extrapolation range, better stick to a simpler model with a clear defined SSB-Rec relationship (Hockeystick, Ricker, Cushing, Beverton-Holt). See O'Brien 1999 for an approach to do it within a glm-framework (https://www.ices.dk/sites/pub/CM%20Doccuments/1999/T/T0199.pdf) or try a two-step approach first fitting a mechanistic SSB-Rec relationship (Ricker, BH, Hockeystick) and second using the residuals to fit the environmental relationship using a more flexible approach.

```
# look at the extrapolation behaviour of the EMSRR for high and low SSBs
ssb_extrap_segm = data.frame(x0 = c(0, min(df$ssb),
  max(df$ssb)), x1 = c(min(df$ssb), max(df$ssb),
  5e+14))
ssb_extrap_segm$y0 = predict(gam.fit, data.frame(ssb = ssb_extrap_segm$x0,
  covar1 = mean(df$env1), covar2 = mean(df$env2)),
```

```
  type = "response")
ssb_extrap_segm$y1 = predict(gam.fit, data.frame(ssb = ssb_extrap_segm$x1,
  covar1 = mean(df$env1), covar2 = mean(df$env2)),
  type = "response")

# plot
plot(df_lagged$ssb, df_lagged$rec, xlim = c(0, 5e+14),
  ylab = "Rec", xlab = expression("SSB"[t - 1]))
# add extrapolation behaviour
segments(x0 = ssb_extrap_segm$x0, x1 = ssb_extrap_segm$x1,
  y0 = ssb_extrap_segm$y0, y1 = ssb_extrap_segm$y1,
  col = c("red", "black", "red"), lty = 2, lwd = 1.5)
legend("topright", y.intersp = 0.7, cex = 0.8, legend = c("historical range",
  "extrapolation range"), col = c("black", "red"),
  lty = 2, lwd = 1.5, bty = "n")
title("GAM extrapolation behaviour for SSB", adj = 0)
```

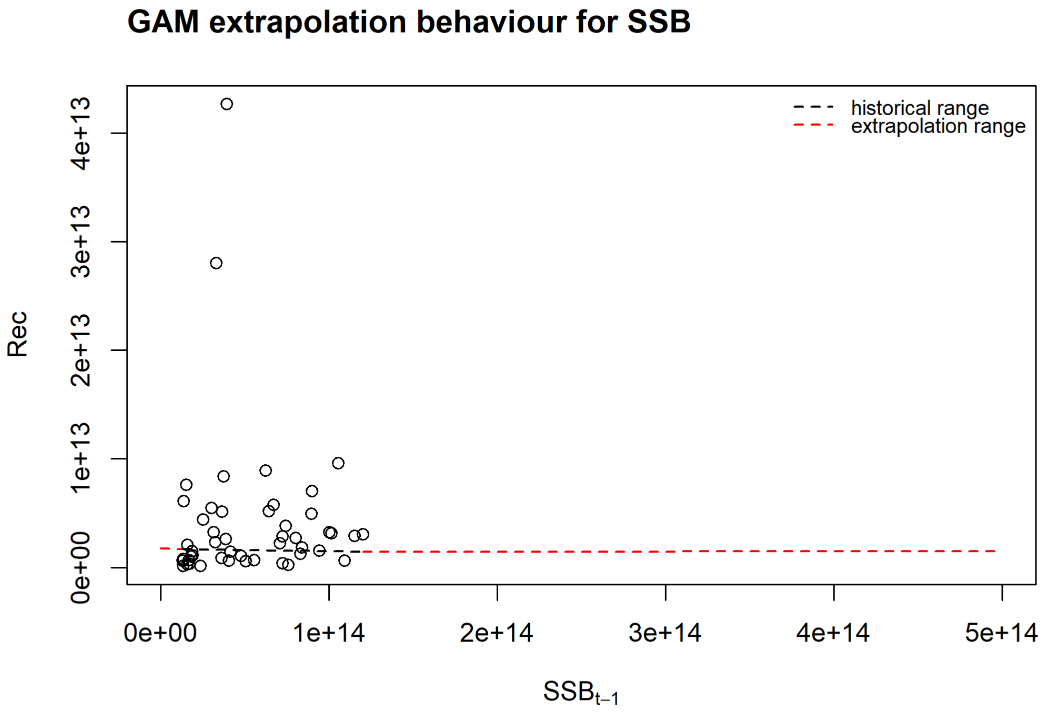

Figure 7. Extrapolation behavior of the GAM-model for different SSBs.

Annex 4: Incorporating SPiCT assessment objects in mixed fishery scenarios

Translation of SPiCT object to FLStock

In order to use SPiCT-assessed stocks in mixed fishery scenario, the output of the assessment must be translated into an FLStock object. Since the assessment is biomass based, this is simply an FLStock with a single age dimension. The following function can be used to directly extract the information into an FLStock. The function assumes yearly time steps in the mixed fishery model, and thus the information on numbers and weights corresponds to the beginning of each historical year. The use of seasonal time steps will require adaption of the procedure.

```r
spict2flr <- function(
 spict_fit,
 output = "stock",
 wt_units = "kg",
 n_units = "10^3",
 catch_units = "t",
 stock_name = "",
 disc = NULL
){

 yrs <- floor(spict_fit$inp$timeC)

 # extract biomass and make FLStock
 Bs <- as.data.frame(get.par("logB", spict_fit, exp = TRUE))
 # head(Bs)
 Bs$time <- as.numeric(rownames(Bs))
 Bs$year <- floor(Bs$time)
 tmp <- data.frame(year = yrs)
 tmp$B <- Bs$est[match(tmp$year, Bs$time)]
 flq <- FLQuant(tmp$B, dim=c(1,nrow(tmp)), dimnames=list(age=1, year=tmp$year), units="t")

 stock <- FLStock(stock=flq, name=stock_name)
 stock@stock.wt[1,] <- 1
 stock@stock.n <- stock@stock / stock@stock.wt
 stock@stock.wt@units <- wt_units
 stock@stock.n@units <- n_units


 # F or harvest rate (averaged over year)
 Fs <- as.data.frame(get.par("logF", spict_fit, exp = TRUE))
 Fs$time <- as.numeric(rownames(Fs))
 Fs$year <- floor(Fs$time)
 tmp <- aggregate(Fs$est, list(year=Fs$year), FUN = mean) # take mean over year?
 names(tmp)[which(names(tmp)=="x")] <- "f"
 stock@harvest[,ac(yrs)] <- tmp$f[match(yrs, tmp$year)]
 stock@harvest@units <- "f"

 # catches
 stock@catch[,ac(yrs)] <- spict_fit$inp$obsC[match(yrs, spict_fit$inp$timeC)]
 stock@catch.wt[,] <- 1
 stock@catch.n[] <- c(stock@catch / stock@catch.wt)
 stock@catch@units <- catch_units
 stock@catch.wt@units <- wt_units
 stock@catch.n@units <- n_units
```

```
 # discards
 if(!is.null(disc)){
  stock@discards[,ac(yrs)] <- disc
 }else{
  stock@discards[,ac(yrs)] <- 0
 }
 stock@discards.wt[1,] <- 1
 stock@discards.n[] <- c(stock@discards / stock@discards.wt)
 stock@discards@units <- catch_units
 stock@discards.wt@units <- wt_units
 stock@discards.n@units <- n_units

 # landings
 stock@landings <- stock@catch - stock@discards
 stock@landings.wt[1,] <- 1
 stock@landings.n[] <- c(stock@landings / stock@landings.wt)
 stock@landings@units <- catch_units
 stock@landings.wt@units <- wt_units
 stock@landings.n@units <- n_units

 ## Other pars =========================
 stock@mat[1,] <- 1
 stock@harvest.spwn[1,] <- 0
 stock@m[1,] <- 0
 stock@m.spwn[1,] <- 0

 ## check name =====================================
 # name(stock)

 # plot
 # plot(stock)

 return(stock)
}
```

The resulting FLStock objects can then be used to condition fleet objects based on metier-specific catch interactions (i.e. catchability).

Parameterization of FLBEIA

Currently, only FLBEIA models are able to handle stocks with biomass dynamics

See FLR Tutorial of *Conditioning FLBEIA in Data Limited Situations: BoB Stripped Mullet* (https://flr-project.org/doc/FLBEIA_Data_Poor_MSE.html).

The section *Initial Random population Based on SPiCT Fit* outlines the procedure of converting the Pella-Tomlinson surplus production model (SPM) parameters from SPiCT into the form used by FLBEIA. Later on, the sections *FLBDsim object* and *FLBiols object* outline the procedure of using these parameters to define the stock and its biomass dynamics.

Annex 5: Summary of Technical meeting with UK on mixed-fisheries science hosted by European Commission

On June 17 2022, the European Commission (EC) hosted a technical meeting to discuss the use of mixed fisheries considerations in TAC negotiations between the EU and UK. Several WGMIXFISH members were invited to better understand the existing technical concerns raised by stakeholders and to aid in the definition of future Terms of Reference (ToRs) to be addressed by ICES / WGMIXFISH.

As a background to the meeting, participants were briefed on the how WGMIXFISH considerations have played a role in TAC negotiations since 2021. This included a commitment in the written record between the UK and the EU to take account of the multi-stock character of the fisheries when agreeing fishing opportunities and to develop Terms of Reference to ICES to further develop mixed fisheries science and to understand uncertainties in catch projections, with a focus on the Celtic Sea (Article 5f, written record between the UK and EU, 2021)[1]. Despite the recognised utility of mixed fisheries considerations, some concerns have been raised about possible inconsistencies in the catches projected under the scenarios with observed mixed fishery dynamics. If these issues can be resolved, there is interest in having ICES mixed fisheries scenarios play a greater role in the setting of TACs.

Examples of technical concerns included cases of unrealistic choke situations for some fleets as identified by the mixed fishery models. WGMIXFISH members identified the source of these inconsistencies as likely originating from either unrealistic quota shares per fleet, currently based on historical catch proportions, or in métier definitions that combine fishing activities across space and therefore imply catches of stocks are linked where they are spatially separated (i.e. “false technical interaction”). This second component also links to the assumption of fixed fishing patterns. The WGMIXFISH members are currently addressing the first issue through the use of alternate approaches for defining fleet quota shares that better reflect a given country’s TAC allocation; e.g. see ToR C regarding the use of Fisheries Data Exchange System (FIDES). The second issue derives from two sources; i) the degree of aggregation available in the data used in fleet / metier definitions (e.g. WGMIXFISH Accessions, and InterCatch data), and ii) the assumption that future fishing patterns at the fleet level reflect past behaviour. Short-term solutions may include redefining the métier, but this is likely to require additional data not currently used by WGMIXFISH. Further it will not lead to a different outcome under the assumption of fixed fishing patterns, as choking effects occur at the fleet level as an average of métier effects. In the longer-term, WGMIXFISH will evaluate whether the eventual move to using RDBES data will address the metier aggregation issue (e.g. via lower spatial aggregation). However, it would also require a more fundamental change to how mixed fisheries models are currently used, by including scenarios with potential future changes in fleet dynamics. For this it would be necessary to get input from managers and stakeholders in the definition of management scenarios which reflect plausible changes in fishing patterns (i.e. the likely reallocation of fleets effort from one

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[1] Written record of fisheries consultations between the United Kingdom and the European Union for 2021, 44p. url:https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/993155/written-record-fisheries-consultations-between-uk-eu-2021.pdf. Accessed 28/06/2022.

métier to another), or the development of models to predict such changes. That process may also need to be subject to review within ICES.

The group agreed to a follow-up meeting to discuss methodological solutions, such as those presented in this report, and how additional input from a future-planned WKMIXFISH2 (*Scoping workshop on future mixed fisheries advice*) may be used to further collaborate with other stakeholders. Given the typical workload of WGMIXISH, consisting of two meetings per year (WGMIXFISH-METH, WGMIXFISH-ADVICE), and related time constraints, the possibility of funding for additional research and method development was mentioned by the EC.