Synthesis of ProByFish modelling approach and the effect of TACs for target species on bycatch species

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Summary

The ProByFish study was initiated to assist in the development of methods to evaluate the impact of different fisheries management options on the objectives of the Common Fisheries Policy (CFP). The study developed robust methods to a) define target and bycatch species and b) to divide the bycatch species into valuable and collateral bycatch species, the first generally retained on board and landed and the latter generally discarded. The classification of a species depended on the fleet and area in which the fleet operates. The study also identified species which can only sustain low levers of fishing and proceeded to include examples of these in mixed fisheries models.

This report describes the work under the study to analyse of effect of TACs for target species on fishing mortalities of hybrid, valued and collateral bycatch species assuming different management strategies to define TACs for the target species, while no management applies on the bycatch species. The analyses were conducted in a mixed fisheries Management Strategy Evaluation (MSE) framework to examine the probability that single stock TACs are sufficient under natural variability, mixed fishery dynamics and management strategies. The result shows that the effect of changing the species on which to define a TAC are minor compared to the effects concerning the uncertainty around the implementation of the landing obligation.

Contents

Extended summary of approaches and results

Probyfish uses the non-spatial fleet- and métier based model FLBEIA for management strategy evaluation (Garcia et al., 2017). A summary of the various models and areas is given in this report. The regions differed in the degree of implementation of species into mixed fisheries models at the beginning of the project and this is reflected in the end result.

Criteria for including stocks

The stocks included were derived from the top 95% of the landings from mixed fisheries. Where numerous species could not be added at one time, species were selected to represent high value target species and sensitive bycatch species. This choice was based on the expectation that the species of less value or sensitivity are likely to be less impacted by fishing and hence, the information on choke species issues and bycatch stock sustainability that can be derived from including the remaining species is likely to be minor.

Species likely to be sensitive to the pressure from mixed fisheries were identified by estimating the fishing mortality required to reduce SSB by 75% for species occurring in trawl surveys in Europe was estimated using a combination of life history models (Le Qesne and Jennings 2012) and catchability models (Walker et al. 2017). The methods was presented at WGECO and used together with criteria from the International Union for Conservation of Nature (IUCN) to list sensitive species in the Northeast Atlantic. The species which can sustain less fishing mortality than the major commercial species saithe, that are susceptible based on a Productivity-Susceptibility analysis (Altuna-Etxabe et al., 2019) or that is ranked by IUCN as Critically Endangered, Endangered or Vulnerable was characterised as sensitive.

Scenarios investigated

In each area, two scenarios were run reflecting the species managed:

'Target' scenario: only the target stocks as defined in the relevant Multiannual Plan were managed by TACs

'Current' scenario: all the stocks in the current TAC and quota system were managed by TACs

A further three scenarios were used to reflect the implementation of the TACs under each of the species:

'Fixed' scenario: the effort remains the same as in the initial year

'Min' scenario: the fishery ends once the most restrictive TAC is reached

'Previous' scenario: effort is restricted by the effort corresponding to all the quotas and the previous years effort. This is the scenario that resembles the status quo most closely.

The management procedure consisted of setting a TAC for each of the stocks annually. The TACs were obtained using the harvest control rule used by ICES to generate the management advice annually.

Definitions of protected stocks

Indicators of healthy stock status differed between age-based (i.e. quantitatively assessed stocks) and biomass-based stocks. The following indicators were used:

1) age-based: Median biomass greater than MSY Btrigger, Bpa and Blim (B/Btrigger > 1.0, B/Bpa > 1.0, B/Blim > 1.0). Median fishing mortality less than Fmsy and Fpa (F/Fmsy < 1.0, F/Fpa < 1.0).

2) biomass-based *with* SPiCT models presented in advice: Median biomass greater than Bmsy and MSY Btrigger (B/Bmsy > 1.0, B/Btrigger > 1.0). For these stocks, a proxy Btrigger = 0.5*Bmsy was used. This should be approximately equivalent to B/B0 > 0.25, used for other SPiCT stocks. Median fishing mortality less than Fmsy (F/Fmsy < 1.0).
3) biomass-based *without* SPiCT models presented in advice: Median biomass greater than Bmsy and MSY Btrigger. For these stocks, a proxy Btrigger = 0.25*B0 was used. (B/Bmsy > 1.0, B/B0 > 0.25). Median fishing mortality less than Fmsy (F/Fmsy < 1.0).
4) fixed biomass: Median fishing mortality less than Fmsy (F/Fmsy > 1.0) as only fishing mortality reference points exist

Bay of Biscay demersal fishing

The Bay of Biscay model covers ICES divisions 8abd. In Probyfish, the number of stocks included was extended from the original 12 stocks of which only 2 were modelled with full dynamics to 28 species. The selection was based on a species prioritization approach proposed by Altuna-Etxabe, Ibaibarriaga et al. (2019) and the analysis carried out in Task 1 of the ProbyFish project to identify target and valuable bycatch species. Of these 28 species, 14 had an assessment that allowed the full dynamics to be modelled: hake, megrim, white anglerfish, black anglerfish, horse mackerel, mackerel, sole, bass, blue whiting, dogfish, smooth-hounds, cuckoo ray, thornback ray and red mullet. The scenario 'Current' and 'Target' differed for the species thornback ray, smooth-hounds, cuckoo ray and undulate ray.

The difference between SSB levels was bigger between implementation scenarios than between the species scenarios. Continuing the Previous scenario leads to stable or declining SSB of most of the stocks. However, under the Min scenario where fishing is stopped when the first TAC is exhausted, the SSB increased in most of the cases. Furthermore, the increase was bigger when the current management was maintained, i.e when the TAC was maintained for the current TAC stocks. The probability of SSB being below Blim for data-rich stocks was low with the exception of white anglerfish. For data-limited stocks, thornback ray and smoothhounds, the probability of being below 25% of the biomass in absence of fishing (0.25B0) was around 20% and 35% respectively, but there were not big differences between scenarios. For black-bellied anglerfish and red mullet, the probability was close to 100%. Furthermore, the probability was lower under the current management configuration than when there were TACs on only target species. For cuckoo ray, under current TAC species, the probability of SSB being below 0.25B0 was around 13% and when the TAC was removed for non-target stocks it increased to 20%.

Celtic Sea demersal fishing

The Celtic Sea model cover ICES divisions 7f,g,h,j,k. The stocks included in the Probyfish model were selected based on importance to the commercial fishery and sensitivity to fishing and included cod, haddock, whiting, anglerfish, hake, megrim, sole, plaice, Nephrops, dogfish, red gurnard and thornback ray. In addition to these species, black-bellied angler, spurdog, black Scabbard fish, European conger and common mora were considered but had insufficient information. The TAC species were identical to the target species in the multiannual plan in this area, and hence, only two scenarios were estimated.

The median SSB for all the stocks except whiting show a strong increasing biomass trend under the Min scenario. As the cod stock is below Blim, this scenario operates with a TAC of zero for several years, substantially reducing fishing pressure. In the Previous scenario, fishing effort is much higher and stock biomasses increases are lower. The cod biomass continues to fluctuate around Blim and whiting falls below Blim after 5 years. Haddock and anglerfish show declining biomass trends but remain above their Blim reference points.

North Sea demersal fishing

The North Sea model covers demersal fisheries ICES areas 4a-c, 7d, 3a20 and 6a. In Probyfish, the number of stocks included was extended to a total of 14 species selected based on important commercial species and the evaluation of species sensitivity. The scenarios of current management include a larger number of TAC managed stocks than the target (map) scenario (brill, lemon sole, ling, turbot and witch).

The biomasses were slightly lower under the target scenario, but the differences were small compared to the difference between implementing the Min and Previous management scenario. Under the Min fleet effort control setting, all stocks were in good status by the terminal year. Only witch was found to be fished above Fmsy in median, but Fpa was not exceeded. Under the Previous fleet effort control scenario, several age-based stocks show above 5% risk to Blim (cod and witch) and Fpa (cod, eastern channel plaice and witch). For biomass-based stocks, anglerfish was below 0.25B0 in 28% of the iterations. Cod, anglerfish, English channel plaice, haddock, sole, turbot, whiting and witch median fishing mortality exceeded Fmsy under the previous effort scenario.

Technical details: Bay of Biscay demersal fishing

Model implemented

The simulation was carried out using the FLBEIA model (Garcia, Sánchez et al. 2017) to fish stocks and demersal fisheries ICES areas 8abd. The implementation was based on the model and conditioning used to conduct impact assessments of multiannual plans for demersal mixed fisheries in the Bay of Biscay (STECF 2015; Prellezo, Carmona et al. 2016) as further developed by Garcia, Dolder et al. (2019). In the simulations conducted in 2015, 12 stocks were included in the simulation but only two of them were simulated using a population dynamic model and hence responded to changes in fishing effort. The rest were simulated using a constant CPUE approach because no assessment model was available to condition the operating model. As their contribution to the economic performance of the fleet was high, it was essential to include them in the Probyfish modelling framework. The original 12 stocks were selected based exclusively on their contribution to the total landings and to the income of the fishery.

In Probyfish, the number of stocks included was extended to 28 species selected based on a species prioritization approach proposed by Altuna-Etxabe, Ibaibarriaga et al. (2019) and the analysis carried out in Task 1 of the ProbyFish project to identify target and valuable bycatch species. The conditioning of the stocks was based on the stock assessment model used in the assessment working groups (ICES 2018; ICES 2018; ICES 2018) for the stocks in ICES category 1. For the data-limited stocks, the stock reduction analysis in MSEtoolkit, an add-on to the DLMTookit (Carruthers and Hordyk 2018), was used. For anglerfish a statistical catch at age model was fitted (Jardim, Millar et al. 2014). In some cases the data available was so limited that it was not possible to apply any of the stock's assessment models tested. In this case, species were simulated using a constant CPUE approach.

Two scenarios were run reflecting the species managed: 'Target' scenario: only the target stocks were managed by TACs and 'Current' scenario: all the stocks in the current TAC and quota system were managed by TACs. A further three scenarios were used to reflect the implementation of the TACs under each of the species: 'Fixed' scenario: the effort remains the same as in the initial year, 'Min' scenario: the fishery ends once the most restrictive TAC is reached and 'Previous' scenario: effort is restricted by the effort corresponding to all the quotas and the previous years effort. This is the scenario that resembles the status quo most closely. The management procedure consisted of setting a TAC for each of the stocks annually. The TACs were obtained using the harvest control rule used by ICES to generate the management advice annually.

Each scenario was examined with 1000 iterations to account for the uncertainty in the initial state (conditioning of the model). For the stocks in category 1, except for megrim, the initial stock size is included without uncertainty as uncertainty is not provided in the assessment. As megrim is assessed with a Bayesian virtual population analysis model uncertainty was introduced in the historical period using the join probability distribution estimated by the model. For these stocks in the projection the uncertainty was introduced using the approach in the working group were the fishing mortality ranges were estimated (ICES 2015). For the stocks assessed with DLMtoolkit, the tool itself provided a probability distribution for the historical parameters. The parameters in the projection were conditioned using the mean of the last historical years. Thus, in each iteration the parameters were constant but they changed iteration by iteration.

For all the stocks except white anglerfish, a segmented regression was used to simulate the recruitment in the projection. When the historical period had uncertainty, a stock recruitment model was fitted for each iteration. In the case of white anglerfish the stock recruitment models used in ICES

(2015) were used. In this case, both the structural form of the stock recruitment model used and its parameters were iteration dependent. Furthermore, in all the cases a log-normal random error was multiplied to the point estimate of the recruitment in each year and iteration to account for natural variability in the recruitment process. The error was centred in 1 and the variability followed the variability shown in the historical period.

Geographic extent of model

ICES divisions 8abd. Most of the stocks have a wider distribution that the area considered for the fleet data. Hence, an artificial fleet was created to account for the catch that occurs outside the considered area.

Stocks included

Stocks to be included in the simulation were selected using the prioritization approach proposed by Altuna-Etxabe, Ibaibarriaga et al. (2019) and the results in Task 1. The priorization approach consists of first evaluating the potential risk of all the exploited species using a Productivity-Susceptibility Analysis (PSA) (Hobday, Smith et al. 2011). Then, the species are ranked according to the assessed potential risk, the level of catches and the corresponding revenue. The first 25 species of the ranking were selected as the most exploited, vulnerable, and/or economically important species for the fishery: bass, blue whiting, hake, horse mackerel, mackerel, megrim, Nephrops, sole, spurdog, white bellied anglerfish, black-bellied anglerfish, cuckoo ray, dogfish, smooth-hounds, thornback ray, red mullet, tope, whiting, tub gurnard, undulate ray, cape gurnard, conger eel, cuttlefish, broadtail shortfinned squid, John dory, pouting and silverfish. The species *Mustelus asterias* and *Mustelus mustelus* were combined at genus level because the species-specific landings data are unreliable. In addition, 3 species (broadtail shortfinned squid, gurnard and undulate ray) considered relevant for the purpose of Probyfish project were also included. The following species were included without species dynamics, as this was not possible with the available data: Nephrops, spurdog, tope, whiting, tub gurnard, undulate ray, red gurnard, conger eel, cuttlefish, broadtail shortfinned squid, John dory, pouting and silverfish.

Species not included and associated rationale

All the relevant stocks were included. The only limitation was that some of them were included using a constant CPUE approach, i.e without a proper population dynamic model. The data available did not allow to fit a stocks assessment model that would provide the necessary data to condition a population dynamic model. For *Nephrops* stocks, it was not possible to condition the model dynamically because the TV survey used to obtain absolute values of the biomass was not translatable to a mathematical population dynamic model.

Presented in ICES

The model was presented in the ICES WKMIXFISH-methods (ICES 2018). The same model has been used to test the performance of a multi-stock HCR that uses the fishing mortality ranges to provide catch advice. The results were presented in the Annual Scientific Conference (Garcia 2018) and published in (Garcia, Dolder et al. 2019).

Species identified as not sufficiently protected by current management

The median SSB for all the stocks in shown in Figure 1.

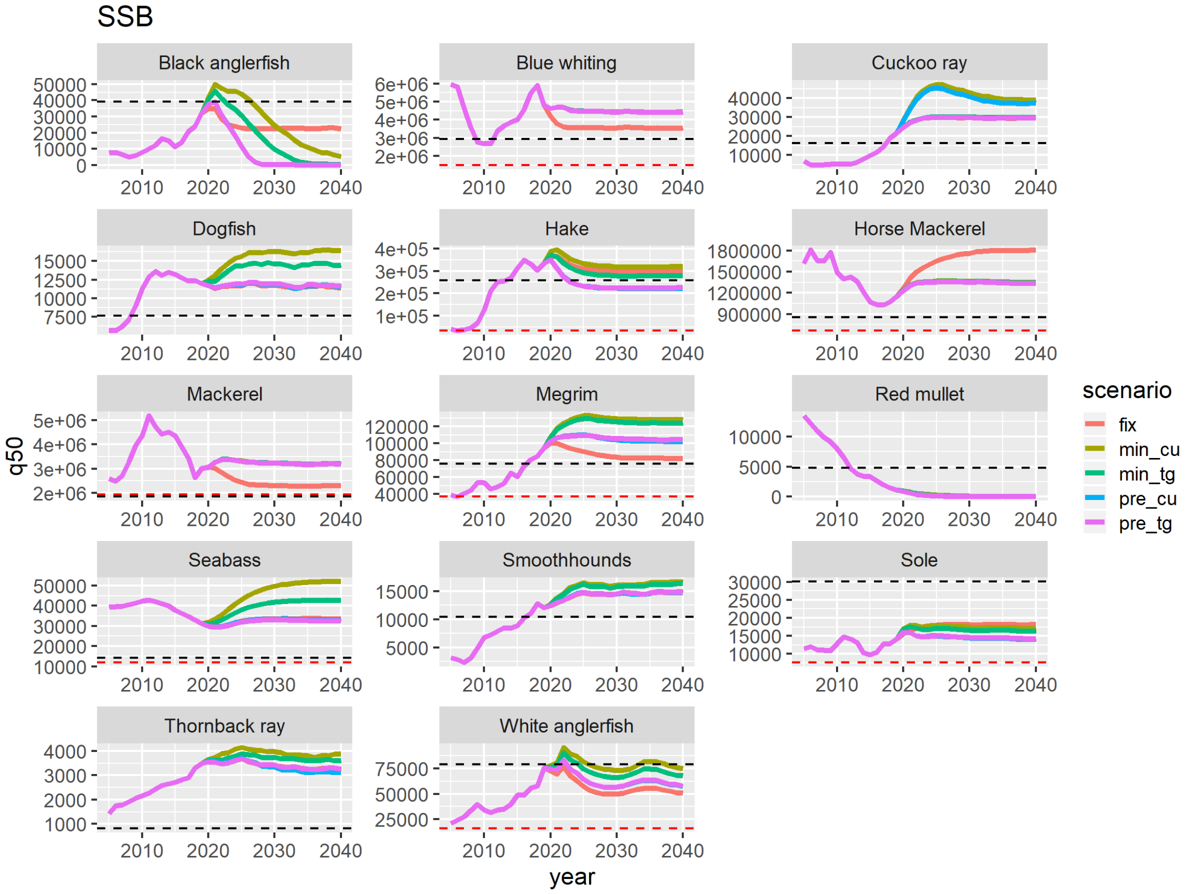

Figure 1. Median SSB for all the stocks with a population dynamic model in the simulation for all the scenarios run. The horizontal dashed black line corresponds to the median of the 25% of the virgin spawning stock biomass and the red one to Blim (fix = statu-quo effort, min_cu = current management constrained by the most restrictive TAC, min_tg = management of target stocks constrained by the most restrictive TAC tas, prev_cu = current management with effort constrained by the quotas of all the stocks but influenced by the previous effort, prev_tg = management of target stocks with effort constrained by the quotas of all the stocks but influenced by the previous effort).

In median, the biomass of black bellied anglerfish and red mullet collapsed under both the Current and Target species management system, independently of whether the implementation of effort was Min or Previous. However, under the Min scenario, the collapse of the black bellied anglerfish stock was delayed using the Current compared to the Target species scenario. The use of 0.25B0 as a reference point presented some challenges, as the biomass in absence of fishing (B0) was estimated to be very high for some species (e.g. sole). In median, sole, red mullet, the two anglerfishes, hake and sole had a biomass in one or more of the scenarios below 0.25B0, indicative of Bpa. For hake only the ‘Target’ scenarios were below the reference level and the median levels for those scenarios were similar. Something similar happened for white bellied anglerfish that was close to the reference level under the Min scenarios. Where Blim was available from the working groups, in median, all the scenarios the SSB were well above Blim for all the stocks. Figure 2 shows the confidence intervals for the SSB. For some of the stocks the uncertainty was very high (undulate ray, thornback ray, dogfish and smooth-hounds). The uncertainty in red mullet was moderate and the probability of collapse of the stocks was high. The uncertainty in anglerfishes was also high. The lower bound of the SSB was well above Blim for all the category 1 stocks except white anglerfish and mackerel. For white anglerfish, the lower bound of the SSB was close to Blim in some years and for mackerel, the biomass was close to Blim from 2027 onwards.

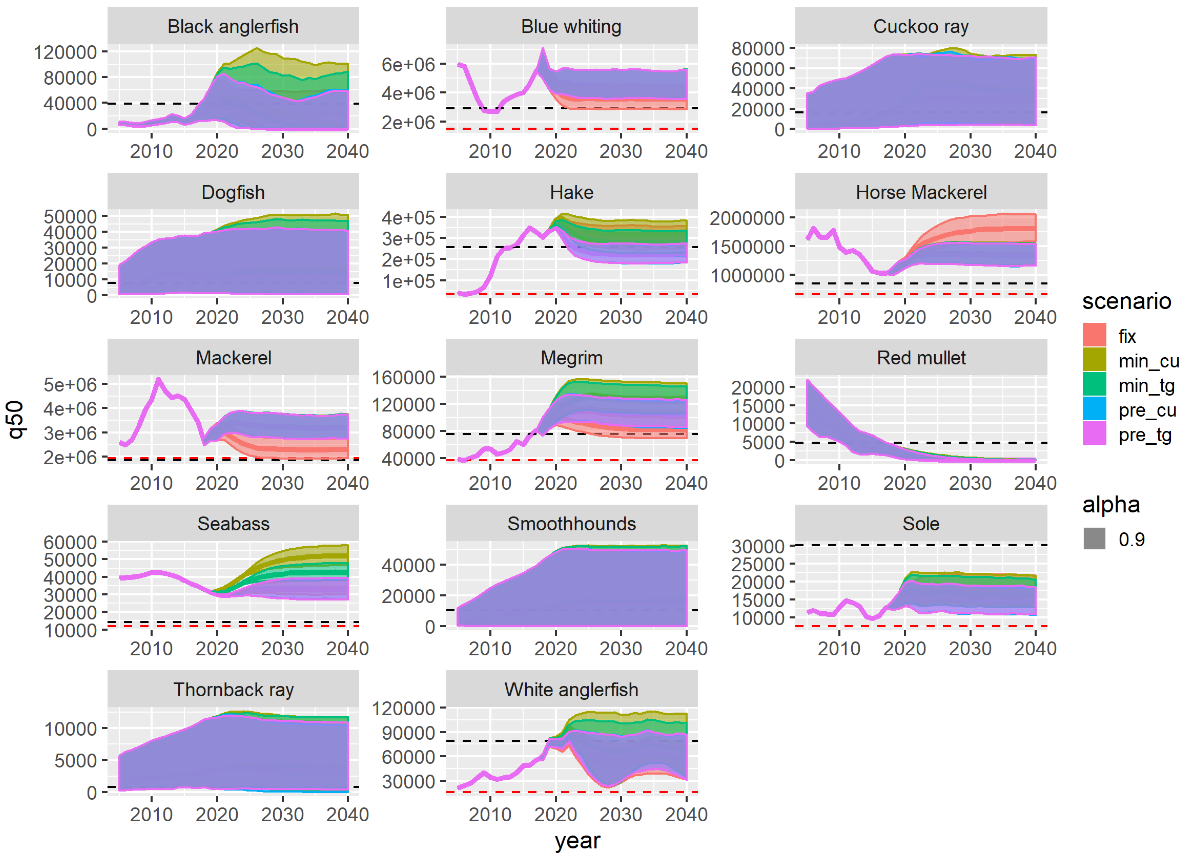

Figure 2. Median SSB and 95% uncertainty intervals for all the stocks with a population dynamic model in the simulation for all the scenarios run. The horizontal dashed black line corresponds to the median of the 25% of the virgin spawning stock biomass and the red one to Blim (fix = statu-quo effort, min_cu = current management constrained by the most restrictive TAC, min_tg = management of target stocks constrained by the most restrictive TAC tas, prev_cu = current management with effort constrained by the quotas of all the stocks but influenced by the previous effort, prev_tg = management of target stocks with effort constrained by the quotas of all the stocks but influenced by the previous effort).

The difference in SSB between implementation scenarios was bigger than between the species scenarios. Continuing the Previous scenario leads to stable or declining SSB of most of the stocks. However, under the Min scenario where fishing stops when the first TAC is exhausted, the SSB increased in most of the cases. Furthermore, the increase was bigger when the current management was maintained, i.e when the TAC was maintained for the current TAC stocks. The trajectories in fishing mortality are shown in Figures 3 and 4, without and with uncertainty, respectively. The uncertainty bounds show the range of outcomes expected in 95% of the years due to e.g. variation in recruitment and other factors. For almost all the stocks, the fishing mortality stabilised just after 2020. Except for black-bellied anglerfish and red mullet, the median fishing mortalities were not high. For anglerfish, except in the fixed effort scenarios, the fishing mortality increased steadily. In the scenarios where only the target stocks were managed the fishing mortality stabilised around 1, when landing obligation was in place, and between 1.25 and 1.5 when it was not. In the current management scenarios, the increase rate was lower, and even if in 2040 the fishing mortality was not stabilized, it was below 0.75. The uncertainty patterns observed in SSB were similar to those observed in fishing mortality. The uncertainty bounds show the range of outcomes expected in 95% of the years due to e.g. variation in recruitment and other factors.

Figure 4. Median fishing mortality and 95% uncertainty intervals for all the stocks with a population dynamic model in the simulation for all the scenarios run (fix = statu-quo effort, min_cu = current management constrained by the most restrictive TAC, min_tg = management of target stocks constrained by the most restrictive TAC tas, prev_cu = current management with effort constrained by the quotas of all the stocks but influenced by the previous effort, prev_tg = management of target stocks with effort constrained by the quotas of all the stocks but influenced by the previous effort).

Figure 3. Median fishing mortality for all the stocks with a population dynamic model in the simulation for all the scenarios run (fix = statu-quo effort, min_cu = current management constrained by the most restrictive TAC, min_tg = management of target stocks constrained by the most restrictive TAC tas, prev_cu = current management with effort constrained by the quotas of all the stocks but influenced by the previous effort, prev_tg = management of target stocks with effort constrained by the quotas of all the stocks but influenced by the previous effort).

The probability of SSB being below 25% the virgin biomass (B0) for data-limited stocks and below Blim for data-rich stocks is shown in Figure 5. For red mullet, the probability was equal to 100% for all the scenarios and projection years. On the contrary, the SSB of data-rich stocks and mackerel was always above Blim with the exception of white anglerfish. For thornback ray and smoothhounds, the probability of being below the reference point was around 20% and 35% respectively, but there were not big differences between scenarios. For black-bellied anglerfish the probability was close to 100%, for the Previous scenarios but it was slightly below for the Min where the TAC of all the stock are fulfilled and the Fix scenario where the effort was equal to the status-quo level. Furthermore, the probability was lower under current management configuration with TAC on more species. For cuckoo ray, under current TAC species, the probability of SSB being below 0.25B0 was around 20% and when the TAC was removed for non-target stocks it decreased to 13%. For dogfish, for which the probability was between 36% and 25% in the projection, the differences came from the implementation (Min or Previous) and not from the number of stocks in the TAC system. The uncertainty in the estimated probabilities, calculated using a bootstrap, were very low in all the cases.

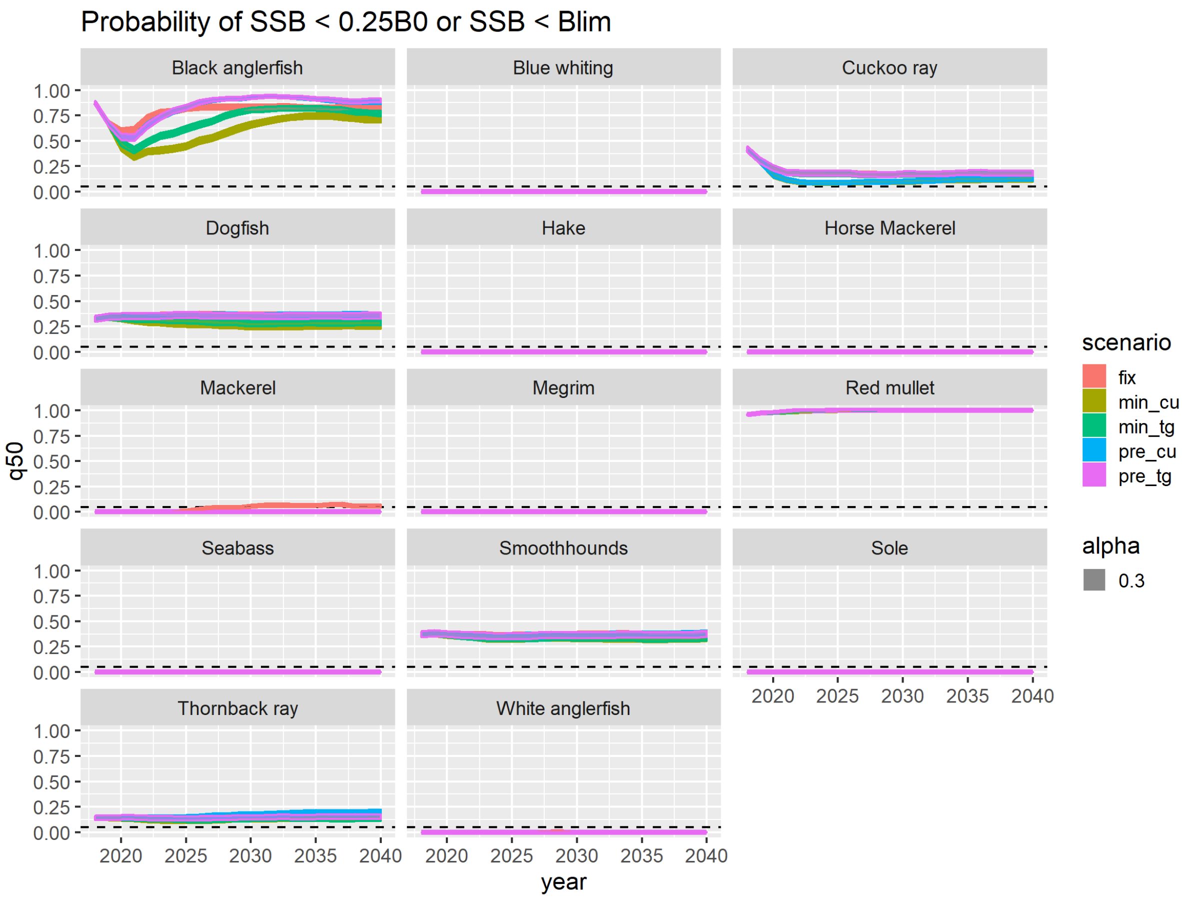

Figure 5. Probability of SSB falling below 25% the virgin biomass (B0) for data-limited stocks and below Blim for data-rich stocks (fix = statu-quo effort, min_cu = current management constrained by the most restrictive TAC, min_tg = management of target stocks constrained by the most restrictive TAC tas, prev_cu = current management with effort constrained by the quotas of all the stocks but influenced by the previous effort, prev_tg = management of target stocks with effort constrained by the quotas of all the stocks but influenced by the previous effort). Dotted line indicates a probability of 5%.

Species identified as not sufficiently protected by TAC on target species alone

When the set of species subject to the TAC and quota system was limited to the target species the results generally changes little. However, the biomass level was lower and the probability of SSB being below 25% of the virgin biomass (B0) was higher. The biggest difference was observed for hake. The results are tabulated in the attached excel sheet.

Areas for future work

- The biomass obtained with MSEtoolkit are very low comparing to the virgin biomass level. The historical conditioning of the stocks is crucial to obtain credible estimates in the future. Thus, an evaluation of the performance of MSEtoolkit under different data availability will be carried out, based on a data rich stock. This evaluation will provide a better understanding of the results of MSEToolkit and will help to improve the conditioning of the stocks.
- Analysis of the sensitivity of mixed fisheries models and robustness of management strategies to variability in key parameters related with stock productivity. The variability in

stock productivity parameters will be derived from the assessment model used to condition the stocks and the analysis of the performance of MSEToolkit under different hypothesis about the dynamic of the stocks.

- Sensitivity of the results to different fleet configuration will be also tested based on the results from Task 3. The objective of testing different fleet configurations is twofold, first to evaluate the robustness of mixed fisheries models and second to tailor the management strategies.
- The mixed fisheries model will be further developed to allow the definition of TACs for group of species. New management strategies based on grouped TACS will be defined and tested to evaluate their effectiveness.
- It will be investigated if there are studies available that allow to evaluate technological changes, like changes in mesh size, for the fleets and stocks included in this case study. Changes in selectivity could be also derived from changes in fishermen behaviour.
- Analyse effect of having TACs only on Probyfish target and valuable bycatch species by successively adding bycatch species until all species are protected.

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Technical details: Celtic Sea demersal fishing

Model implemented

The simulation was carried out using the FLBEIA model (Garcia, Sánchez et al. 2017). In Probyfish, the species were selected based on their commercial importance as a target stock, or because they offer useful examples of data poor species that are commonly bycaught. The conditioning of the stocks was based on the stock assessment model used in the assessment working groups for the stocks in ICES category 1. The data poor stocks that lack formal stock assessments and catch data were conditioned using survey data to estimate stock abundance and observer data to estimate catch rates. Uncertainty was added to the model for these stocks using the outputs from SPiCT assessments for each species.

All of the TAC species in the Celtic Sea model are included in the MAP, and hence there is only one species scenario. Two scenarios were used to reflect the implementation of the TACs under each of the species: 'Fixed' scenario: the effort remains the same as in the initial year, 'Min' scenario: the fishery ends once the most restrictive TAC is reached and 'Previous' scenario: effort is restricted by the effort corresponding to all the quotas and the previous years effort. This is the scenario that resembles the status quo most closely. The management procedure consisted of setting a TAC for each of the stocks annually. The TACs were obtained using the harvest control rule used by ICES to generate the management advice annually.

Each scenario was examined with 100 iterations to account for the uncertainty in the initial state (conditioning of the model). The parameters in the projection were conditioned using the mean of the last historical years. Thus, in each iteration the parameters were constant but they changed iteration by iteration. For all the stocks, a segmented regression was used to simulate the recruitment in the projection. Furthermore, in all the cases a log-normal random error was multiplied to the point estimate of the recruitment in each year and iteration to account for natural variability in the recruitment process. The variability followed the variability shown in the historical period.

Geographic extent of model

ICES divisions 7f,g,h,j,k.

Stocks included

Stocks to be included in the simulation were selected based on importance to the commercial fishery and sensitivity to fishing. Cod, haddock, whiting, anglerfish, hake, megrim, sole, plaice, Nephrops, dogfish, red gurnard and thornback ray. The reasons for including these species was either their commercial importance as a target stock, or because they offer useful examples of data poor species that are commonly bycaught. Cod, haddock, whiting, anglerfish, hake, megrim and sole were included using a full age based model, whereas plaice, Nephrops, dogfish, red gurnard and thornback ray used a biomass dynamic model. In addition to these species, black-bellied angler, spurdog, black scabbard fish, European conger and common mora were considered.

Species not included and associated rationale

All major demersal commercial stocks are included. Spurdog catch data was not available and due to the aggregating nature of the species, it was decided to exclude. The data availability for black scabbard, conger and mora was lacking, with little catch data, survey or observer data.

Presented in ICES

The model will be presented at the upcoming meeting of ICES WGMIXFISH.

Species identified as not sufficiently protected by current management

The median SSB for all the stocks in shown in Figure 6. Under the min scenario, which uses ICES harvest control rules to set TACs for the target species, all stocks except whiting show an strong increasing biomass trend. This is due to the cod stock being below Blim, meaning that there is a TAC of zero for several years, and because of the landing obligation this massively reduces fishing pressure.

In the previous scenario, which is constrained by the quotas of all the stocks but influenced by the previous effort (prev), fishing effort is much higher and stock biomasses do not increase in the same way. The cod biomass continues to hover around the Blim reference point and whiting drops below Blim after 5 years. Haddock and monkfish show declining biomass trends but remain above their Blim reference points.

The results are tabulated in the attached excel sheet.

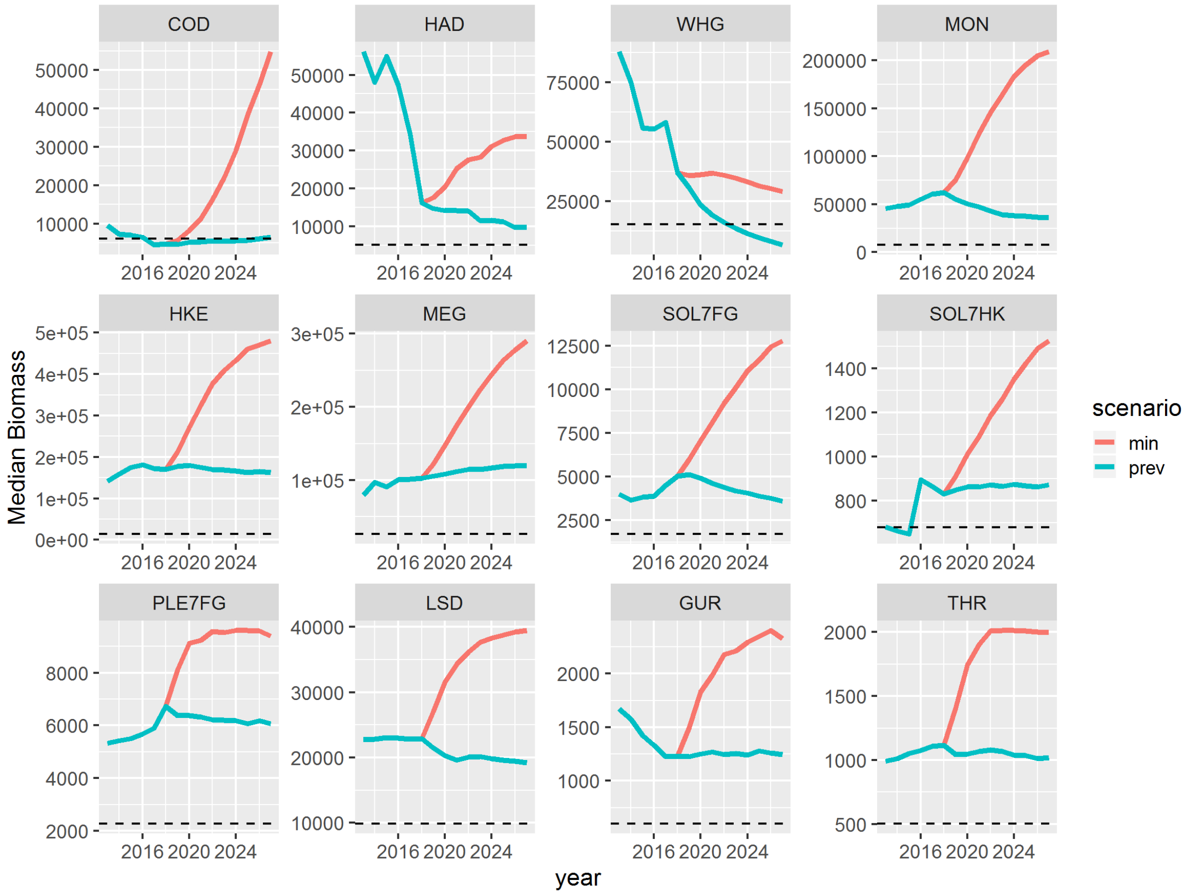

Figure 6. Median stock biomass for the stocks within the model. Horizontal dashed line, represents the Blim estimate for target stocks and 25% virgin biomass for the stocks not assessed by ICES (LSD, GUR and THR). Two scenarios were tested: min scenario = TAC management, when fishing halts when the first TAC is filled, prev = TAC management of target stocks with effort constrained by the quotas of all the stocks but influenced by the previous effort

The probability of the stocks falling below either the ICES estimated Blim or below 25% virgin biomass is shown in Figure 7, with cod being most susceptible to being below Blim. This probability decreases over time under both scenarios, but that happens much quicker under the min scenario, where fishing effort is greatly reduced. Under the prev scenario, after 10 years, the stock still has a 50% probability of being depleted. Whiting stocks are currently above Blim, but under the prev scenario, this is predicted to not be the case within 10 years. Haddock also has a small chance (<25%) of dropping below Blim.

Although the median biomass for the bycatch stocks (LSD, GUR and THR) is comfortably above Blim, due to the uncertainty in the data for those stocks each of them has some probability of decreasing below Blim over the next 10 years. This is greatest for LSD (29%), followed by GUR (20%) and then THR (10%).

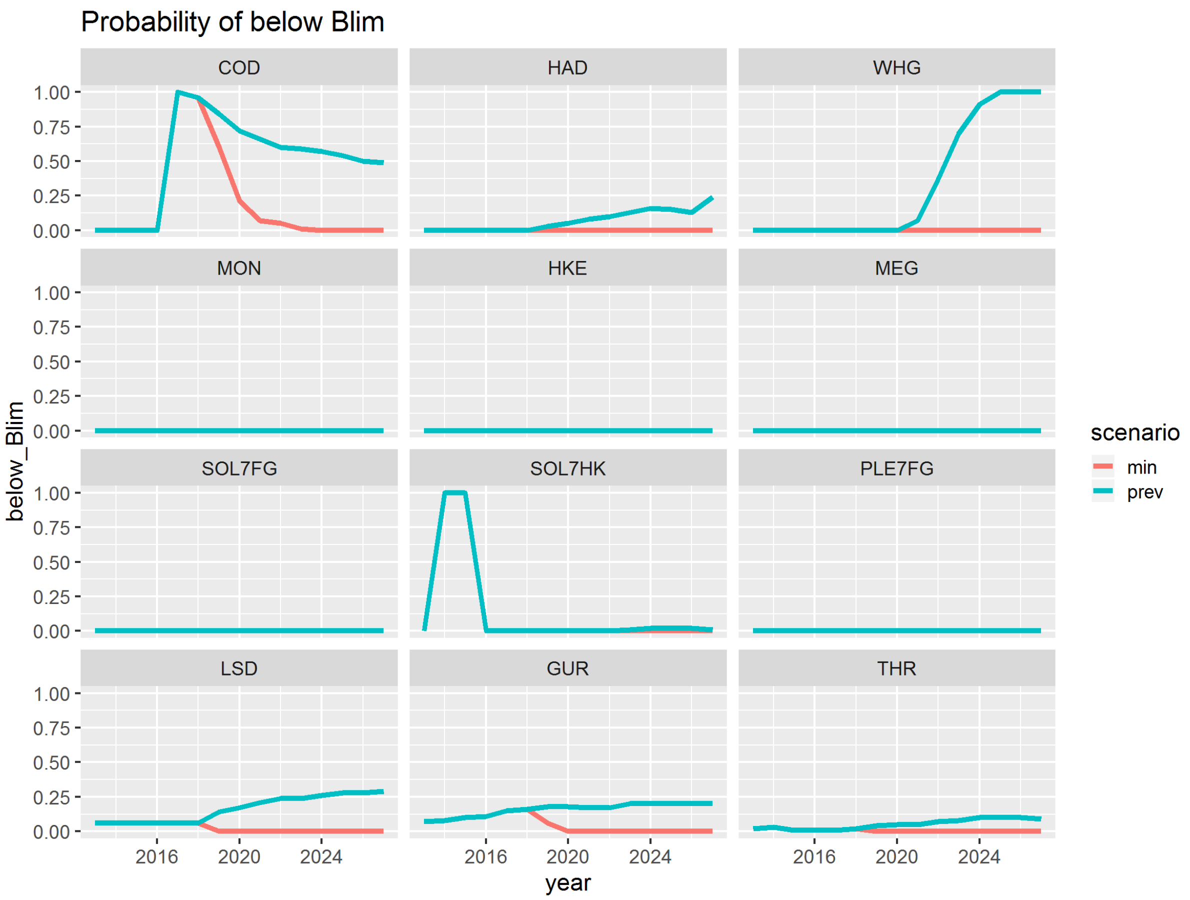

Figure 7. Probability of the biomass for the stocks falling below the Blim estimate for target stocks or 25% virgin biomass for the stocks not assessed by ICES (LSD, GUR and THR). Two scenarios were tested: min scenario = TAC management, when fishing halts when the first TAC is filled, prev = TAC management of target stocks with effort constrained by the quotas of all the stocks but influenced by the previous effort

Species identified as not sufficiently protected by TAC on target species alone

As the target species under the MAP encompass all the modelled TAC species, the species identified as not protected by a target species TAC alone equals those not protected under current management.

Areas for future work

- Develop and implement improved stock recruit relationships, especially for haddock,
- Iterate on the implementation for data poor stocks by improving the catch estimates from observer data and abundance estimates from survey data
- Analyse effect of having TACs only on Probyfish target and valuable bycatch species by successively adding bycatch species until all species are protected.

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Technical details: North Sea demersal fishing

Model implemented

The simulation was carried out using the FLBEIA model (Garcia, Sánchez et al. 2017) to fish stocks and demersal fisheries ICES areas 4a-c, 7d, 3a20 and 6a. In Probyfish, the number of stocks included was extended to a total of 14 species selected based on important commercial species and the evaluation of species sensitivity. The conditioning of the stocks was based on the stock assessment model used in the assessment working groups (ICES 2018; ICES 2018; ICES 2018) for the stocks in ICES category 1. For the data-limited stocks, the stock reduction analysis in MSEtoolkit, an add-on to the DLMTookit (Carruthers and Hordyk 2018), was used. In some cases the data available was so limited that it was not possible to apply any of the stock's assessment models tested. In this case, species were simulated using a constant CPUE approach. Each scenario was examined with 1000 iterations to account for the uncertainty in the initial state (conditioning of the model).

Two scenarios were run reflecting the species managed: 'Target' scenario: only the target stocks were managed by TACs and 'Current' scenario: all the stocks in the current TAC and quota system were managed by TACs. A further two scenarios were used to reflect the implementation of the TACs under each of the species: 'Min' scenario: the fishery ends once the most restrictive TAC is reached and 'Previous' scenario: effort is restricted by the effort corresponding to all the quotas and the previous years effort. This is the scenario that resembles the status quo most closely. The management procedure consisted of setting a TAC for each of the stocks annually. The TACs were obtained using the harvest control rule used by ICES to generate the management advice annually.

Two sets of stocks with restrictive (i.e. *choking*) TAC (*current*, *target*) were combined with two settings for fleet effort control (*min*, *previous*), resulting in four distinct scenarios. The definition of current TAC and target TAC stocks were:

1) Current TAC (*current*) – includes all stocks that receive TAC advice including non-target stocks (ANF*, BLL*, COD-NS†, HAD†, LEM*, LIN*, NEP6**, NEP7**, NEP8**, NEP9**, PLE-EC†, PLE-NS†, POK†, SOL-NS†, TUR†, WHG-NS†, WIT†)
2) MAP-target TAC (*map*) – includes target TAC stocks only, as defined by the Multiannual Plan (MAP) for demersal stocks in the North Sea (ANF*, COD-NS†, HAD†, NEP6**, NEP7**, NEP8**, NEP9**, PLE-EC†, PLE-NS†, POK†, SOL-NS†, WHG-NS†)

In addition to these stocks, the model included several other non-restricting stocks (DAB*, NEP5**, NEP10**, NEP32**, NEP33**, NEP34**, NEPOTH-NS**). Hence, the difference between current and target scenarios was the presence of TACs for brill, lemon sole, ling, turbot and witch.

† = age-based dynamics, * = biomass dynamics; ** = fixed dynamics

Each scenario was run approximately 200 times (i.e. iterations). The initial model was conditioned with data up to year 2018. Fleet/métier selectivity and catchability was based on the final year of data (2018). Variation among iterations was introduced to the stock dynamics according to the following protocol: The covariance matrices of the SPiCT model fit to biomass dynamic stocks (ANF, BLL, DAB, LEM, LIN) was resampled using a random multivariate lognormal distribution. In line with the procedure outlined by Garcia et al (http://www.flr-project.org/doc/Data_Poor_MSE_in_FLBEIA.html), some parameter combinations resulting in unstable behavior were filtered out. This is unfortunately necessary given the differences in the production models used by SPiCT, which uses continuous time, versus that of FLBEIA, which uses discrete time. Following this resampling, the SPiCT model was refit using the new parameter set for each iteration. Time series of catches were maintained constant, but stock biomass and growth parameters were adjusted according to the updated SPiCT fit. Each fleet/métier's catchabilities were subsequently updated, as well at each stock's true reference points (e.g. virgin biomass (B0), Bmsy, Fmsy).

For age-based stocks, variation was introduced through recruitment dynamics only. A segmented regression stock-recruitment relationship was fit to each stock for the period of 1995-2018. Truncation of the time series was done to take into account possible regime shifts in recruitment dynamics due to e.g. climate change. Future recruitment was predicted by this relationship with uncertainty based on random log-normal variation (CV=0.5). As the stock's biomass and catches were unaffected by this procedure, fleet/métier catchabilities did not require updating.

Indicators of healthy stock status differed between age-based (i.e. quantitatively assessed stocks) and biomass-based stocks. The following indicators were used:

5) age-based (COD-NS, HAD, PLE-EC, PLE-NS, POK, SOL-NS, TUR, WHG-NS, WIT) – Biomass (B/Btrigger > 1.0, B/Bpa > 1.0, B/Blim > 1.0). Fishing mortality (F/Fmsy < 1.0, F/Fpa < 1.0).
6) biomass-based *with* SPiCT models presented in advice (DAB, BLL) – Biomass (B/Bmsy > 1.0, B/Btrigger > 1.0). For these stocks, a proxy Btrigger = 0.5*Bmsy. This should be approximately equivalent to B/B0 > 0.25, used for other SPiCT stocks. Fishing mortality (F/Fmsy < 1.0).
7) biomass-based *without* SPiCT models presented in advice (ANF, LEM, LIN) – Biomass (B/Bmsy > 1.0, B/B0 > 0.25). Fishing mortality (F/Fmsy < 1.0).
8) fixed biomass (NEP6-9). Only fishing mortality reference points exist (F/Fmsy > 1.0)

Geographic extent of model

ICES divisions: 4a-c, 7d, 3a20 and 6a

Stocks included

The stocks included in the model were cod, haddock, saithe, sole, plaice (two stocks), whiting, nephrops (several functional units, dynamics not modelled), turbot, brill, witch flounder, dab, anglerfishes (both species together), lemon sole and ling.

Species not included and associated rationale

Several stocks were considered during Probyfish but are not yet included in the model for various reasons relating to data availability or assessment quality:

1) *Tusk* – Main issue is significant catches outside of the main fleets (i.e. by Norway). Due to relatively long time series (landings since 1988, index since 2000) and low levels of discards (ca. 2%), the possibility of using a SPiCT assessment to characterize the stock's dynamics seems very promising (Fig. 8). A remaining difficulty is in the conditioning of the FLBEIA fleets, as a substantial amount of catches are from Norwegian fleet segments, which are not specified in the model. Data from tusk (USK) was not fully reported for EU countries in the MIXFISH data accession in previous years, and thus FDI data will be reviewed in more detail to see if the stock may be incorporated.

2) *Spurdog* - Main issues are uncertainties in discard rates and significant catches outside of the model domain. An age-based modelling of dynamics is likely to be applicable given the quality of the assessment, however further data exploration is required in order to condition the fleets.
3) *Thornback ray* - Main issues are uncertainties in discard rates and species identification. Further data exploration is needed in order to condition the stock's dynamics (using life-history information or surplus production model) and the fleets (possibly using additional FDI data). Fisher et al (2018) will be used as a starting point for SPiCT fitting.
4) *Cuckoo ray* - Main issues are uncertainties in discard rates and species identification. Further data exploration is needed in order to condition the stock's dynamics (using life-history information or surplus production model) and the fleets (possibly using additional FDI data). Fisher et al (2018) will be used as a starting point for SPiCT fitting.
5) *Spotted ray* - Main issues are uncertainties in discard rates and species identification. Further data exploration is needed in order to condition the stock's dynamics (using life-history information or surplus production model) and the fleets (possibly using additional FDI data).
6) *Halibut* - Main issue is poor stock definition.
7) *Flounder* - Main issues are uncertainties in likely high discard rates.
8) *Wolffish* - Main issue is poor stock definition.
9) *Sole* (English Channel) – Main issue is a downgrading of the stock to a category 3 following last year's interbenchmark. The main reasons for the downgrading included missing or incorrectly processed data as well as poor survey coverage, which affect the representativeness of indices. The stock is scheduled for a full benchmark assessment in 2020, as which point is may re-enter into the MIXFISH advice.

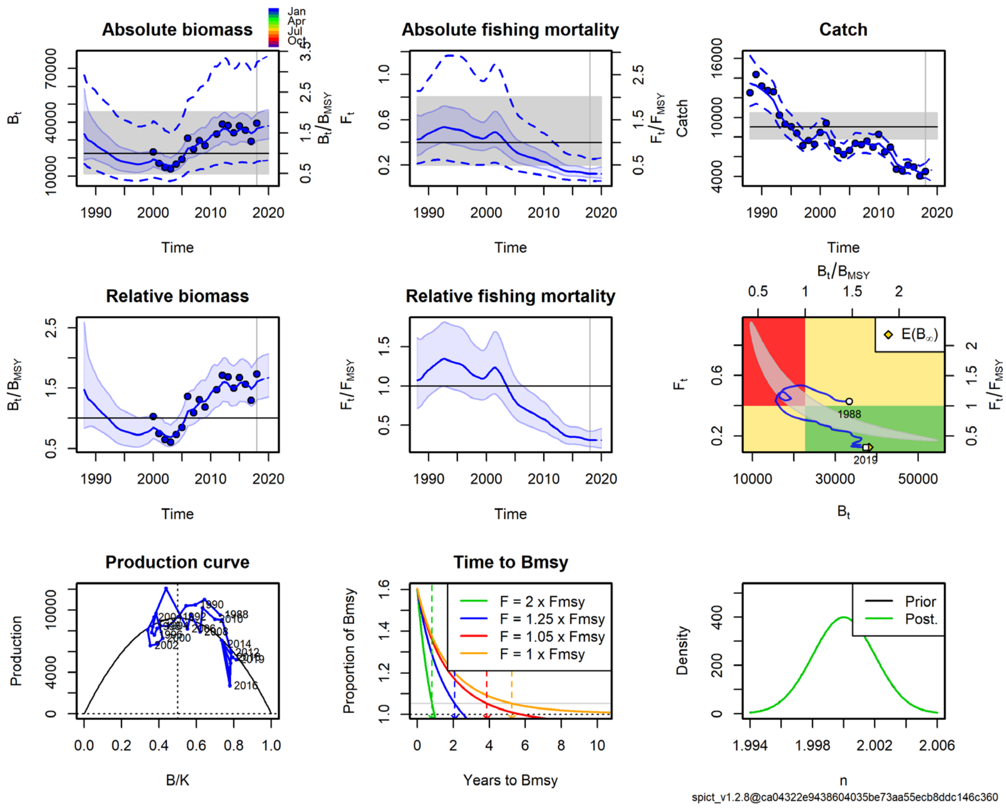

Figure 8. Summary plot of SPiCT model fit for Tusk (USK).

Presented in ICES

The mixed fisheries advice for the North Sea is currently presented within the Greater North Sea Ecoregion Fisheries Overview, rather than as a separate WGMIXFISH-Advice document as delivered in previous years. Advice is conducted using the FCube model (Ulrich et al. 2011) and includes target stocks that fall under current management plans. These include age-based stocks (ICES category 1 stocks: COD-NS, HAD, PLE-EC, PLE-NS, POK, SOL-NS, TUR, WHG-NS), and several Nephrops stocks with fixed biomass dynamics (NEP5, NEP6, NEP7, NEP8, NEP9, NEP10, NEP32, NEP 33, NEP34, NEPOTH-NS). Of the Nephrops stocks, only NEP6-9 are considered category 1 stocks with defined reference points (i.e. harvest rate). The remaining NEP stocks do not have well-defined reference points, and are not restrictive to fleet effort in the simulations.

The model uses age-based stocks when applicable, but fleets are defined on an age-aggregated basis. This means that the selectivity patterns of each fleet/métier are identical to that of the stock as a whole and only differ in terms of their effort and catchability. It is assumed that selectivity differences among métiers are minimized by the fact that stocks are primarily caught by a smaller subset of gears which outweigh less representative gears in terms of catches. The current implementation of the model in FLBEIA, used in this work, includes fleet/métier-specific selectivity. The impact of this change will be addressed in more detail at this year's WGMIXFISH-Methods meeting before further proceeding with the adoption of the FLBEIA model in future mixed fisheries advice. Preliminary comparisons show the models to be largely consistent in their output.

Species identified as not sufficiently protected by current management

Figures 9-10 shows trajectories of a biomass-based indicators by stock and scenario. Figures 11-12 show risk probabilities of stocks dropping below defined thresholds of good status by stock, year, and scenario. Figure 13 shows fishing rate (F/Fmsy) trajectories by stock and scenario.

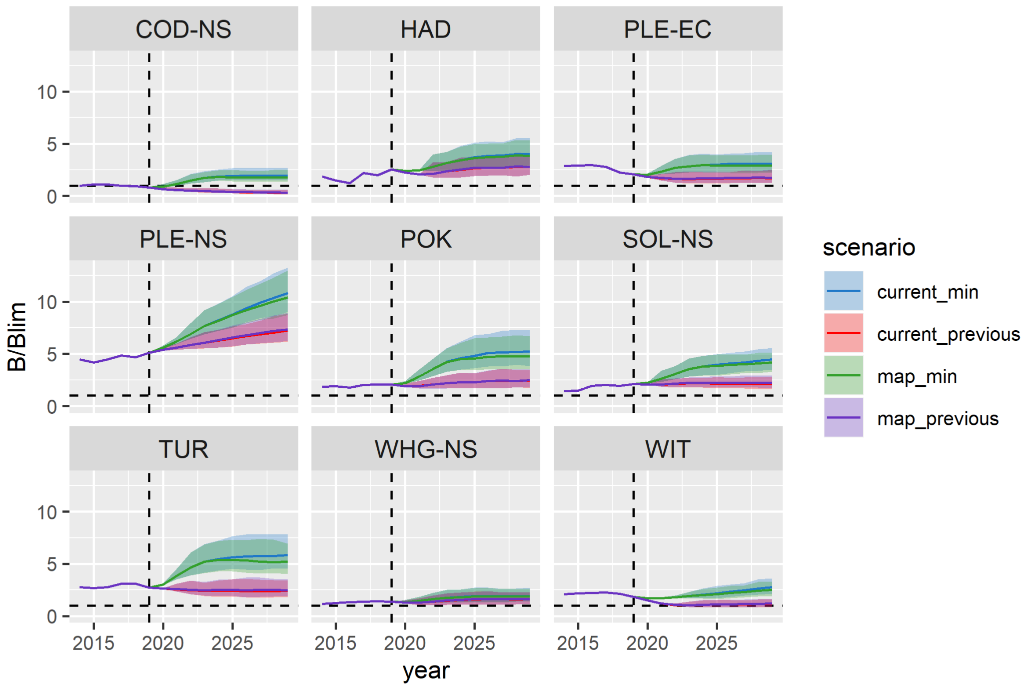

Figure 9. B/Blim trajectories by stock and scenario. Median values (colored lines) and variation (shaded areas; 5% and 95% quantiles) among iterations are shown. The year of the simulation start

(2019) and reference indicator value (B/Blim = 1.0) are shown as dashed black lines. Map_min denotes the Target TAC scenario and the Min implementation scenario and so forth.

The scenarios of current management include a larger number of TAC managed stocks than the target (map) scenario. The biomasses were slightly lower under the target scenario, but the differences were small compared to the difference between implementing the Min and Previous management scenario. Under the Min fleet effort control setting, all stocks were in good status by the terminal year. Only witch was found to be fished above Fmsy in median, but Fpa was not exceeded.

Under the Previous fleet effort control scenario, several age-based stocks show above 5% risk to Blim (cod and witch) and Fpa (cod, eastern channel plaice and witch). For biomass-based stocks, anglerfish was below 0.25B0 in 28% of the iterations. Cod, anglerfish, English channel plaice, haddock, sole, turbot, whiting and witch median fishing mortality exceeded Fmsy under the previous effort scenario.

The results are tabulated in the attached excel sheet.

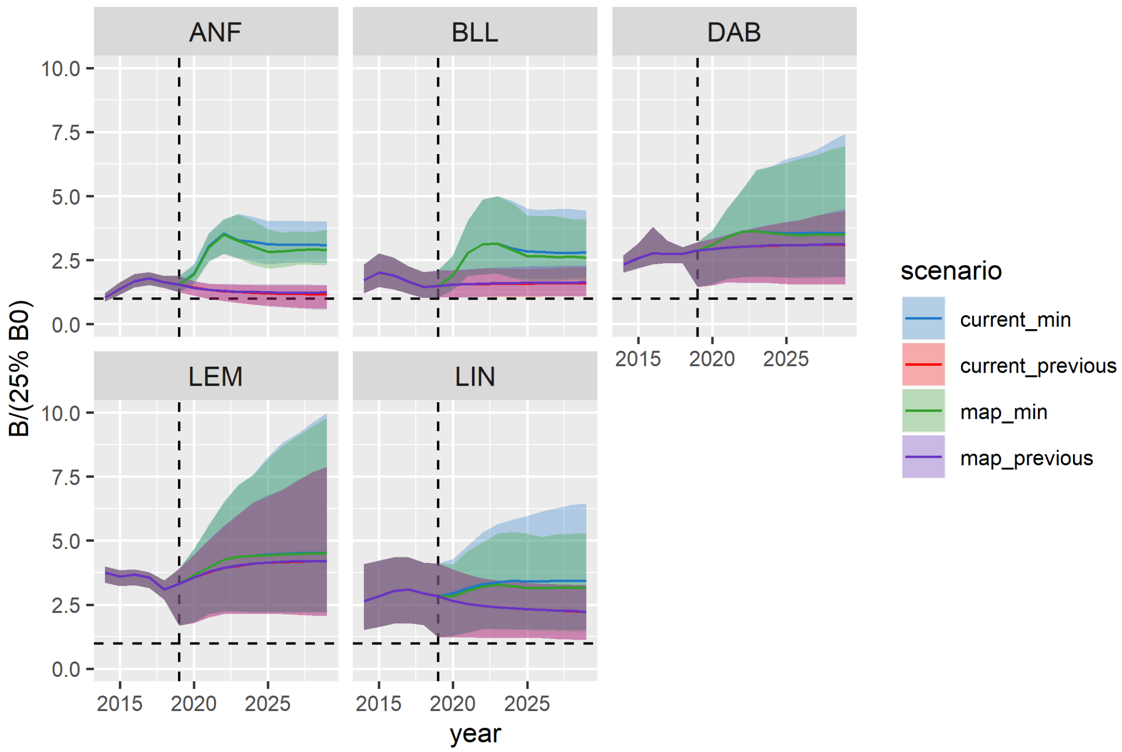

Figure 10. B/(25% B0) trajectories by stock and scenario. Median values (colored lines) and variation (shaded areas; 5% and 95% quantiles) among iterations are shown. The year of the simulation start (2019) and reference indicator value (B/(25% B0) = 1.0) are shown as dashed black lines.

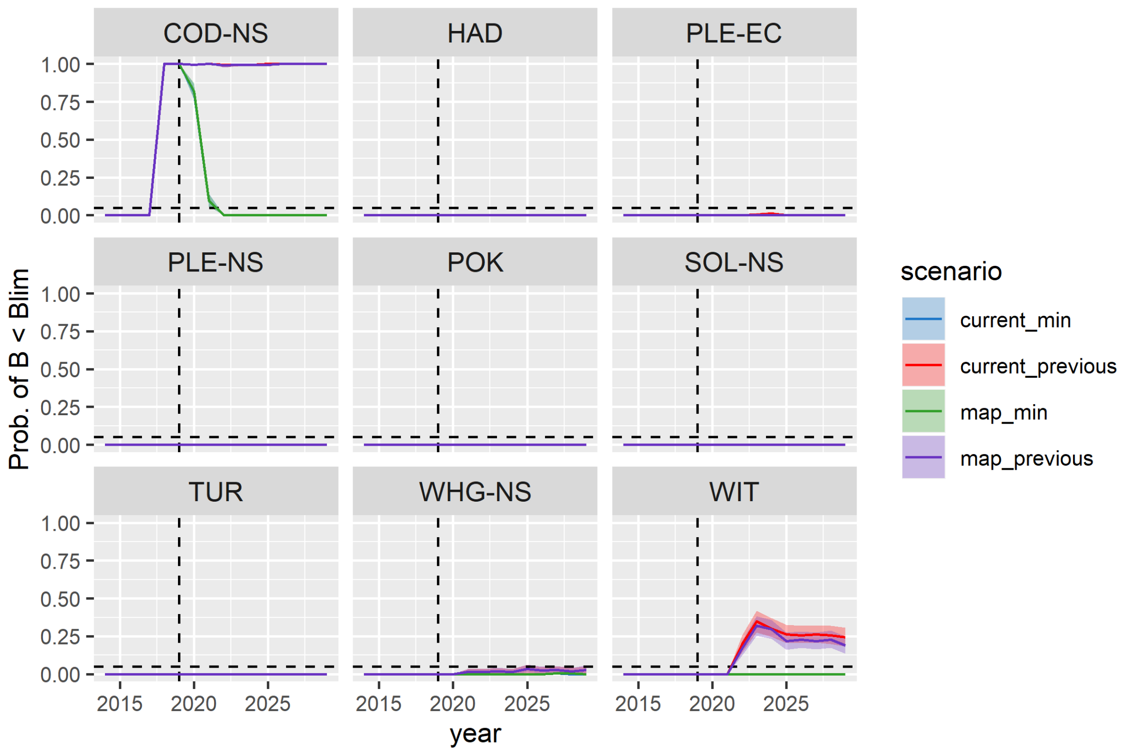

Figure 11. Probability of B < Blim by stock, year, and scenario. Shaded areas designate bootstrapped confidence intervals (2.5% and 97.5%, n = 500). The year of the simulation start (2019) and 5% risk threshold are shown as dashed black lines.

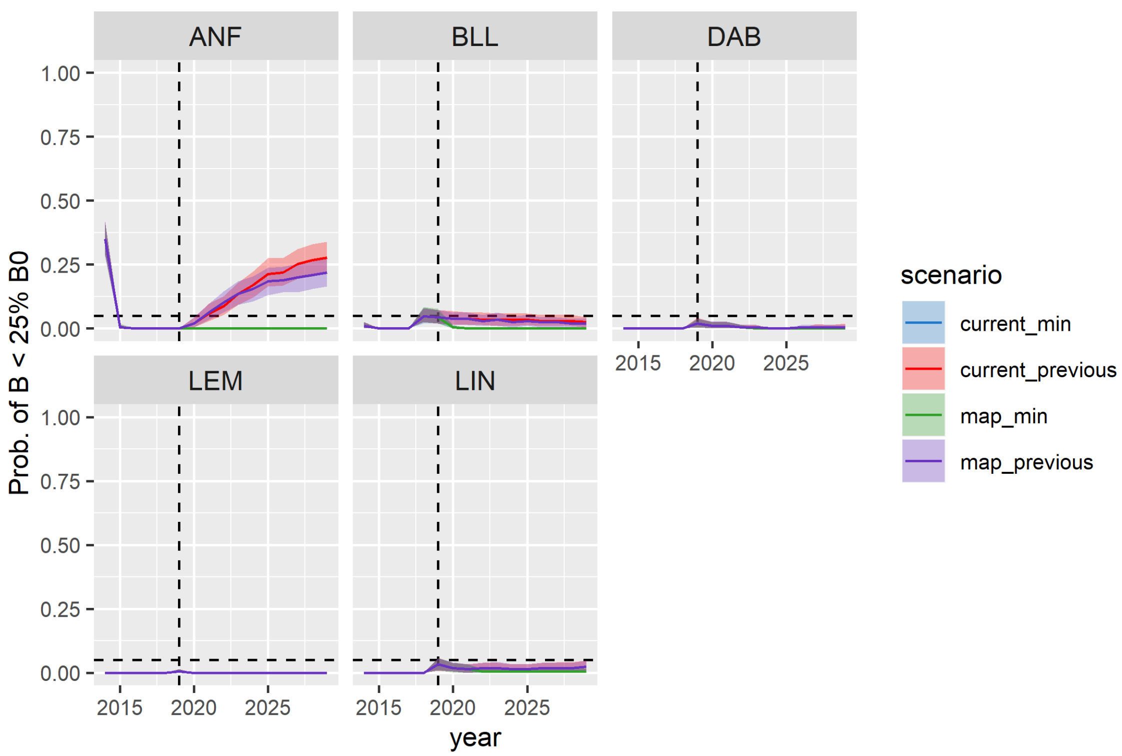

Figure 12. Probability of B < 0.25% Blim by stock, year, and scenario. Shaded areas designate bootstrapped confidence intervals (2.5% and 97.5%, n = 500). The year of the simulation start (2019) and 5% risk threshold are shown as dashed black lines.

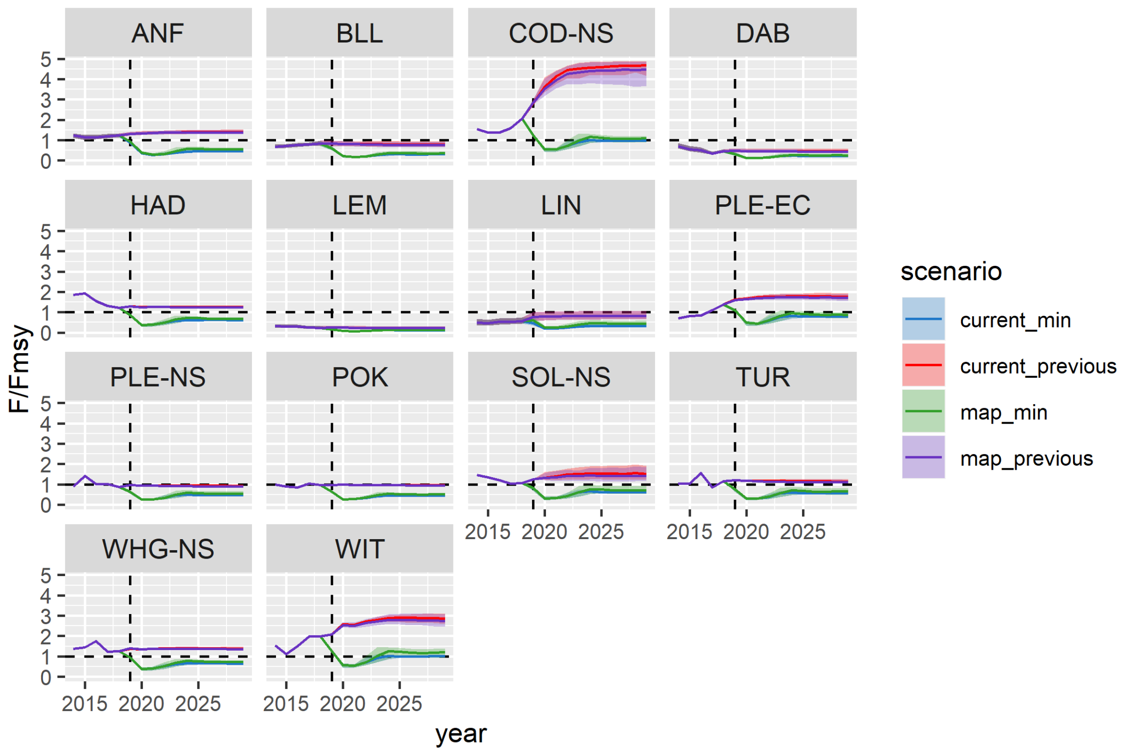

Figure 13. F/Fmsy trajectories by stock and scenario. Median values (colored lines) and variation (shaded areas; 5% and 95% quantiles) among iterations are shown. The year of the simulation start (2019) and reference indicator value (F/Fmsy = 1.0) are shown as dashed black lines.

Areas for future work

A priority for the remainder of the future work in the project will be to attempt the incorporation of additional stocks. An initial review of elasmobranch life history information has been useful in their specification but, ultimately, the ability condition the fleets will determine whether not exploitation behavior is realistic. Determining overall stock size will also be a limitation, since without this reference point, stock status will not be possible. A review of additional data from FDI is currently underway to determine the feasibility of these additions.

Shared TAC - Some stocks contain shared TACs, yet this behavior has yet to be implemented in the current model. For example, NEP TACs are actually provided as a cumulative TAC for the whole North Sea. Other examples of combined TACs include: witch and lemon sole, turbot and brill, and dab and flounder. FLBEIA can allow for such situations, and this aspect may be addressed in the future. This aspect will be investigated further within Task 4.2.

Conditioning of SPiCT stocks – Due to the discrete time steps used by FLBEIA during forecasting, some misspecification exists when translating SPiCT-fit stocks, due to their continuous time nature. Even with the parameter filtering procedure, ca 30% of the iterations failed during projection. The effects of this to possibly bias variability in the iterations requires further investigation.

Stock recruitment relationships (SRR) – All age-based stocks were fit using a segmented regression to the same span of historical years. Going forward, SRRs should be more standardized according to procedures used in each stock's respective reference point determination. In at least one case (WIT), our SRR assumptions likely reduced the productivity of the stock, which resulting in consistent overfishing (F/Fmsy > 1.0 during many iterations).

Analyse effect of having TACs only on Probyfish target and valuable bycatch species by successively adding bycatch species until all species are protected.

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