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Scientific, Technical and Economic Committee for Fisheries (STECF)
-
Review of the Technical Measures Regulation
(STECF-21-07)

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Abstract

Commission Decision of 25 February 2016 setting up a Scientific, Technical and Economic Committee for Fisheries, C(2016) 1084, OJ C 74, 26.2.2016, p. 4–10. The Commission may consult the group on any matter relating to marine and fisheries biology, fishing gear technology, fisheries economics, fisheries governance, ecosystem effects of fisheries, aquaculture or similar disciplines. This report evaluates the performance of technical measures to conserve fishery resources and protect marine ecosystems in accordance with Article 31 of Regulation (EU) 1241/20. The report presents the findings from STECF Expert Working Group 21-07: Review of the Technical Measures Regulations from the meeting held remotely from 11th to 15th October 2021. The 33 stocks analysed in this report correspond to those that were identified to have age-structured information available, in accordance with Annex XIV of Regulation (EU) No 2019/1241: Species for selectivity performance indicators. The report of the EWG-2107 was reviewed by the STECF during its November 2021 Plenary Meeting and subsequently released.

SCIENTIFIC, TECHNICAL AND ECONOMIC COMMITTEE FOR FISHERIES (STECF) - Review of the Technical Measures Regulation (STECF-21-07)

Request to the STECF

STECF is requested to review the report of the STECF Expert Working Group meeting, evaluate the findings and make any appropriate comments and recommendations.

Background provided by the Commission

The EWG 21-07 was requested to address the following Terms of Reference:

1. Calculate the respective selectivity-at-age that (a) predict the highest yield at current fishing mortality rates or harvest rates, and (b) provide the greatest protection of juveniles.
2. Compare the optimised selectivity-at-age predicted under (1) with current selectivity-at-age estimates for the stocks concerned in terms of both (a) yield gains and (b) protection of juveniles
3. Compare the optimised selectivity-at-age predicted under (1) with current selectivity-at-age estimates by fleet, gear and area, which should be analysed to the most disaggregated level that is feasible in terms of both yield gains and protection of juveniles.
4. For regional case studies, explore trade-offs between fishing pressure and selectivity with a view to minimising impacts and maximizing catches under different scenarios for catch, fishing mortality and in relation to fisheries reference points. STECF is further asked to comment on practical issues regarding the attainment of the biologically optimal selection pattern in the context of mixed fisheries and multi-gear fisheries.

STECF comments

EWG 21-07 was a follow-up to the EWG 20-02 (October 2020). The expert working group met online from the 11th to the 15th October 2021. The meeting was attended by 15 experts, including four STECF members and three JRC experts. Three DG MARE representatives and one observer also attended the meeting.

STECF notes that all the ToRs were addressed by the EWG. A dataset of 33 stocks (20 in north-eastern Atlantic and 13 in the Mediterranean) was provided to the EWG. ToR 1 and ToR 2 were tackled and presented together; ToR 3 was addressed by extending the approach for ToR 1 and 2 to compare fleet-specific selectivity patterns to the optimised selectivity pattern derived under ToR 1 in terms of both yield and the protection of juveniles. The analysis for ToR 3 was limited to a subset of stocks for which fleet disaggregated data are available.
ToR 4 was dealt with in two parts. In the first part ("4a"), for each stock the combined effects of varying fishing mortality rate and selectivity patterns were explored in terms of minimising impacts on spawning stock biomass (SSB) and maximizing catches.
The second part of ToR 4 ("4b") was interpreted as a request to comment on practical implications of trying to attain optimal selectivity in the context of mixed fisheries and multi-gear fisheries from the point of view of changes in gear technology. STECF comments follow this order.

STECF notes that throughout this document, 'selectivity' refers to 'population selectivity' to describe the differential vulnerability to fishing of the demographic components of an entire fish population, as a result of both the gear used (e.g., active or passive gear, mesh shape and size) and availability (e.g., due to the choice of time and place to fish). An increase in selectivity thus means here an increase in age at 50% selection (S50) towards the optimal age at first catch Lcopt at population level.

STECF notes that the analyses performed under ToRs 1 to 4a are solely based on mathematical computations involving varying population age structure dynamics and selectivity in a single stock approach, and do not contain any socio-economic consideration. Economic and management considerations in a mixed-fisheries context are discussed in ToR 4b.

STECF also notes that all the analyses (except ToR 4b) were performed with the R/FLR package FLSelex, which was developed by JRC specifically for this EWG and is available on https://github.com/Henning-Winker/FLSelex.

Stock-specific results and findings are given in the relevant sections of the EWG report and are not reproduced here. Nevertheless, based on the findings presented in the report, a number of general observations can be made in relation to the ToRs as follows.

ToRs 1 and 2

For each stock of the Annex, current selectivity (ToR 2) and optimised selectivity (ToR 1, following different scenarios for optimising yield, explained below) were quantified and the stock dynamics were projected forward for each of these selectivity patterns until equilibrium was reached. At equilibrium, (a) yield and (b) proportion of juveniles in the catch were quantified for each of these selectivity patterns. For each stock, the results were summarized as a comparison of (a) yield and (b) proportion of juveniles in the catch between current selectivity and each optimised selectivity pattern (ToR 2). The two optimisation scenarios (ToR 1) represent (i) a situation where young fish can be avoided, e.g. through spatial-temporal closure of nursery areas or through exclusion devices applied to fishing gears ("crank") and (ii) increased mesh size ("shift"). The results show which stocks benefit in terms of yield and/or protection of juveniles by improving selectivity and stocks that are currently already fished close to optimal selectivity.

Four case studies (two in Atlantic waters, two in the Mediterranean) were selected to present and discuss the methods and results in detail. The selected case studies were West of Scotland cod (cod.27.6a), which is heavily over-exploited and below Blim, northern hake (hke.27.3a46-8abd), which is exploited at FMSY and is above Blim, red mullet in GSA 09 (MUT09), which is over-exploited but with high biomass, and hake in the Adriatic Sea (HKE.17_18), which is over-exploited with biomass around 70 percent of the precautionary biomass Bpa. The results for all the stocks are summarized in tables and plots available in the EWG 21-07 report and in Appendix 3 to the EWG report.

Regarding ToRs 1 and 2, STECF notes that:

- Any increase in selectivity will lead to a reduction in the proportion of juveniles in the catches;
- Benefits of increased selectivity include a decrease of growth overfishing, lower risk of recruitment overfishing, greater proportion of large spawners, and increased stock biomass;
- Stocks which are subject to a higher level of growth overfishing, which are typically large-bodied and late-maturing (e.g., hake stocks in the Mediterranean, cod), will (in the long term) benefit the most;
- Increase in long-term yields are linked with increase in selectivity for the vast majority of the stocks investigated. For a few exceptions only (some haddock and whiting stocks in the Northeast Atlantic), which are currently under-exploited, optimisations in yield are associated with a decrease in S50, leading to an increased proportion of juveniles in the catch;

- Similar to a reduction in F towards FMSY, an increase in selectivity towards optimisation is associated with a short-term loss in yield depending on the magnitude of change and the biological characteristics of the stock. In general, those short-term losses will be more than compensated by the long-term gains;
- The “shift” scenario (mimicking an increase of mesh size) typically comes with higher yield gains compared to the “crank” scenario (mimicking nursery areas closure or use of exclusion devices), with only few exceptions, such as red mullet in GSA07 and GSA09, cod in 6a, hake in SWW, and some whiting and haddock stocks;
- The “crank” scenario generally gives better results in terms of reduction of juvenile catches, with only few exceptions, such as cod in 6a, whiting in 7a, and hake and megrim in SWW.

ToR 3

The analyses foreseen under ToR 3 were performed on a subset of stocks (13 in ICES areas, 6 in the Mediterranean) for which fleet disaggregated data were available. Two different approaches were taken. In the first approach, the results show for each fleet (within each stock) the comparison of projected (a) yield and (b) proportion of juveniles in the catch between current fleet selectivity and the optimised selectivity patterns quantified in ToR 1 as well as the current selectivity for all fleets. These results indicate, for each stock, fleets with selectivity patterns far from optimal selectivity and fleets with selectivity patterns closer to optimal selectivity. The second approach is a so-called “Jackknife” approach, in which projections are run with one fleet excluded at a time and the fishing mortality scaled to current level of fishing mortality. In this way, it can be seen what the gains are if a particular fleet would be excluded (again, within each stock).

Regarding ToR 3, STECF notes that:

- Active gears in general perform worse in terms of protection of juveniles and yield for the analysed stocks;
- Current otter bottom trawl (OTB) selectivity leads to lower yield when compared to current selectivity of all fleets combined;
- In the Northeast Atlantic, beam trawls (TBB) often have high proportions of juveniles in the catch, with the exception of plaice in the eastern English Channel (ICES area 7d);
- Current OTB selectivity gives rise to a high proportion of juveniles (80% in numbers) in the catches of Mediterranean hake;
- The Jackknife analysis indicates that compared to the current situation, excluding OTB selectivity would give the greatest improvement in the protection of juveniles and yield to stocks of larger-bodied demersal species, such as cod and hake;
- The results from ToR 3 suggest that increases in yield and improvements in protection of juveniles can be obtained through various mechanisms; i) increasing the selectivity for OTB, ii) allocating less effort to fishing with such gears and/or iii) shifting the effort to areas/seasons where the impacts on juveniles can be minimized.

ToR 4a

In ToR 4a, for each stock, the combined effects of varying fishing mortality rate and selectivity pattern were explored in terms of yield and SSB, as well as indicating the values of FMSY as a function of selectivity. The results are summarized as “isopleths” plots, which illustrate how yield and SSB can be increased by either reducing fishing mortality (shown on the X.axis) or increasing selectivity pattern (Y-axis).

As concerns ToR 4a, STECF notes that:

- All the stocks that are overexploited would gain in both yield and SSB if selectivity is increased simultaneously with decreased fishing mortality; the greatest gain would be for those stocks that are most heavily overexploited;
- Simultaneously increasing the selectivity and decreasing F would require smaller changes compared to manipulating only one parameter. This may increase the incentive (or rather decrease the disincentive) for change;
- Increased selectivity has often proportionally larger long-term effects on yield than on SSB. In many cases, a decrease in F in combination with increased selectivity is needed to see marked increases in SSB;
- Small-bodied and fast-growing species, which are commonly assumed to have high natural mortality of younger age classes (e.g., whiting stocks), have less to benefit in terms of yield from the increase in selectivity at current fishing mortality. In some cases, increased selectivity would lead to decreasing yield, but it would always result in larger SSB;
- Stocks that are currently underexploited (F<FMSY) (e.g., North Sea whiting and Irish Sea plaice) would not produce higher yield with increasing selectivity and/or decreasing F.

ToR 4b

STECF notes that EWG 21-07 responded to the 2nd part of ToR 4 (“4b”) with a detailed discussion of the short-term effects of selectivity changes in selected mixed fisheries (qualitatively) and a summary of a case study of the North Sea on selectivity changes in mixed fisheries that was carried out under a different project (quantitatively using FLBEIA) (Outrequin, 2021; Outrequin et al., in prep.).

As concerns ToR 4b, STECF notes that:

- In mixed-fishery situations, technical measures are often compromises that tend to increase short-term costs for the industry, through short-term losses, re-designing of vessels and/or equipment costs;
- The mixed-fisheries multi-gear examples demonstrate the complexity in improving selection patterns. Possible solutions differ case-by-case and include a combination of gear-based and spatial/temporal measures and reductions in fishing effort;
- Simulations showed that for a given level of fishing mortality implementation of larger mesh sizes in the North Sea, at least for the main gears, would result in the long-term in larger landings, larger remaining biomass and less unwanted catches.

STECF conclusions

STECF concludes that the EWG 21-07 fully addressed all of the ToRs.

STECF concludes that the approach taken by the EWG is scientifically sound. The data used are the best available, and are sufficient to support the methods and findings. While the EWG discusses some caveats relating to the interpretation of results in Section 5 of the report, the outcomes are reliable and informative. However, while the data and methods used by the EWG are appropriate, the outputs from simulations and projections for each stock are deterministic and hence the precision of the results cannot be quantified.

STECF concludes that increasing selectivity contributes to reaching some of the current objectives of the CFP, especially if applied together with reductions in fishing mortality. Advantages of such an approach include:

- reaching the current F_{MSY} (i.e. maximum sustainable yield exploitation rate, defined as the target of fisheries management in Article 2.2 of the 2013 CFP basic regulation) with less overall reduction in fishing pressure, in particular for stocks that are currently heavily overfished.
- ensuring a higher protection of juveniles by improved exploitation patterns, as required in Article 3.2a of the current TMR.
- improved compliance with the landing obligation due to reduced incentives to underreport catches <MCRS (Article 15 of 2013 CFP basic regulation).
- discard reduction due to lower catches of individuals below MCRS (Article 2.5a and Article 4.1a of the TMR regulation).
- reducing the impact of fishing on exploited fish stocks, according to Article 2.3 of the 2013 CFP Basic Regulation which stipulate that "*The CFP shall implement the ecosystem-based approach to fisheries management so as to ensure that negative impacts of fishing activities on the marine ecosystem are minimized*". In particular, improving selectivity together with reducing fishing pressure towards F_{msy} would lead to higher biomass than by reducing fishing pressure alone. This means that a given level of catches would be achieved with comparatively less effort, implying thus fewer greenhouse gas emissions, habitats impacts and bycatches of sensitive species.

STECF concludes that further work is still needed to progress along the review of the Technical Measures Regulation, as discussed in ToR 7.3 of this PLEN 21-03 report.

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REPORT TO THE STECF

EXPERT WORKING GROUP ON
Review of the Technical Measures Regulation
(EWG-21-07)

Virtual meeting, 11-15 October 2021

This report does not necessarily reflect the view of the STECF and the European Commission and in no way anticipates the Commission's future policy in this area

1 INTRODUCTION

According to Article 31 of Regulation (EU) 2019/1241 on the conservation of fishery resources and protection of marine ecosystems through technical measures, the Commission is required to report every third year, following evaluation by STECF, on the extent to which technical measures both at regional level and at European Union level have contributed to achieving the objectives set out in Article 3 and reaching the targets set out in Article 4 of Regulation (EU) 2019/1241. The first report was due to be submitted on the 31 December 2020 and it appeared with some delay due to covid-19 in September 2021 (COM, 2021a,b). The next report is due 31 December 2023. To facilitate this reporting, STECF is requested by the Commission to evaluate the performance of technical measures to conserve fishery resources and protect marine ecosystems. For the first report the STECF had set up EWG 20-02 for the evaluation. The Terms of Reference for EWG 20-02 (STECF, 2020a) included two tasks that were explicitly concerned with the fisheries selectivity on commercial species in relation to the objectives and targets set out in Article 3.2(a) and Article 4.1(a) respectively of the regulation: the objective to "optimise exploitation patterns to provide protection for juveniles and spawning aggregations of marine biological resources" and the target that "catches of marine species below the minimum conservation reference size are reduced as far as possible". Other tasks addressed impacts arising from innovative gear and effects on sensitive species, habitats and marine ecosystems. Here, we are concerned with the former: fisheries selectivity on commercial species, namely the species listed in Annex XIV of Regulation (EU) 2019/1241.

In October 2020 it was, of course, not possible to evaluate the impact of the new Regulation, because it had only been in force since a bit more than one year (since August 2019). EWG 20-02 (STECF, 2020a) decided to look at a longer historical period of time and compare time series of a selectivity indicator with the timing of the introductions of various technical measures in the past. The indicator chosen was the ratio between the fishing mortality rate on the fish at the age of recruitment to the fishery and the mean fishing mortality rate over a range of adult ages (the so-called F_{bar} used in stock assessments and advice): F_{rec}/F_{bar}. In a comparison with a set of alternative indicators, this indicator had been identified as the most promising, being robust to variation in recruitment and changes in fishing mortality (Vasilakopoulos et al., 2020). Nevertheless, EWG 20-02 (STECF, 2020a) listed a range of caveats to the use of this indicator for the purpose of this analysis and, overall, did not identify any obvious correlations between changes in the selectivity indicator and specific changes in technical measures for the species investigated. STECF PLEN 20-03 (STECF, 2020d) concluded that the ToR that had been asked of EWG 20-02 was extremely wide-ranging in scope and that to address it explicitly and provide an informed, meaningful response, would have required far more time and expertise than that afforded to EWG 20-02. STECF PLEN 20-03 (STECF, 2020d) also concluded that, although temporal trends in selectivity were found, the extent to which such changes can be attributed to implementation of technical measures cannot be deduced.

Following this, STECF and the Commission considered how to proceed to be ready for the next evaluation, which is due in 2023. After long deliberations, and the identification by STECF PLEN 21-01 (STECF, 2021a) of the mid-term need to establish and agree on a methodology and the appropriate indicators that can be used to perform the evaluation of the regulation, it was decided to take a step-by-step approach and explore the merits of some partial approaches one by one. In the early summer of 2020, DG MARE proposed a first version of the current ToRs 1-3 and these were discussed by STECF PLEN 21-02 (STECF, 2021b). STECF PLEN 21-02 (STECF, 2021b) proposed some slight modifications and the addition of ToR 4. STECF PLEN 21-02 (STECF, 2021b) considered the ToRs 1-3 to be, at least in theory, straightforward and feasible to be tackled by EWG 21-07. There were some concerns that the ToRs 1-3 would be only a very simplistic and partial step towards a more fully comprehensive evaluation, but it was decided that a small step would be more feasible than a (too) large step. In order to accommodate the possibility that time would allow for more in-depth analyses, STECF PLEN 21-02 (STECF, 2021b) proposed to add a 4th ToR in which the specific scientific expertise of the EWG participants could be used in case studies towards a more comprehensive evaluation. Finally, the Commission issued the current ToRs 1-4, slightly modified from the proposal by STECF PLEN 20-02 (of which ToRs 1-3 were based on the proposal by DG MARE) (STECF, 2021b). In particular, the second part of ToR 4 was added by the Commission at a late stage: the request to comment on practical issues regarding the attainment of the biologically optimal selection pattern in the context of mixed fisheries and multi-gear fisheries.

1.1 Terms of Reference for EWG-21-07

Following discussions after STECF EWG 20-02, STECF 21-01 and STECF 21-02, the EWG 21-07 is requested to:

1. Calculate the respective selectivity-at-age that (a) predict the highest yield at current fishing mortality rates or harvest rates, and (b) provide the greatest protection of juveniles.

2. Compare the optimised selectivity-at-age predicted under (1) with current selectivity-at-age estimates for the stocks concerned in terms of both (a) yield gains and (b) protection of juveniles

3. Compare the optimised selectivity-at-age predicted under (1) with current selectivity-at-age estimates by fleet, gear and area, which should be analysed to the most disaggregated level that is feasible in terms of both yield gains and protection of juveniles.

4. For regional case studies, explore trade-offs between fishing pressure and selectivity with a view to minimising impacts and maximizing catches under different scenarios for catch, fishing mortality and in relation to fisheries reference points. STECF is further asked to comment on practical issues regarding the attainment of the biologically optimal selection pattern in the context of mixed fisheries and multi-gear fisheries.

2 GENERAL APPROACH TO THE TERMS OF REFERENCE

Fisheries selectivity describes the ability to target and capture fish by size and species during harvesting operations, allowing bycatch of juvenile fish and non-target species to escape unharmed (Garcia, 2009). Therefore, fisheries selectivity may either refer to (un)desirable species (species selectivity) or sizes (size selectivity). Species selectivity typically refers to the avoidance of unwanted species (e.g., endangered species, choke species), while size selectivity refers to the avoidance of specific sizes (usually small ones) of a given species. Size selectivity is the focus of this report.

There are three types of size selectivity (Millar & Fryer, 1999): contact selectivity (often referred to as 'gear selectivity'), which is the differential retention probability of fish that encounter a gear; available selectivity, which expresses the differential availability of different fish sizes to a gear; and population selectivity, which is the combination of the two (i.e. gear selectivity plus fish availability). Consequently, population selectivity describes the differential vulnerability to fishing of the demographic components of an entire fish population, as a result of both the gear used (e.g., active or passive gear, mesh shape and size) and availability (e.g., due to the choice of time and place to fish) (Millar & Fryer, 1999; Scott & Sampson, 2011). Population selectivity differs from gear selectivity in that it is the product of all gears acting upon a stock and of the spatio-temporal allocation of both fish and fishers. Within this report, 'selectivity' refers to 'population selectivity', unless otherwise specified.

It should be noted that, because this document uses population selectivity, the metric of S_{50} (age at which 50% is selected) cannot directly be related to mesh size. Through selectivity experiments, length-based selectivity parameters (such as L50, length at which 50% is retained) can be related to mesh size of individual gears; with age-length information these can be transformed into gear selectivity at age (an exercise that was done in the Annex of this report). But, as explained above, population selectivity results from the combination of gears in use and the spatio-temporal allocation of fish and fishers.

The approach to the Terms of Reference is as follows:

ToR 1 and ToR 2 are presented together (Results section 4.1.). For each stock of the Annex (see Table 3.1.1), the current selectivity (ToR 2) is described by the best fit of a flexible selectivity function on the F-at-age curve, and the resulting selectivity curve is then varied according to two alternative scenarios ("cranking" and "shifting", explained below, ToR 1). The maximum yield at equilibrium is computed for each of the so generated new selectivity curves, and the selectivity curve that attained the maximum equilibrium yield across all variations is selected as optimized selectivity for each scenario. The so optimised selectivity patterns are considered and the age-structured stock dynamics are then projected forward under the current fishing mortality (F_{cur}) for each of these selectivity patterns until equilibrium is reached (50 years). At this equilibrium point, the yield and the percentage of juvenile fish in the catch are quantified for each of the selectivity patterns and compared to the equilibrium values attained from projections based on the current selectivity for F_{cur} and, in addition, based on the scientific advice for F (ICES / GFCM). This procedure addresses both ToRs 1 and 2 in that the optimised selectivity patterns (ToR 1) are evaluated in terms of (a) yield and (b) protection of juveniles; and then a comparison is made with the current selection pattern (ToR 2) in terms of (a) yield and (b) protection of juveniles. Thus, it can be assessed which stocks have the largest potential gains in terms of yield and protection of juveniles by improving selectivity, and which stocks are currently already fished with close to optimal selectivity. The EWG defines juveniles as immature individuals (following the maturity-at-age values used in the official stock assessment model).

ToR 3 (Results section 4.2) is addressed by extending the approach described above for ToR 1 and 2 to compare fleet-specific selectivity patterns to the optimised selectivity pattern derived under ToR 1 in terms of both yield and the protection of juveniles. The analysis for ToR 3 is limited to a subset of stocks for which fleet disaggregated data are available (Table 3.1.1). In this case, two approaches are followed to evaluate fleet-specific selectivity. In the first approach, fleet-specific selectivity curves are fitted to available partial fleet F-at-age data for each stock that could be included in the analysis. The age-structured stock dynamics are then projected forward for one fleet-specific selectivity curve at a time under F_{cur} and outcomes are compared to the current (combined fleet) and the optimised selectivity projections from ToRs 1 and 2 in terms of the equilibrium (a) yield and (b) proportion of juveniles in the catch. Therefore, for each fleet, the comparison is made between fishing under the fleet's selectivity against what the optimised selectivity would result in. In this way it can be assessed, for each stock, which fleet's selectivity pattern is far from optimal selectivity and which fleet may be closer to optimal selectivity. The second approach is a so-called Jackknife approach, in which projections are made for exclusions of one fleet at a time and the partial changes of fishing mortality are scaled to current. The Jackknife analysis therefore presents evaluation of the partial selectivity impact for each of the excluded fleets by predicting the potential gains in terms of yield and protection of juveniles if a particular fleet were to be excluded.

With respect to ToR 4, the EWG interprets the first part ("4a") as follows (Results section 4.3.). Firstly, for each stock the combined effects of varying fishing mortality rate and selectivity patterns are explored in terms of minimising impacts on spawning stock biomass (SSB) and maximizing catches. To map the optimal exploitation regimes (i.e. combinations of F and selectivity) that can produce high yields at high levels of SSB, isopleths were constructed by computing the equilibrium states of all F and selectivity combinations for each stock. This 'isopleth approach' allows to identify which combinations lead to high catches and high SSB, and to visualise by contrast the unfulfilled potential (if any) of selectivity to promote higher yields at lower levels of stock depletion. It thus facilitates the choice of pathways of change in F and/or selectivity to move towards more sustainable exploitation regimes and had been proposed as analytic tool for this purpose in previous STECF EWGs on Technical Measures (STECF 2013; 2015). To evaluate the relation to fisheries reference points, non-stationary F_{MSY} values (or proxies of it), which vary as function of selectivity, are depicted in the isopleth plots.

The second part of ToR 4 ("4b", Results section 4.4.) is interpreted as a request to comment on practical implications of trying to attain optimal selectivity in the context of mixed fisheries and multi-gear fisheries from the point of view of changes in gear technology. Here the EWG (i) discusses the short-term effects of selectivity changes in selected case studies (qualitatively), (2) and (ii) presents a synthesis of main results from a simulation study on selectivity changes in North Sea. This study on mixed fisheries with FLBEIA was recently carried out under a different project.

3 MATERIAL AND METHODS

3.1 Data

The stocks analysed in this report (Table 3.1.1) correspond to those that were identified to have age-structured information available, in accordance with Annex XIV of Regulation (EU) No 2019/1241: Species for selectivity performance indicators.

For the ICES region of the Northeast Atlantic, stock assessment outputs in the form of 'FLStock' objects based on 2020 benchmark were received timely before to the meeting as requested. In addition, a new dataset of 'FLStock' objects for the most recent 2021 assessment became available as part of the preparation for the ICES WKREF1 workshop (2-4th Nov, 2021), which were prepared in a joint effort of ACOM, ICES assessment working group and M. Cardinale (Expert) and H. Winker (Co-Chair), who are also the Co-Chairs of WKREF1. EWG agreed to use the most recent 2021 'FLStock' data for the analysis, also considering that it undergone very thorough consistency checks against the ICES 2021 advice. For the Mediterranean Sea, available 'FLStock' objects were extracted from the electronic annexes of the STEFC Stock Assessments in the Mediterranean Sea (STECF-20-09, STECF-20-16) and prepared prior to the meeting by the JRC (Table 3.1.1). Only those stock assessments were used that formally passed the benchmarking process. Although the assessments output vary arguably in quality, they were considered to represent the best available information.

Partial fishing mortality at age F_a at fleet/gear were available for ICES stocks (2017-2019) from the 2020 Review of technical measures (STECF, 2020a). In addition, fleet information in the form of 'FLFleet' objects from the ICES Working Group on mixed fisheries advice were received from ICES as requested. However, on closer inspection by the EWG, disaggregated catch-at-age data were not available for key such as North Sea and North Western waters, and the EWG therefore agreed to use the partial F_a fleet dataset (level 4) from STECF-20-02 (STECF, 2020a) for the analysis (ToR 3). For this purpose, the data set was compiled in the form of a list 'FLQuants' objects, which containing the partial F_a vectors by fleet by the JRC.

For Mediterranean stocks partial F_a by fleet segment were only available for selected Western Mediterranean stocks in the STEFC EWG-21-01 report on the West Med assessments (Table 3.1.1): conversion factors, closures, effort data and recreational fisheries. The data extracted from the Tables presented in EWG 21-01 and a dataset was compiled in the form of a list 'FLQuants' objects, which containing the partial F_a vectors by fleet before the meeting by the JRC.

Table 3.1.1: Summary Table of stocks by region and area that were used for the analysis in this report. The column 'Fleet Data' indicates the subset of stocks for fleet data were available. NEA: Northeast Atlantic, MED: Mediterranean Sea; BS: Baltic Sea, NS: North Sea; NWW: Northwestern Waters; SWW: Southwestern Waters.

Region	Area	Stock	Species	Assessment	Fleet Data
NEA	BS	cod.27.22-24	*Gadus morhua*	ICES, SAM, 2021	Yes
NEA	BS	ple.27.21-23	*Pleuronectes platessa*	ICES, SAM, 2021	Yes
NEA	NS	cod.27.47d20	*Gadus morhua*	ICES, SAM, 2021	Yes
NEA	NS	had.27.46a20	*Melanogrammus aeglefinus*	ICES, TSA, 2021	Yes
NEA	NS	ple.27.420	*Pleuronectes platessa*	ICES, AAP, 2021	Yes
NEA	NS	ple.27.7d	*Pleuronectes platessa*	ICES, AAP, 2021	Yes
NEA	NS	pok.27.3a46	*Pollachius virens*	ICES, SAM, 2021	Yes
NEA	NS	whg.27.47d	*Merlangius merlangus*	ICES, SAM, 2021	Yes
NEA	NWW	cod.27.6a	*Gadus morhua*	ICES, SAM, 2021	Yes
NEA	NWW	cod.27.7e-k	*Gadus morhua*	ICES, SAM, 2021	No
NEA	NWW	had.27.6b	*Melanogrammus aeglefinus*	ICES, XSA, 2021	Yes
NEA	NWW	had.27.7a	*Melanogrammus aeglefinus*	ICES, ASAP, 2021	Yes
NEA	NWW	had.27.7b-k	*Melanogrammus aeglefinus*	ICES, SAM, 2021	No
NEA	NWW	ple.27.7a	*Pleuronectes platessa*	ICES, SAM, 2021	Yes
NEA	NWW	whg.27.7a	*Merlangius merlangus*	ICES, ASAP, 2021	No
NEA	NWW	whg.27.7b-ce-k	*Merlangius merlangus*	ICES, SAM, 2021	No
NEA	SWW	hke.27.3a46-8abd	*Merluccius merluccius*	ICES, SS3, 2021	No
NEA	SWW	ldb.27.8c9a	*Lepidorhombus boscii*	ICES, XSA, 2021	No
NEA	SWW	meg.27.7b-k8abd	*Lepidorhombus whiffiagonis*	ICES, Bayesian, 2021	Yes
NEA	SWW	meg.27.8c9a	*Lepidorhombus whiffiagonis*	ICES, XSA, 2021	No
MED	WM	HKE.01_05_06_07	*Merluccius merluccius*	STEFC, a4a, 2020	Yes
MED	WM	HKE.08_09_10_11	*Merluccius merluccius*	STEFC, a4a, 2020	Yes
MED	WM	MUR.05	*Mullus surmuletus*	STEFC, a4a, 2020	Yes
MED	WM	MUT.01	*Mullus barbatus barbatus*	STEFC, a4a, 2020	No
MED	WM	MUT.06	*Mullus barbatus barbatus*	STEFC, a4a, 2020	No
MED	WM	MUT.07	*Mullus barbatus barbatus*	STEFC, a4a, 2020	Yes
MED	WM	MUT.09	*Mullus barbatus barbatus*	STEFC, a4a, 2020	Yes
MED	WM	MUT.10	*Mullus barbatus barbatus*	STEFC, a4a, 2020	Yes
MED	CEM	HKE.17_18	*Merluccius merluccius*	STEFC, SS3, 2020	No
MED	CEM	HKE.19	*Merluccius merluccius*	STEFC, a4a, 2020	No
MED	CEM	HKE.20	*Merluccius merluccius*	STEFC, a4a, 2020	No
MED	CEM	MUT.17_18	*Mullus barbatus barbatus*	STEFC, a4a, 2020	No
MED	CEM	MUT.22	*Mullus barbatus barbatus*	STEFC, a4a, 2020	No

3.2 Software used

For the analyses of the impact of varying fisheries selectivity patterns, the R package FLSelex was produced and is available on https://github.com/Henning-Winker/FLSelex. This package is used in FLR and it requires the stock data as FLR objects (Fisheries Library in R: Kell et al., 2007). The Co-chair Henning Winker (JRC) developed tested the package on the stock data prior to the meeting with the support of the FLR Core Team Members Iago Mosqueira (Wageningen University) and Laurence Kell (Imperial College).

3.3 Using apical *F* as a standardized metric for evaluating selectivity

Comparing the impacts of alternative selectivity pattern requires setting the instantaneous rate of fishing mortally F at comparable constant levels. For this purpose, it is important to consider that the definition of selectivity differs across regions. In Europe, it common to use $\bar{F}_y$ as a measure of annual F, whereas in many other regions (e.g. US West Coast, South Africa, Australia and New Zealand) the so called apical $F_{apical} = max(F_a)$ is used as a standard metric.

With regards to isolating the selectivity effect, $\bar{F}_y$ has the undesirable property that its scale depends on the pre-specified age range across which F_a is averaged. For example, if $\bar{F}_y$ is set to ages 2-4 to represent the dominant age classes under the current selectivity regime, but the goal is to evaluate the effect of selecting fish only at age-5, a common $\bar{F}_y$ would result in disproportionately high F_a on ages 5+. This is because $\bar{F}_y$ is computed for age ranges that are hardly selected for the definition $S_a = F_a/max(F_a)$ as is used in FLR. For this reason, and consistent with previous studies (e.g. Sampson and Scott 2011), the F_{apical} is used as F as the standardized quantity to compare stock responses across selectivity pattern in FLSelex. To implement this in FLR, the $\bar{F}_y$ range determined by *fbarmin* and *fbarmax* is dynamically adjusted in the FLStock object to the $max(F_a)$ under each selectivity scenario under equilibrium conditions.

3.4 Selectivity-at-age

The starting point for the FLSelex analysis are the FLStock objects based on the most recent age-structured assessments (e.g. a4a, SAM, SS3) conducted by ICES and STECF (Table 1.1). Due to the age-structured assessment model outputs, selectivity is expressed as selectivity-at-age (Sa), such that:

$$S_a = \frac{F_a}{max(F_a)}$$

where F_a is the instantaneous rate of fishing mortality at age (e.g. Sampson and Scott 2011).

A common assumption is that S_a follows a logistic curve in the form of an ogive. However, initial exploration of FLStock objects based on recent ICES benchmark assessments indicate the a logistic is the exception than the norm (c.f. Sampson and Scott, 2011). The North Sea plaice ple.27.420 provides an example where the observed fishery selectivity F_a pattern estimates, and thus the population selectivity diverges clearly from a logistic selectivity assumption (Figure 3.1).

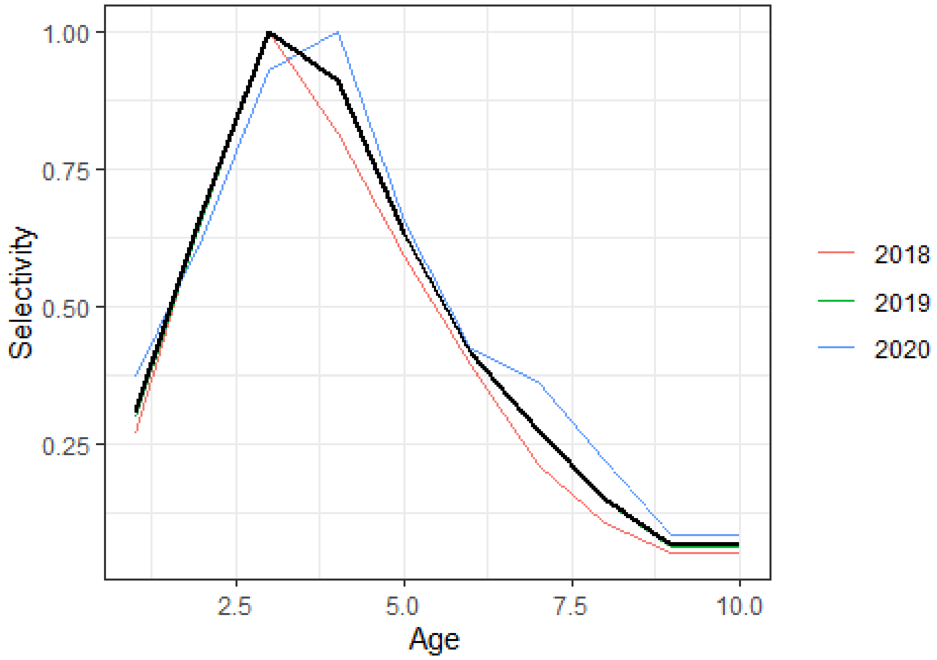

Figure 3.1: *Observed S_a = F_a/F_{max} for North Sea plaice ple.27.420 over the recent 3 years*

3.5 The Selex function

A variety of dome-shaped selectivity curves can arise because F_a and thus S_a is estimated on combined fleet level, combining multiple fleet (gear) segments that fish over a wide range of different areas. In fact, Sampson and Scott (2011) demonstrated that a logistic population selectivity pattern would require that all age-classes would be equally distributed in space and time and harvested with the gear that is associated with a logistic selectivity.

To accommodate a wide variety of selectivity curves, FLSelex provides a flexible 5-parameter parametric selex() function (cf. Huynh et al., 2018), which comprises the following three compounds:

1. A $logistic$ describing the ascending limb of the selectivity curve

$$S_a = \frac{1}{1 + exp\left(-log(19)\,\frac{a - S_{50}}{S_{95} - S_{50}}\right)}$$

where S_{50} and S_{95} are the ages where S_a corresponds to 0.5 and 0.95.

2. An adjustable $halfnormal$ decribing the descending

$$S_a = -(D_{min} - 1)\,\frac{dnorm\,(age\,, S_{max}, S_{max} D_{cv})}{max\left(dnorm\,(S_{max}, S_{max} D_{cv})\right)} + 1$$

where $dnorm$ denotes a normal probability density distribution, S_{max} corresponds to the mean of the normal distribution where S_a peaks, D_{cv} determines the slope of the descending limb with the standard deviation of the normal given by the product $S_{max} D_{cv}$, and D_{min} determines the mimimum the descending slope (height).

The expected S_a is then defined as a piece-wise function of the form (Figure 3.2):

$$S_a = \begin{cases} g(logistic) & \text{if } age < S_{max} \\ g(halfnormal) & \text{if } age \geq S_{max} \end{cases}$$

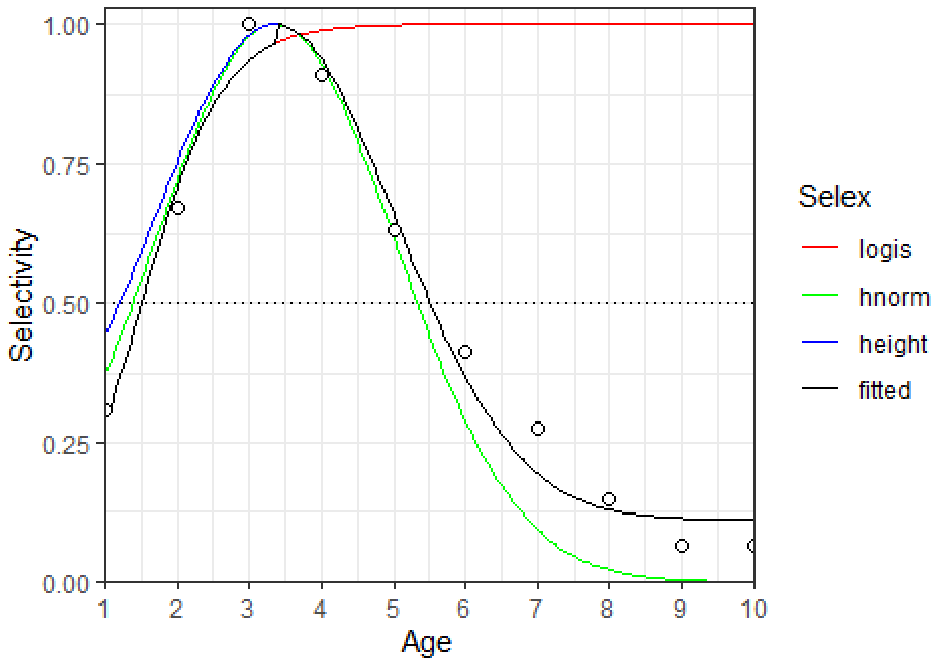

Figure 3.2: *Observed S_a and fitted S_a for North Sea plaice illustrating the compounds of the piece-wise selex function. logis: logistic of acending curve (S_{50}, S_{95}), hnorm: unadjusted halfnormal (S_{max}, D_{cv}) for the descending curve, height: adjusted height of the halfnormal (D_{min})*

3.6 Varying selectivity-at-age

The FLSelex package provides three inbuilt options to vary the five estimated selex parameters, of which the EWG agreed to explore the following two:

1. The option $Crank$ sequentially changes S_{50}, thereby changing ascending slope of the curve, given an upper bound at S_{95}. This change in selectivity pattern is intended to represent a situation where targeting of young fish can be minimized, e.g. through spatial-temporal closure of nursery grounds or gear through exclusion devices. The range of selectivity variations through "cranking" is shown for illustrative examples from the Northeast Atlantic (cod.27.6a, hke.27.3a46-8abd) and the Mediterranean Sea (MUT.09, HKE.17_18) in Figure 3.3.

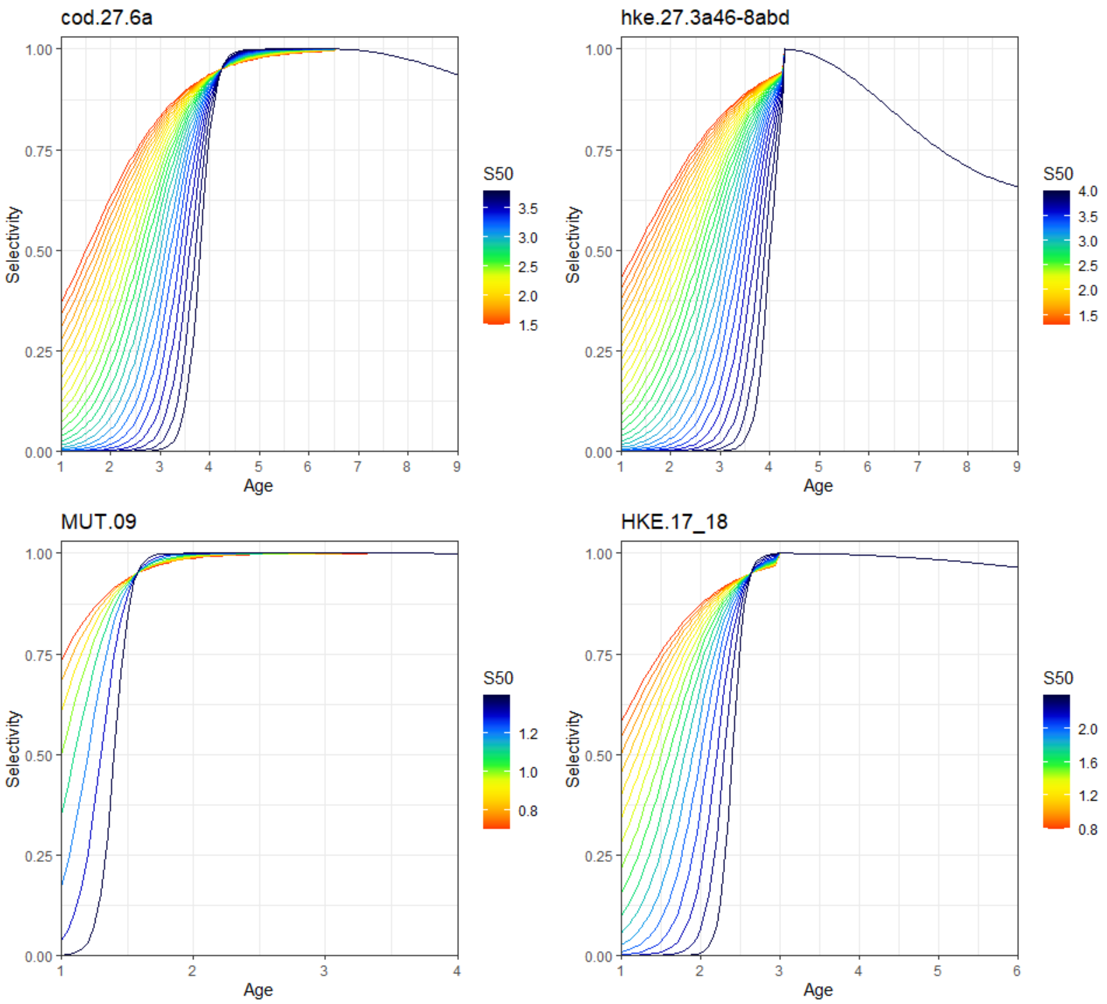

Figure 3.3: *"Cranking" the ascending slope of the estimated selectivity curve by varying S_{50}, shown for examples from the Northeast Atlantic (cod.27.6a, hke.27.3a46-8abd) and the Mediterranean Sea (MUT.09, HKE.17_18)*

2. The option $shift$ sequentially changes S_{50}, S_{95} and S_{max} thereby shifting the selectivity curve, while retaining the shape unchanged. The default upper bound is to theoretical age at A_{opt} where an unfished cohort attains its maximum biomass (Froese et al. 2008; Froese et al. 2016). Change in the selectivity pattern through "shifting" is intended to approximate situations where (1) a reduction of small specimens in the catch is achieved through larger mesh sizes of active gears, thereby reducing drag associated with higher catchability of larger and faster fish, (2) a shift of fishing effort to areas where larger fish have higher densities or (3) a combination of (1) and (2). The range of selectivity variations through "shifting" is illustrated for the four example stocks in Figure 3.4.

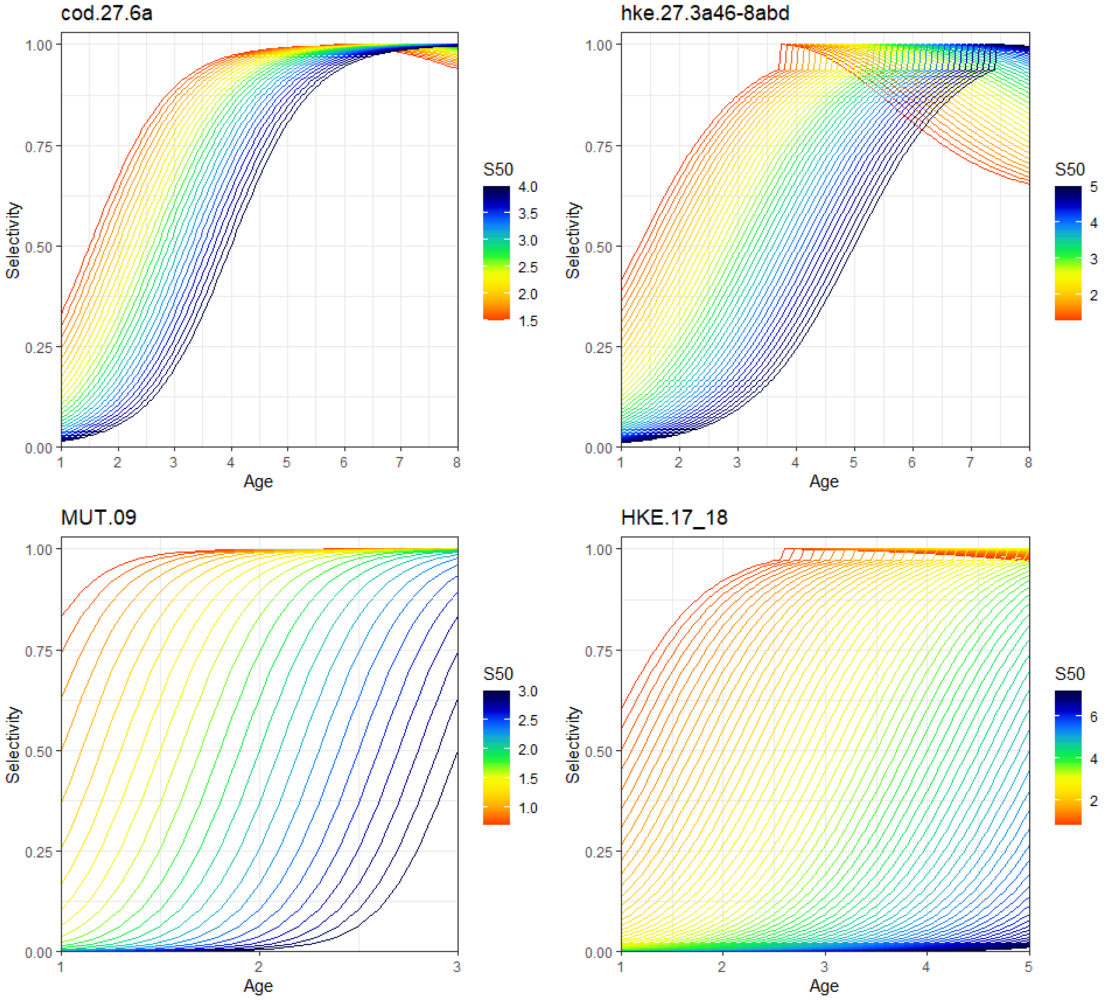

Figure 3.4: *"Shifting" the estimated selectivity curve in its unchanged shape by changing S_{50}, S_{95} and S_{max} simultaneously, shown for examples from the Northeast Atlantic (cod.27.6a, hke.27.3a46-8abd) and the Mediterranean Sea (MUT.09, HKE.17_18)*

3.7 Equilibrium optimisation and forecasting of selectivity scenarios (ToRs 1 and 2)

As outlined in the "General Approach to the Terms of Reference", addressing ToRs 1, 2 and 3 entails the following principle steps. Firstly, the maximum yield at equilibrium is computed for each of the "cranked" and "shifted" selectivity curves, and the selectivity curve that attained the maximum equilibrium yield across all iterations is selected as optimized selectivity curve for the respective scenario. In this way, optimised selectivity patterns are then projected forward under the current fishing mortality (F_{cur}) for each of these selectivity patterns until equilibrium is reached (50 years).

The yield optimisation at equilibrium in FLSelex is computed using the C++ optimisation routine in the FLR package FLBRP, which estimates reference points and values of SSB, recruitment, yield and catch at equilibrium for the selectivity curves generated through "cranking" and "shifting" over a wide range of F values (see Isopleths ToR 4), including the F_{cur} (ToRs 1,2 and 3).

Forecasting over a range of selectivity pattern in FLSelex is conducted with the FLR package FLasher. All forecasts assume deterministic recruitment, so at long-term forecasts are equivalent to the equilibrium estimates. While forecasting is computational more demanding as thus limited to a specified F value (default F_{cur}), it provides the increased flexible for computing additional quantities of interest from the output in the form of a FLStocks objects. To address ToRs 1, 2 and

3 (b) the percentage of juveniles in the catches is computed as ratio of the number immature to the total number of fish in the catch in addition to (a) the relative change yield (%).

All equilibrium optimisations and forecast were done based on the average weight-at-age w_a, maturity-at-age Mat_a, natural mortality at age M_a vector of the three most years. By the same way, F_{cur} was calculated based on F_a based on three years average, which is consistent with common practice for forecasting under F_{cur} in ICES and STEFC.

3.7.1 STOCK RECRUITMENT RELATIONSHIP (SRR)

The EWG discussed the importance of integrating spawner recruit relationship (SRR) into yield maximisations at equilibrium and projections under alternative selectivity scenarios. The EWG agreed that, where possible (and plausible), a Beverton-Holt SRR should be fitted to recruitment R and SSB estimates from 'FLStock' objects given prior information from a recent meta-analysis of all SSRs that were extracted from the FishLife R package (Thorson 2020; https://github.com/James-Thorson-NOAA/FishLife).

The Beverton-Holt SRRs were fitted using the FLR library FLSRTMB (Winker and Mosquiera; https://github.com/flr/FLSRTMB). The specification of the Beverton-Holt in FLR is:

$$R_y = \frac{aSSB_{y-a_{min}}}{b + SBB_{y-a_{min}}}$$

where R_y is the number of recruits in year y, $SSB_{y-a_{min}}$ is the spawning stock biomass in year y minus minimum age a_{min} defined for the stock (typically age-0 or age-1). To integrate available prior information on the steepness of the Beverton-Holt SSR, the above equation is re-parameterised as function of steepness s and unfished spawning biomass per-recruit SPR_0, such as used, e.g., in Stock Synthesis (Methot and Wetzel, 2013):

$$R_y = \frac{4sSSB_{y-a_{min}}R0}{R_0 SPR_{0_y}(1-s) + SBB_{y-a_{min}}(5s-1)}$$

where steepness s is defined as the ratio of recruitment when SSB equals 20% of the unfished SSB_0 to the virgin recruitment R_0 at $SSB0$ and SPR_{0_y} is treated as non-stationary being function of annual quantities of $W_{a,y}$, $Mat_{a,y}$ and $M_{a,y}$. Given that s is bounded by definition between 0.2 and 1, The prior distribution for s is generated from a truncated logit distribution ($TrunkLogit$) of the form

$$s = 0.2001 + 0.7999 / \left(1 + exp\left(-s_{logit}\right)\right)$$

such that

$$s \sim TrunkLogit\left(s_{logit}, \sigma_{logit}\right)$$

where s_{logit} and $sigma_{logit}$ correspond to the input of species-specific predictions for the distribution of s from the hierarchical taxonomic FishLife model (Thorson, 2020).

The FLSRTMB estimates of $R0$ and s are then converted into the parameters a and b of the Beverton-Holt formulation in FLR, such that

$$a = \frac{4sR_0SPR_0}{5sSPR_0 - 1}$$

$$b = \frac{R_0SPR_0(1-s)}{5s-1}$$

where the reference for SPR_0 to predict a and b was taken the average SPR_{0_y} across all year.

The EWG reviewed the fits of the SSRs for all stocks and deemed the majority of fits adequate (see example in Fig. 3.5, Appendix 1). Exceptions were identified in the cases of one ICES stock, cod.27.7e-k, and the Mediterranean hake stocks, where the Beverton-Holt model resulted in unrealistic unfished SSB_0. All stocks had common that showed severely truncated age-structure, short- or questionable (cod.27.7e-k) historical time series and typically showed a decreasing trend of recruitment, which probability limited a more reliable estimation of the SSR function. In the case of cod.27.7e-k, an alternative SSR was approximated in the form of segmented regression by fixing the break point to the B_{lim} reference point. In the absence of any biomass reference points for Mediterranean hakes, no SSR could be fitted and recruitment was taken the geometric mean across all years. In particular, the selectivity analysis for Mediterranean hakes can therefore only interpreted from per-recruit perspective, which is likely to underestimate potential gains through optimising the selectivity patterns.

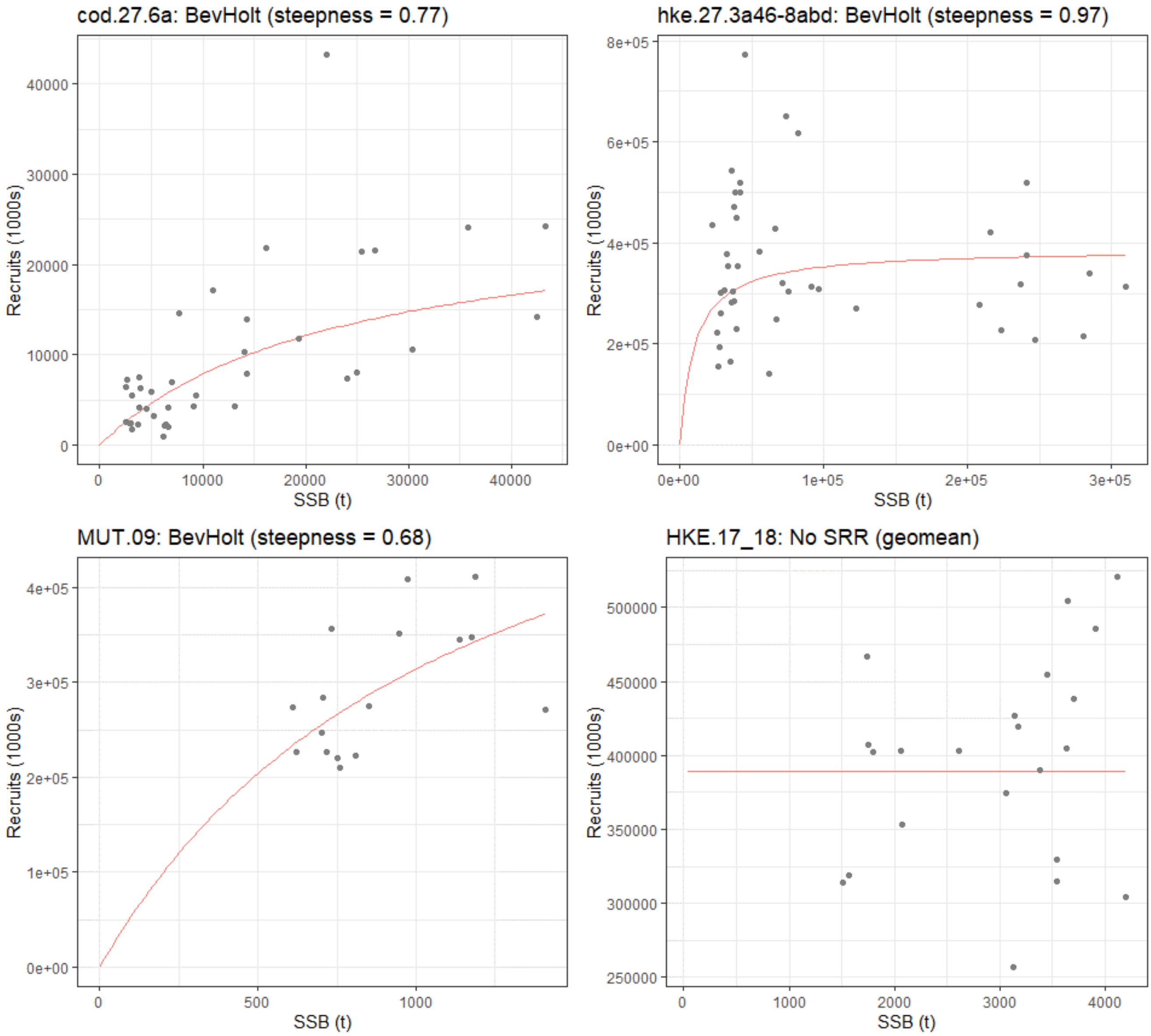

Figure 3.5: *Fits of the Beverton-Holt stock recruitment relationships (SRR) for cod West of Scotland (cod.27.6a), Northern hake (hke.27.3a46-8abd) and Western Mediterranean red mullet in GSA 9 (MUT-09) and geometric mean of constant recruitment for Adriatic hake (HKE.17_18). Estimated steepness values of the Beverton-Holt SRR are indicated in brackets.*

3.7.2 PROJECTION SCENARIOS

For each stock, a total of five scenarios were projected deterministically over a horizon of 50 years to attain equilibrium quantities for (a) yield and (b) the proportion of juveniles in the catches (Table 3.7.1).

Table 3.7.1: Specification of projection scenarios evaluated for ToRs 1-3

No	Scenario	Specification
1	**Cur** (Reference)	Projections are made using the current selectivity (best fits to the observed selectivity-at-age) and at current F (F_{cur}), which serves the reference case of the status quo situation against which the four following alternative scenarios are evaluated
2	**Crank**	Projections are made at F_{cur} using "cranked" selectivity curve (Section 3.4) that resulted in the maximum yield
3	**Shift**	Projections are made at F_{cur} using "shifted" selectivity curve (Section 3.4) resulted in the maximum yield.
4	**Amat**	Projections are made under F_{cur} using "shifted" selectivity curve (Section 3.4) for which the age-at-50%-selectivity (S_{50}) corresponds to age-at-50%-maturity (A_{mat50}).
5	**F_{adv}**	Projections are made using the current selectivity, but at F levels that correspond to the scientific advice for F_{MSY} (F_{adv}) based on the benchmark assessments.

3.8 Evaluating impacts of fleet-specific selectivity (ToR 3)

3.8.1 ONE FLEET AT A TIME

The analysis on impacts of fleet-specific selectivity builds on the projection scenarios described in in the previous Section 3.7.2 (Table 3.7.1) for for ToR 1 and 2. It is designed to compare fleet-specific selectivity patterns to the optimised selectivity pattern derived under ToR 1 in terms of both yield and the protection of juveniles. This analysis is limited to a subset of stocks for which fleet disaggregated data are available (Table 2.1.1.). For each stock, projections were made at F_{cur} for one fleet-based selectivity at the time over a projection horizon of 50 years to attain equilibrium quantities for (a) yield and (b) the proportion of juveniles in the catches.

Fleet-based selectivity curves were derived by fitting the 5-parameter selectivity function (Section 3.5) to the average partial F-at-age values for fleet f ($F_{a,f}$) of the last available data years (ICES: 2017-2019; STEFC: 2019). The partial $F_{a,f}$ values are calculated according to the following formula:

$$F_{a,f} = F_a \frac{C_{a,f}}{C_a}$$

where $C_{a,f}$ is the catch-at-age for fleet f and C_a is the assessment model estimate of catch-at-age for all fleets combined.

To reduce the number of fleets and increase the robustness of the selectivity curves, some fleets were grouped based on expert knowledge and a visual inspection of the empirical selectivity patterns. Only those fleets were analyzed of which the cumulative partial F accounted for at least 95% of the harvest rate of a stock. The OTB, OTT and PTB fleets were grouped as otter trawls, while the SDN and SSC fleet were grouped as Seines, and the PTM and OTM fleets were grouped as Midwater Trawls (see Appendix 2).

3.8.2 JACKKNIFE

The Jackknife projections are based on the selectivity of the fishery after removing individual fleets from the fishery within a region. The new F_a for the fishery was calculated by multiplying the average partial $F_{a,f}$ for the last 3 years of each remaining fleet f with a constant multiplier of catch-at-age C_a. This age specific multiplier was chosen so that the sum of the partial $F_{a,f}$ after excluding a fleet was equal to the overved F_{cur} of the fishery. Finally, the jackknife vectors for F_a was calculated by multiplying all partial $F_{a,f}$ values of the selected fleets with the smallest multiplier. This new F_a was used to calculate a selective curve using the 5-parameter selectivity function (Section 3.5) to make projections for each Jackknife run at F_{cur}.

A similar grouping of the fleets was done as for the fleet- based analysis as described above. Fleets that did not contribute to 95% of the harvest rate of a stock within the region were removed from the analysis.

3.9 Isopleths (ToR 4)

For each stock the combined effects of varying fishing mortality rate and selectivity patterns are explored in terms of yield and SSB in terms spawning stock biomass (SSB) and maximizing catches. To map the optimal exploitation regimes (i.e. combinations of F and selectivity) that can produce high yields at high levels of SSB, three-dimensional ('F x selectivity x equilibrium yield' and 'F x selectivity x equilibrium SSB') isopleths were constructed with FLSelex. The underlying equilibrium values of yield and SSB that were computed for the selectivity curves generated through "shifting" over a wide range of F values (c.f. Section X.X). To evaluate the relation to fisheries reference points, non-stationary F_{MSY} values (or proxies of it in the absense of a SRR), which vary as function of selectivity, are depicted in the so isopleth plots.

4 RESULTS

4.1 Potential gain in terms of yield and proportion juveniles in the catch from optimising selectivity at current F (ToR 1 & 2)

In this section, four illustrative examples are described extensively, while the summary results for all stocks are displayed in tables and graphs. The full results for all stocks are shown in the Appendix 3. The four examples for illustration were chosen to cover a range of different features: two of the examples are ICES stocks and two are Mediterranean stocks; for each area an overexploited and a more sustainably exploited stock were chosen; two of the examples are characterised by dome-shaped selectivity and two are characterised by sigmoid selectivity. The four illustrative examples are cod in the West of Scotland (cod.27.6a), northern hake (hke.27.3a46-8abd), red mullet in GSA 09 and European hake in the Adriatic Sea (GSAs 17-18). In addition to the two scenarios ("crank" and "shift") of optimized selectivity under current F (ToR 1), two more scenarios are displayed here: "Amat" refers to a scenario where selectivity is shifted so that S50=a50 (where a50 is the age at which 50% are mature); Fadv refers to a scenario under current selectivity but with F at the value that is advised (often FMSY).

4.1.1 CASE STUDY EXAMPLES

4.1.1.1 West of Scotland Cod (cod.27.6a)

Characterisation of the stock

Cod in 6a (West of Scotland) are fast-growing and start to recruit to the fishery at age 1. They are fully selected at age 4. Cod in this region mature relatively early (a50= age 2). Natural mortality is assumed to be relatively high at age 1 (between 0.5 and 0.65) and gradually declines to around 0.2 for older fish (ICES, 2021a). This assumption is based on the Lorenzen approach.

Assessment

The stock is assessed with a SAM model. F-at-age is assumed to be the same for ages 4 and older. For younger ages, F is assumed to be auto-correlated between ages. This results in a flat-topped selectivity curve that is close to a logistic curve (sigmoid shape).

State of the stock

The stock has been over-exploited for the entire available time series and has been well below B_{lim} since the mid 1990s. Recruitment appears to be impaired due to the low stock size (ICES, 2020a).

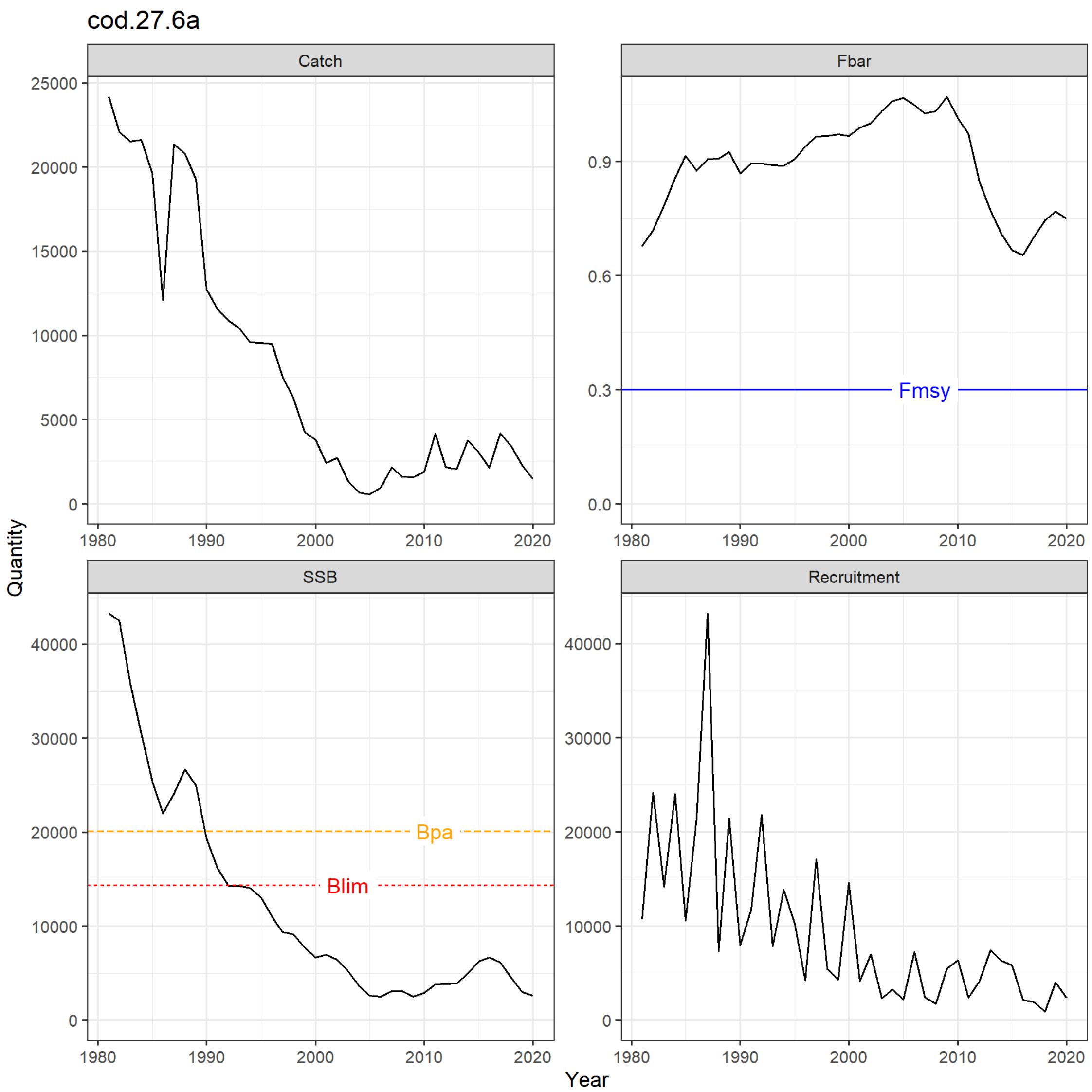

Figure. 4.1.1.1: West of Scotland cod (cod.27.6a). Stock status overview based on the ICES 2021 benchmark assessment.

Selectivity scenarios

The current selectivity pattern is relatively gradual (non-steep): while fish are selected from age 1 onwards, they are only fully selected at age 4 with a S_{50} of around age 2. This means that there is considerable scope for the "crank" scenario to change selectivity. Under the "crank" option, S_{50} of the optimum pattern is around age 3.5, which is a bit below the maximum possible under the "crank" option.

The "shift" scenario gives an optimum S_{50} of around age 4. At that age, cod are around 50cm in length.

Shifting selectivity to match maturity will result in a slight decrease in S_{50} to age 2.

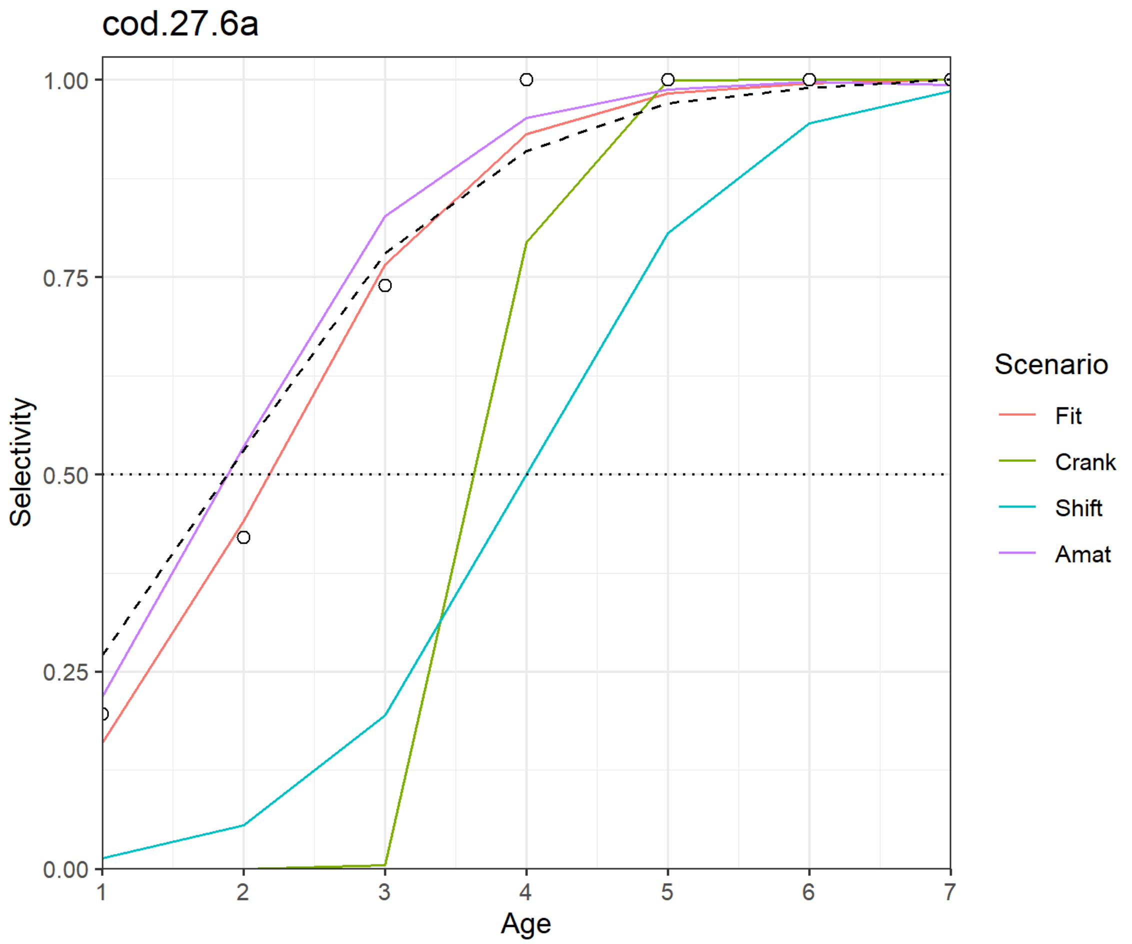

Figure 4.1.1.2: West of Scotland cod (cod.27.6a). Optimal selectivity scenarios. Dots represent the observed selectivity-at-age and dashed line represents maturity-at-age from the assessment model.

Projections

The "cranking" scenario is projected to allow the stock to rebuild in the medium term under current F and it will result in a drastic reduction in juvenile catches and increases in yield. "Shifting" selectivity to age 4 is projected to lead to similar benefits as the "cranking" scenario, but to a lesser extent. Also reducing F to the advised value but keeping current selectivity has similar benefits, but to an even lesser extent. Shifting selectivity to match maturity leads to a slight deterioration of the current selection pattern as the selection curve is moved slightly to the left.

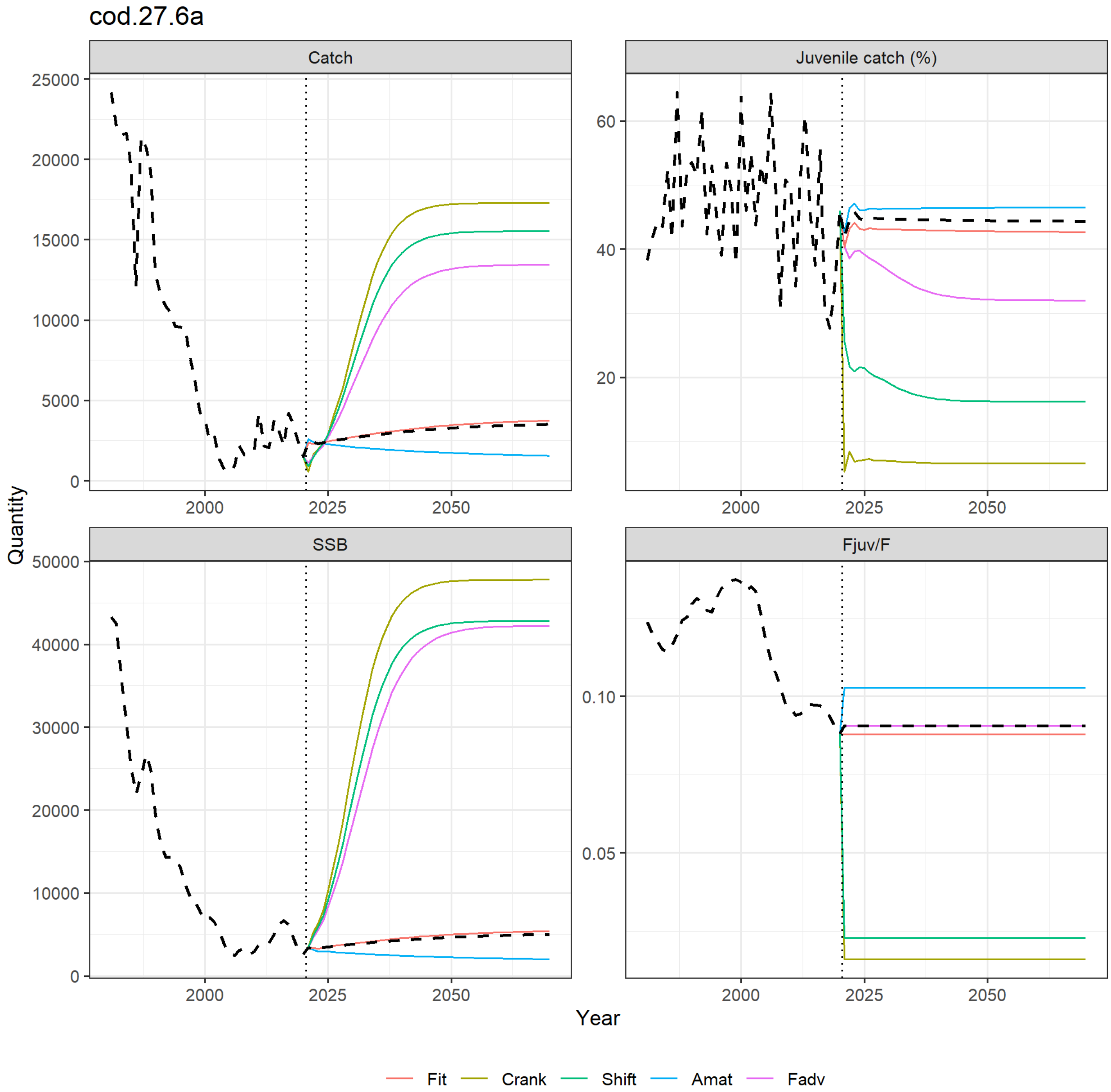

Figure 4.1.1.3: West of Scotland cod (cod.27.6a). Optimal selectivity scenario projections assuming Beverton-H S-R relationship. The dashed line represents the projection under the current observed selectivity.

4.1.1.2 Northern Hake (hke.27.3a46-8abd)

Characterisation of the stock

The northern hake stock (Biscay, Celtic Seas, North Sea and Baltic) is relatively fast growing and fully selected to the fishery around age 4. Hake mature relatively early (a50=2.5 years). Natural mortality is assumed to be 0.4 for all length (and age) classes.

Assessment

The stock is assessed with a Stock Synthesis model and uses length data inputs only (ICES, 2021b). The model is fitted with 7 fleets and each fleet has its own selectivity pattern; some have a double-normal pattern, others single logistic. Selectivity varies over time for one fleet, while it is assumed to be constant for the other six. The resulting selectivity pattern of the combined fleets has a dome shape, which flattens out around age 10.

State of the stock

The stock has been exploited around F_{MSY} since 2011 after a long period of over-exploitation that led to a period where the stock was below B_{lim}. Currently the stock size is well in excess of B_{lim} (ICES, 2021c).

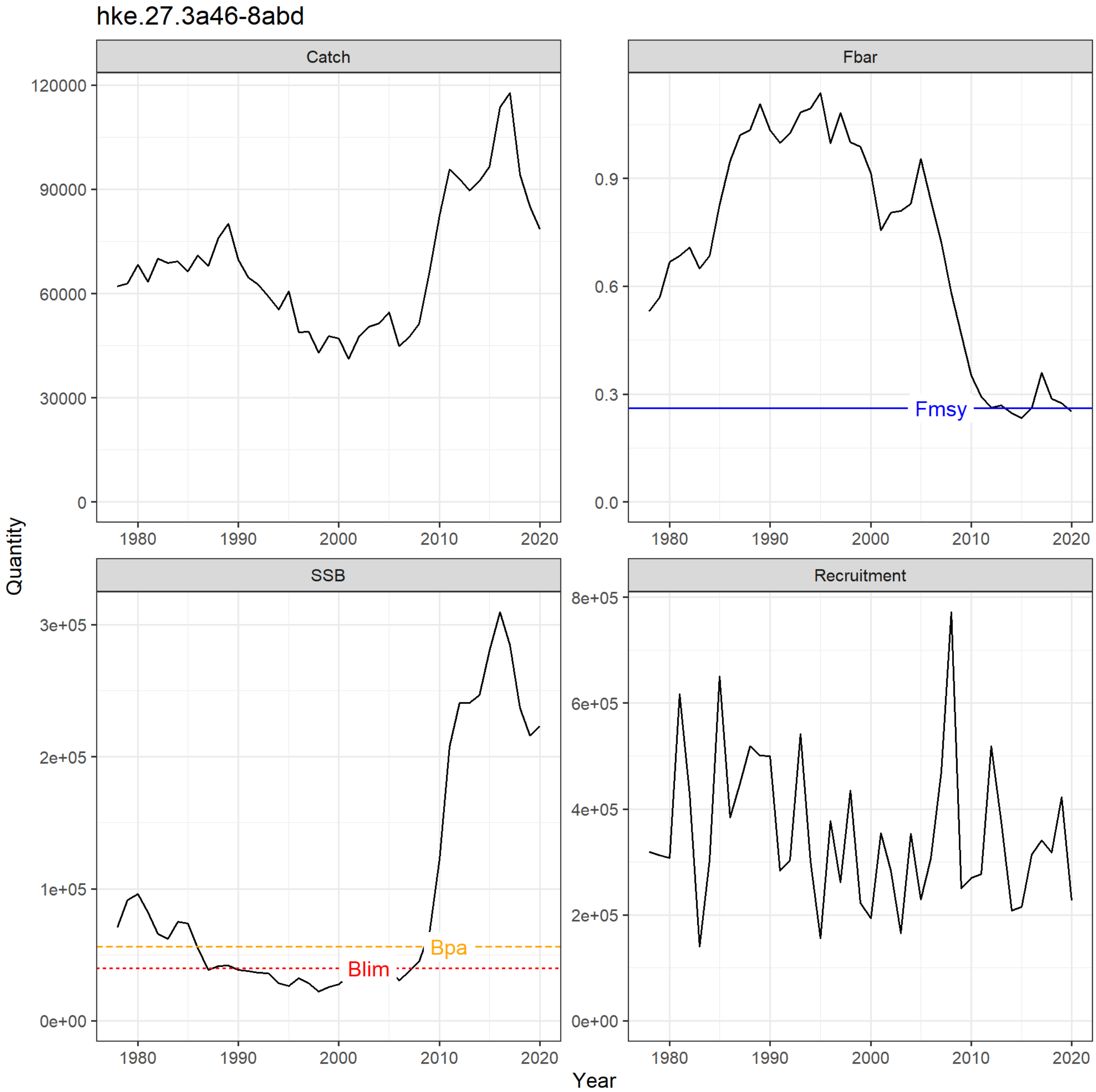

Figure 4.1.1.4: Northern hake (hke.27.3a46-8abd). Stock overview

Selectivity scenarios

Under the current selectivity pattern S_{50} is around age 2. "Cranking" can increase this to almost age 4. "Shifting" also results in an increase of S_{50} to age 4. "Shifting" has the result that apical F increases to older ages. Shifting the selectivity to match maturity results in a moderate increase in S_{50} to around age 2.5.

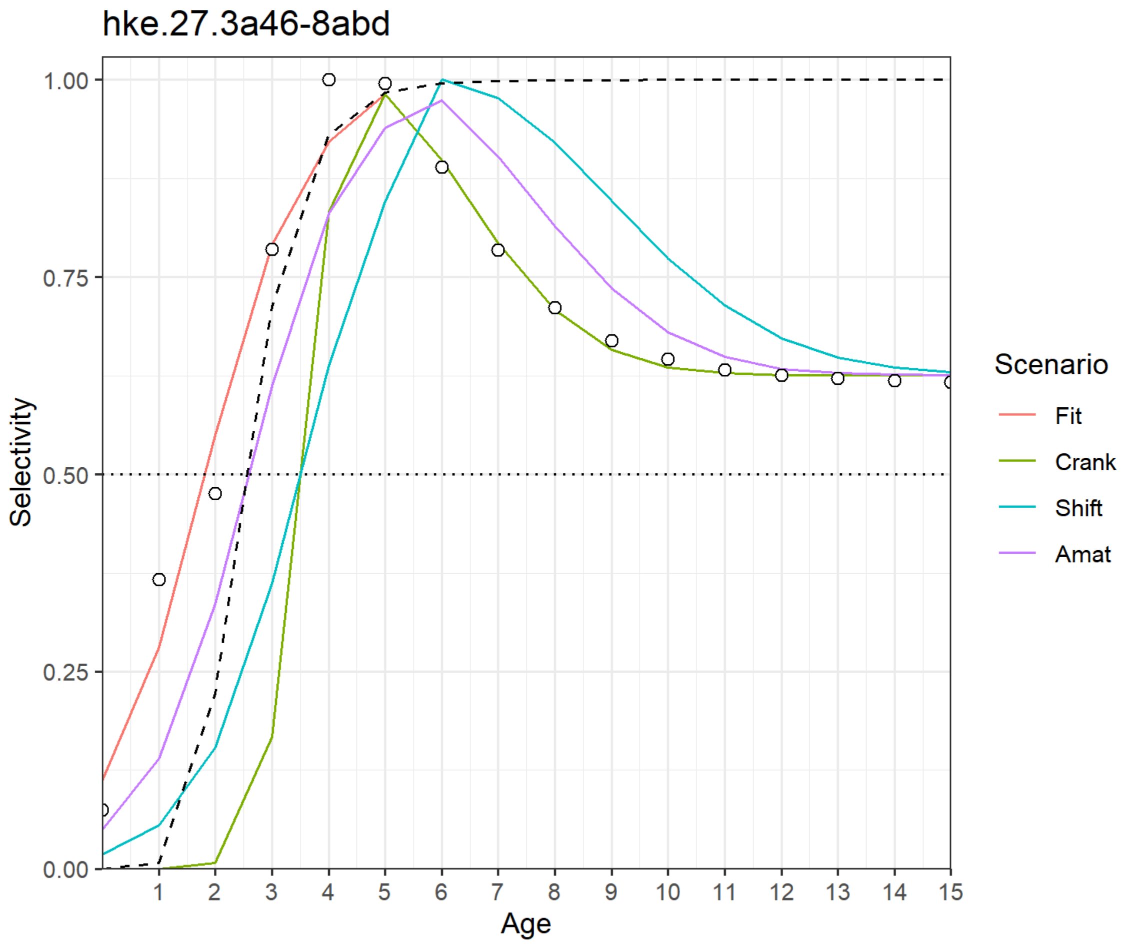

Figure 4.1.1.5: Northern hake (hke.27.3a46-8abd). Optimal selectivity scenarios. Dots represent the observed selectivity-at-age and dashed line represents maturity-at-age from the assessment model.

Projections

Under the current fishing rate, the "crank" scenario is projected to lead to the largest catches and SSB and the lowest percentage of juveniles in the catches after reaching equilibrium. The selectivity curve fitted to the current maturity values ("Amat") and the "shift" scenario would also lead to higher catches and SSB and lower percentages of juvenile catches compared to the status quo scenario (fit and obs). Before reaching equilibrium, short-term losses are to be expected. Reducing F to the advised value but keeping current selectivity has negligible effects.

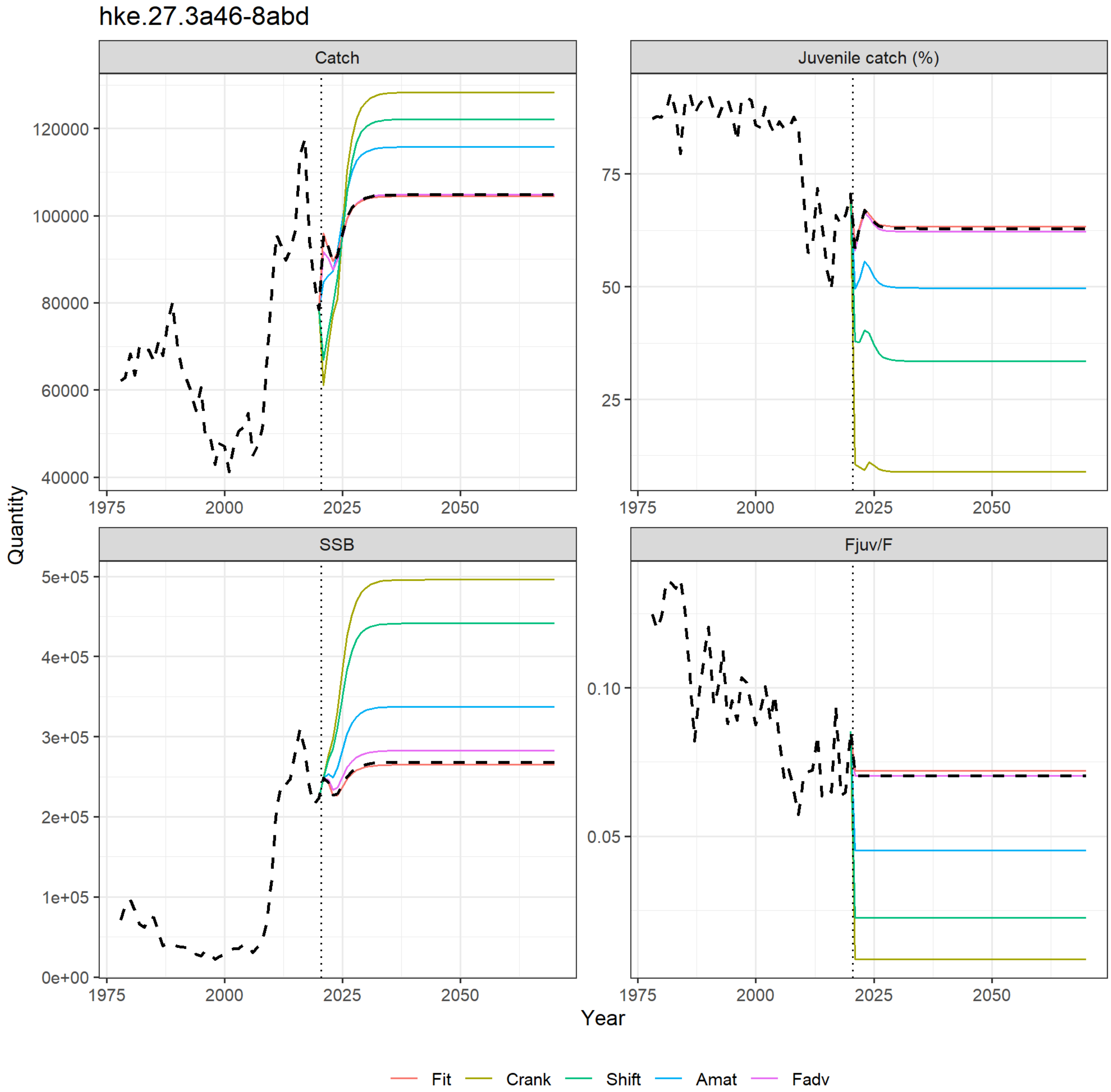

Figure 4.1.1.6: Northern hake (hke.27.3a46-8abd). Optimal selectivity scenario projections assuming BH S-R relationship. The dashed line represents the projection under the current observed selectivity.

4.1.1.3 Red Mullet in GSA 09 (MUT09)

Characterisation of the stock

Red mullet in the Ligurian and northern Tyrrhenian Seas (FAO-GFCM GSA09, western Mediterranean) are fast-growing and short-living, and are almost fully selected by age 1. Red mullet in this region matures relatively early, and they are fully mature at age 1. Natural mortality is assumed to be relatively high at age 1 (M=0.87) and gradually declines to M=0.59 for older fish. This assumption is based on the Chen-Watanabe approach.

Assessment

The stock has been assessed with an a4a model at STECF EWG 20-09 (STECF, 2020b) and GFCM WGSAD 2020 (GFCM, 2020). F-at-age is estimated by means of a separable model with smoothers on age and time. F-at-age is estimated independently for each age, and F at the oldest ages is bound to F of age 2 (i.e., F at ages 2 and higher are assumed to be the same). The model estimates selectivity to be approximately logistic (essentially flat from age 2 onwards).

State of the stock

The stock has been over-exploited for the entire available time series; in recent years F has shown a decreasing pattern, and F in 2019 is 1.66 times the reference point (F0.1 = 0.51). SSB is increasing.

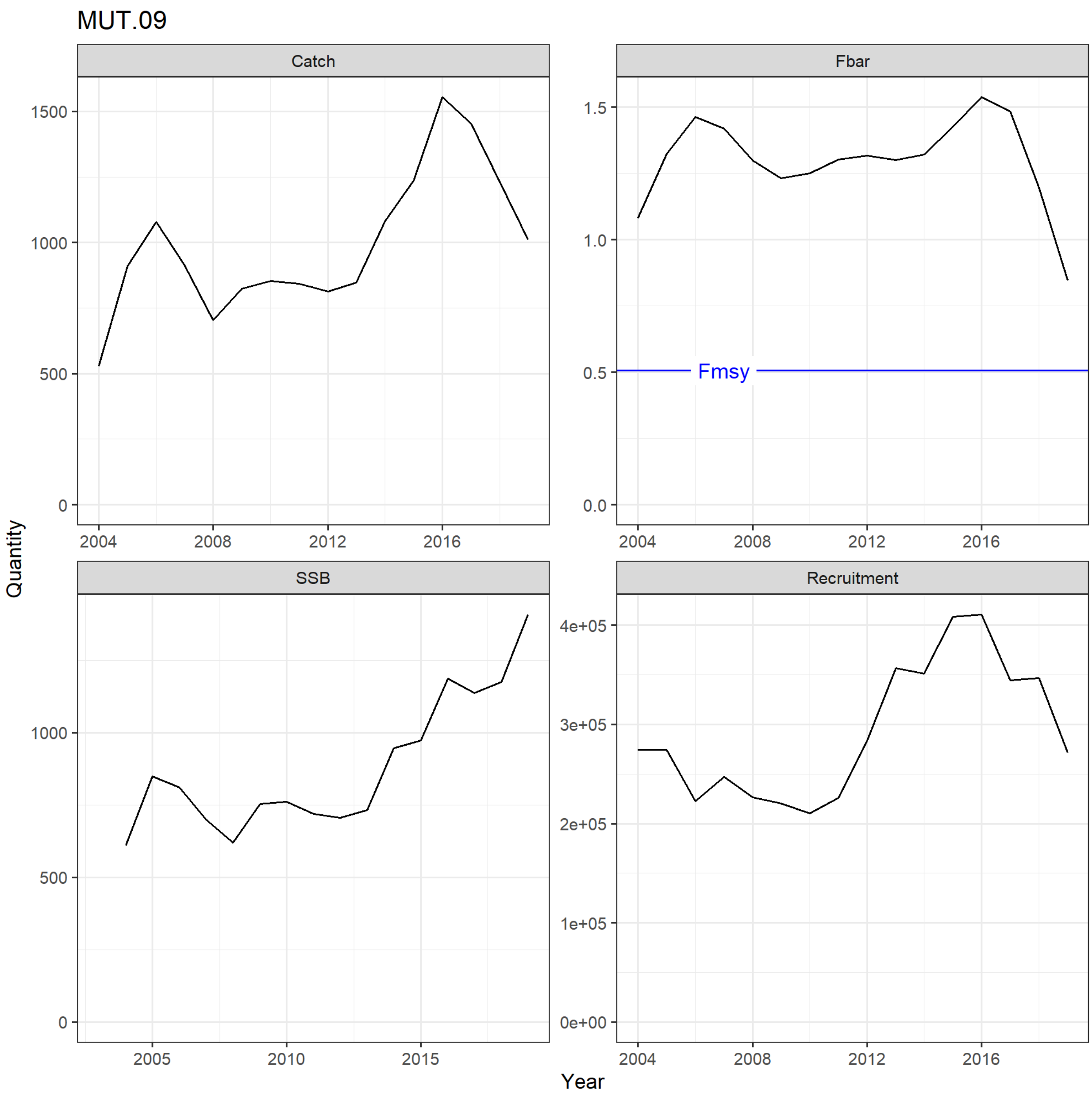

Figure 4.1.1.7: Red mullet in GSA09 (MUT.09). Stock overview.

Selectivity scenarios

The current selectivity pattern is already quite steep and “cranking” can only affect the selection of age 1 fish, as age 2 fish are fully selected, while “shifting” will also affect age 2 fish catches. Therefore, changing the selectivity pattern by means of both “cranking” and “shifting” will reduces the catch of age 1 fish to zero. Shifting selectivity to match maturity will decrease S50.

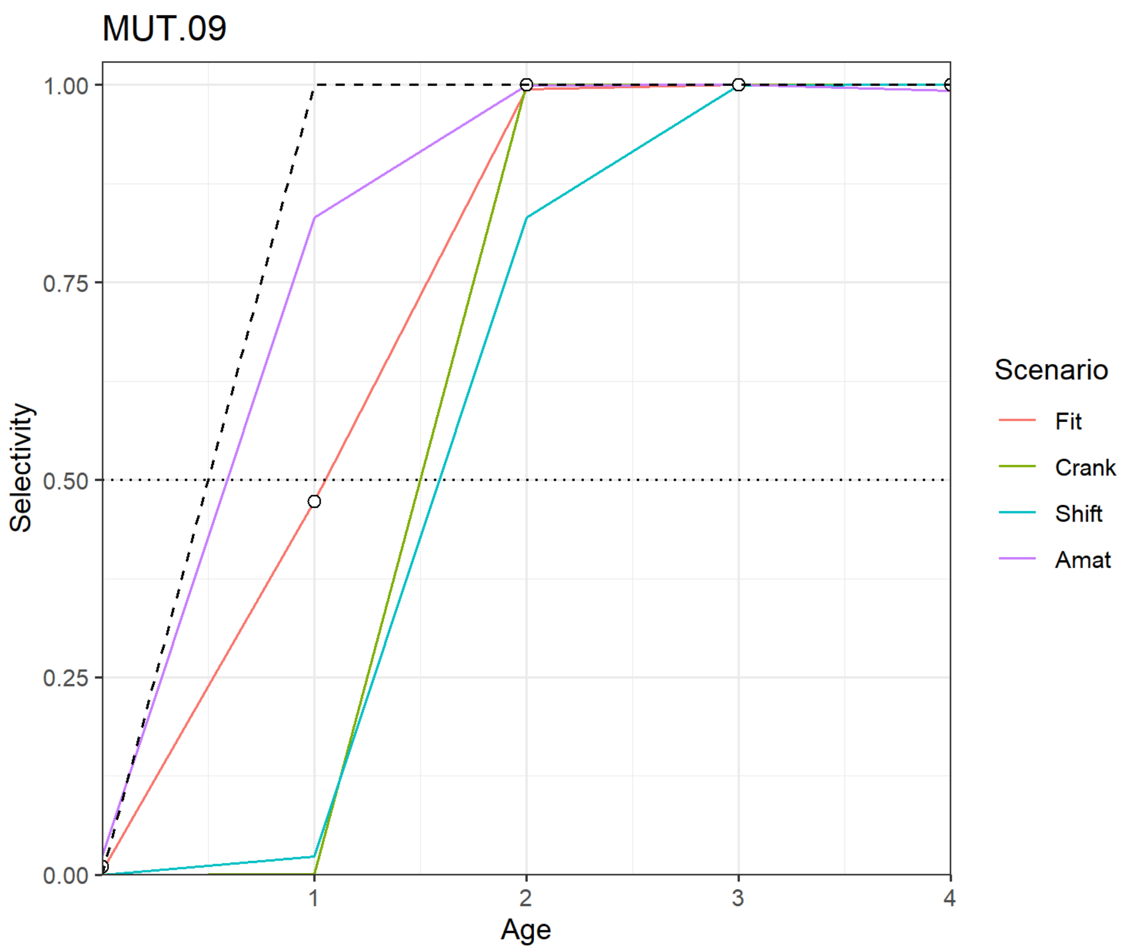

Figure 4.1.1.8: Red mullet in GSA09 (MUT.09). Optimal selectivity scenarios. Dots represent the observed selectivity-at-age and dashed line represents maturity-at-age from the assessment model.

Projections

The current F projections show that the “crank” and “shift” scenarios perform similarly and would produce the highest catches in the long term (in 2030), as well as the lowest catches of juveniles, while the “Amat” scenario would produce lower catches and higher catches of juveniles. Reducing F to the advised value but keeping current selectivity is predicted to lead to increased SSB, slightly reduced catches and slightly reduced juveniles in the catch.

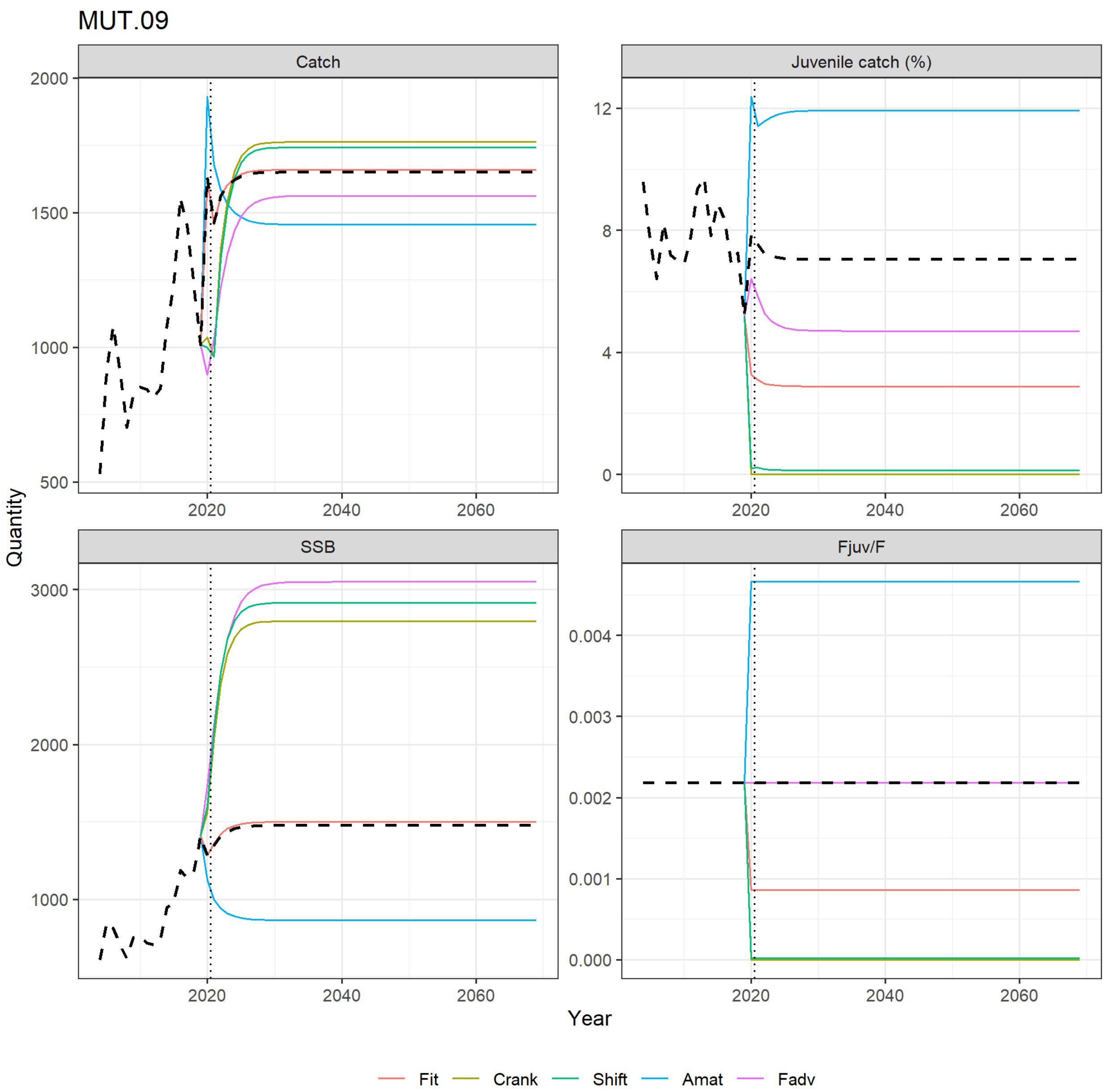

Figure 4.1.1.9: Red mullet in GSA09 (MUT.09). Optimal selectivity scenario projections. The dashed line represents the projection under the current observed selectivity.

4.1.1.4 EUROPEAN HAKE IN THE ADRIATIC SEA (GSAs 17-18)

Characterisation of the stock

The stock of European hake was assumed in the boundaries of the whole Adriatic Sea (GSA 17-18), as suggested by the genetic results of the MAREA StockMed project that shows a common sub-population of hake throughout the Adriatic Sea (Fiorentino et al., 2014). In the Adriatic Sea, European hake spawn throughout the year, but with different intensities. Females attain larger size than males, which grow more slowly after full maturation at the age of three or four years. Consequently, the proportion of males in the population is higher in the lower length classes and proportion of females is higher for greater lengths. Natural mortality is assumed to be relatively high at age 1 and gradually declines to M=0.2 for older fish. This assumption is based on the average obtained from several approaches using life trait histories.

Assessment

The stock has been assessed with an SS3 model during the GFCM benchmark on Adriatic hake (GFCM, 2019). The benchmark investigated all available input data and carried out an analysis of the performance of two different stock assessment models: a stock synthesis (SS3) model and an assessment-for-all (a4a) model, both of them tested with different assumptions and/or input data series. Overall, both models provided similar perspectives on the status of the stock, and a final advice was prepared on the basis of the outcomes of an SS3 model. In 2020, the assessment has been updated both at STECF EWG 20-15 (STECF, 2020c) and GFCM WGSAD 2020 (GFCM, 2020).

State of the stock

European hake in GSAs 17–18 was considered to be in overexploitation and overexploited, with fishing mortality 2.88 times F_{MSY} and with biomass around 70 percent the precautionary biomass (STECF, 2020c).

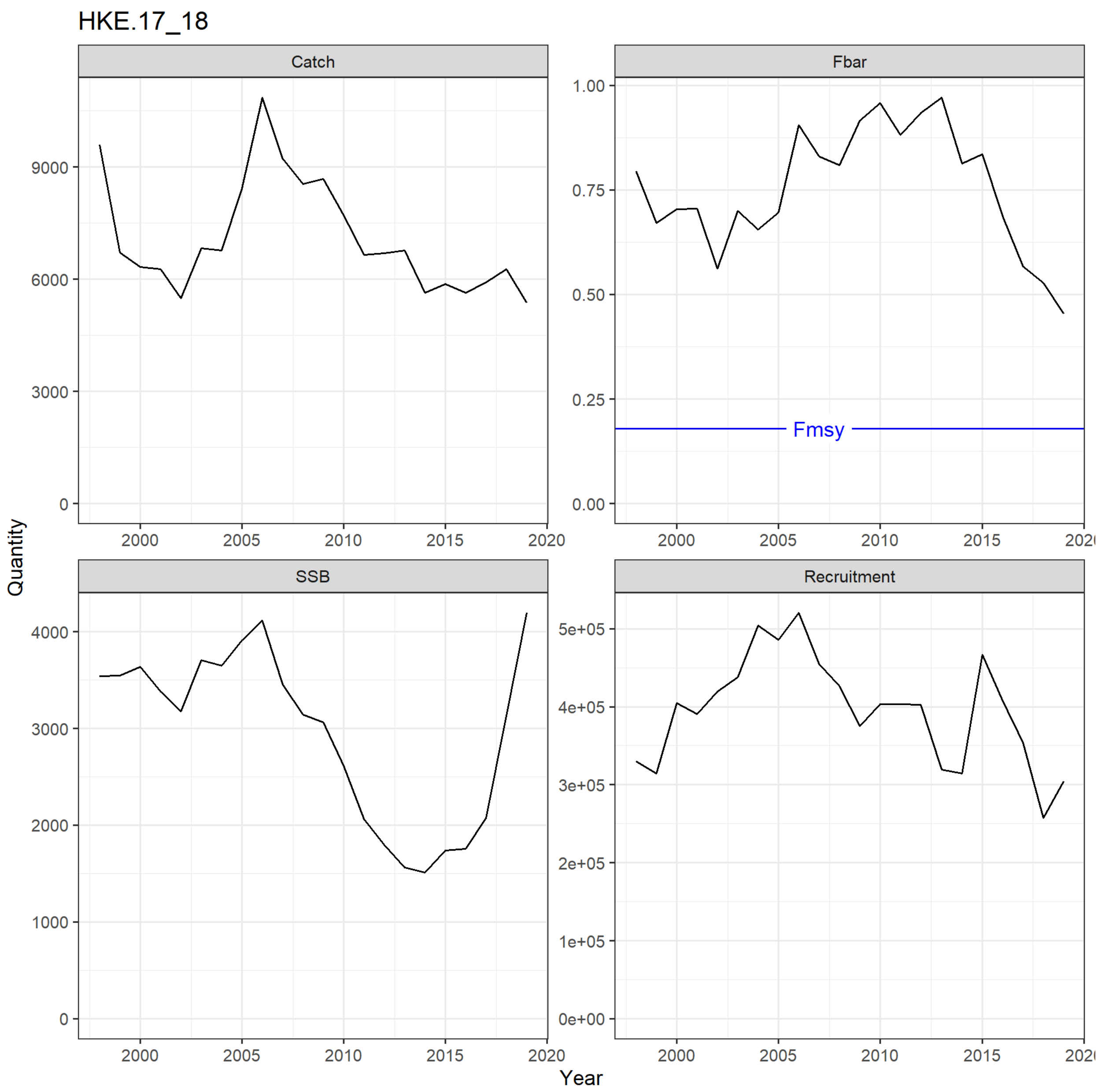

Figure 4.1.1.10: European hake in the Adriatic Sea (HKE.17_18). Stock overview.

Selectivity scenarios

The current selectivity pattern is dome shaped and is already quite steep and ages 3 and 4 are fully selected.

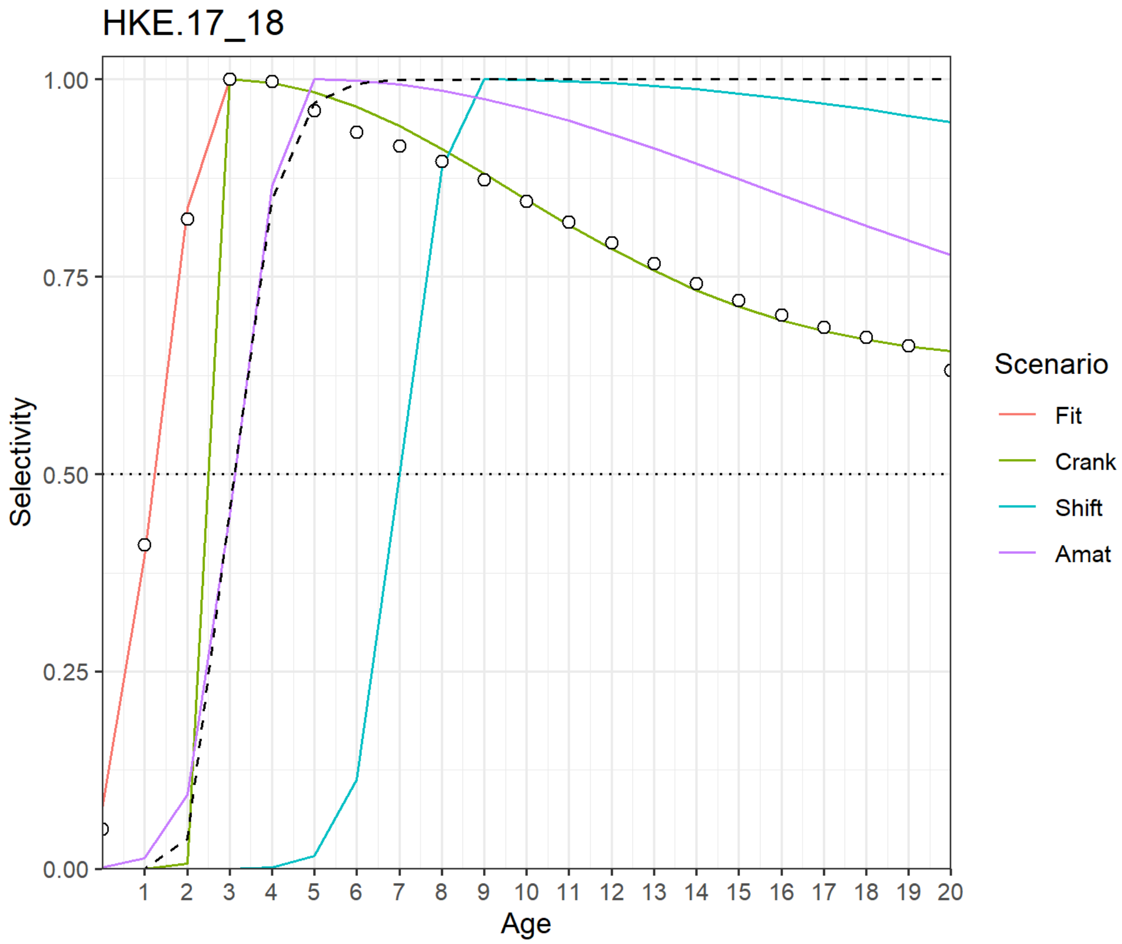

Figure 4.1.1.11: European hake in the Adriatic Sea (HKE.17_18). Dots represent the observed selectivity-at-age and dashed line represents maturity-at-age from the assessment model.

Projections

The current F projections show that the "shift" scenario would produce the highest catches in the long term (2030), while the "crank" and "Amat" scenarios would produce lower catches than the "shift" scenario in a shorter period (2025). However, the changes of the population selection curve are going to produce always higher catches in the medium/long term than the status quo scenarios (fit and obs) as well as lower impact on juveniles and clear increases of SSB. It is important to note that the benefits of a larger SSB are most likely underestimated in the simulations as recruitment is assumed to not increase (i.e., average recruitment) when the SSB increases. On the other hand, the model does not assume a density dependent mechanism, which will have an opposite effect when SSB increases to high levels. In any case, as reference points are generally updated every 3-5 years in GFCM, so that when the SSB will increase, knowledge on density dependent mechanisms and on shape of the stock recruitment relationship will increase and assumptions of long-term simulations can be updated. Reducing F to the advised value but keeping current selectivity has smaller benefits than changing selectivity under current F.

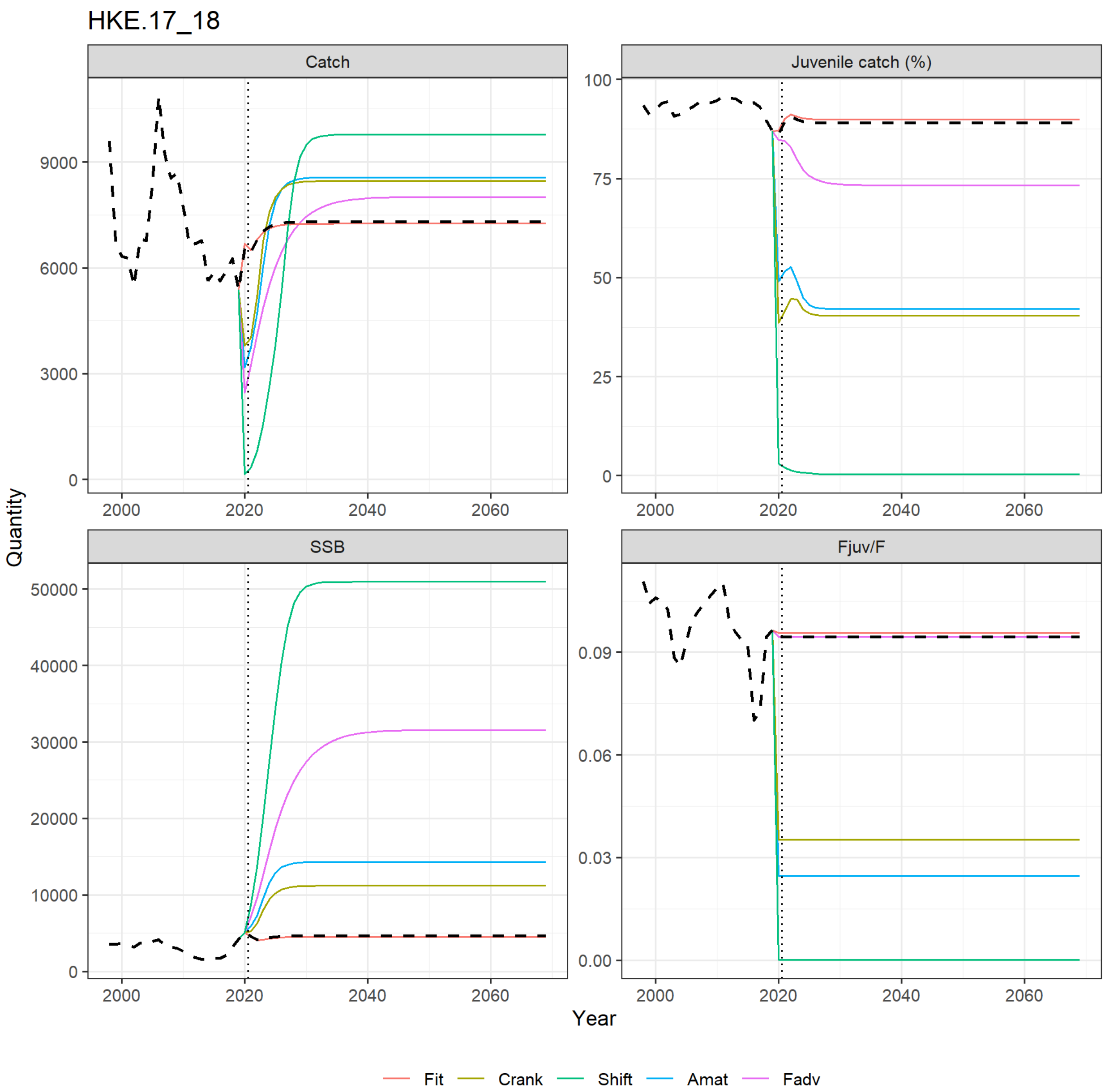

Figure 4.1.1.12: European hake in the Adriatic Sea (HKE.17_18). Optimal selectivity scenario projections. The dashed line represents the projection under the current observed selectivity.

4.1.2. RESULTS FOR ALL STOCKS

In analogy to the results elaborated on above, Tables 4.1.2.1 and 4.1.2.3 display, for each stock, the percentage gain in yield, compared to the current selectivity, of the four scenarios as well as the current percentage of juveniles in the catch and under the same four scenarios; all at the end of the projected time series in the year 2070 (when equilibrium has been reached). The level of overfishing (F/F_{MSY}) is displayed as well. These results are visualized in Figures 4.1.2.1 and 4.1.2.2. For reference, the S_{50} of each scenario as well as the age at 50% mature (a50) are in Tables 4.1.2.2 and 4.1.2.4.

Table 4.1.2.1: Selectivity estimates for Northeast Atlantic stocks summarizing the age-at-50%-selectivity (S50) for the current selectivity-at-age (Cur), the optimised selectivity curves (Crank, Shift) and S50 corresponding to age-at-50%-maturity (A_{mat}). In addition, the age at which the total biomass of an unfished cohort (F = 0) attains a maximum (A_{opt}) as well as the plus group (= maximum age) assumed in the assessment model are provided for reference.

Region	Area	Stock	Age-at-50%-Selectivity (S50)					Plus
			Cur	Crank	Shift	A_{mat}	A_{opt}	Group
NEA	BS	cod.27.22-24	2.7	4.2	6.0	1.9	6	7
NEA	BS	ple.27.21-23	2.3	3.6	6.0	2.0	6	7
NEA	NS	cod.27.47d20	1.9	2.8	4.4	3.0	5	6
NEA	NS	had.27.46a20	1.9	1.3	1.3	2.6	7	8
NEA	NS	ple.27.420	1.5	2.0	7.2	2.5	9	10
NEA	NS	ple.27.7d	1.9	2.0	2.0	2.9	4	7
NEA	NS	pok.27.3a46	3.8	4.7	8.1	4.7	9	10
NEA	NS	whg.27.47d	2.3	1.6	1.6	1.3	4	8
NEA	NWW	cod.27.6a	2.2	3.8	4.0	1.9	4	7
NEA	NWW	cod.27.7e-k	1.1	1.8	4.6	2.0	5	7
NEA	NWW	had.27.6b	2.1	3.3	5.0	2.6	5	7
NEA	NWW	had.27.7a	0.9	0.6	0.6	1.6	4	5
NEA	NWW	had.27.7b-k	3.2	2.7	2.7	1.6	7	8
NEA	NWW	ple.27.7a	1.8	1.3	3.8	2.9	7	8
NEA	NWW	whg.27.7a	0.5	1.2	1.7	1.6	4	6
NEA	NWW	whg.27.7b-ce-k	3.0	2.1	2.1	0.9	6	7
NEA	SWW	hke.27.3a46-8abd	1.8	3.5	3.5	2.6	5	15
NEA	SWW	ldb.27.8c9a	3.4	5.2	5.6	1.0	6	7
NEA	SWW	meg.27.7b-k8abd	3.2	2.7	2.8	2.8	5	10
NEA	SWW	meg.27.8c9a	3.2	5.8	6.0	1.2	6	7

BS: Baltic Sea; NS: North Sea, NWW: North Western Waters, SWW: South Western Waters

Table 4.1.2.2: Prediction for ICES stocks summarizing the yield change (%) relative to the current selectivity under current F (blue: positive; red: negative; colour intensity indicates magnitude of effect) and the associated percentage of juvenile fish in the catch (%) (from red, via orange and yellow to green: high to low values) for the scenarios of fishing according to scientific advice under current selectivity (F_{adv}) and the optimised selectivity curves at current F. For reference, over-fishing ($F_{2020} > F_{adv}$) and "under-fishing" ($F_{2020} < F_{adv}$) is also presented (red: overfishing; green: underfishing).

Area	Stock	F_{2020}/	Yield Change (%)				Juveniles in catch (%)				
		F_{adv}	F_{adv}	Crank	Shift	A_{mat}	Cur	F_{adv}	Crank	Shift	A_{mat}
BS	cod.27.22-24	3.39	277.4	322.9	402.1	-98.5	36.2	20.9	9.9	7.1	50
BS	ple.27.21-23	0.94	1.6	14.9	28.3	-3.9	24.8	23.6	11.7	4.6	28.1
NS	cod.27.47d20	1.6	56.6	44.5	92.4	61.8	71.2	64.3	35.9	12.9	39.7
NS	had.27.46a20	1.02	-3.7	22	17.3	-7.1	41.5	41.8	70.3	65.1	13
NS	ple.27.420	0.71	-2.7	1.3	29.8	7.2	37.9	39.5	28.8	0	20.9
NS	ple.27.7d	0.87	1.2	0	0.8	-0.9	47.1	48.6	45.3	45.7	26.9
NS	pok.27.3a46	1.25	9.9	17.6	43.5	16.2	52.5	48	22.5	0.7	31
NS	whg.27.47d	0.5	30	43.9	28.9	28.9	25.7	26.2	60.8	45.2	45.2
NWW	cod.27.6a	2.5	259.2	362.1	315.2	-58.6	42.7	32	6.6	16.2	46.5
NWW	cod.27.7e-k	3.97	207.6	160.9	375.3	191.3	73.6	43.3	37.4	0.1	35.6
NWW	had.27.6b	1.13	15	33	44.2	12	36.2	22.1	0	0.5	22.5
NWW	had.27.7a	0.27	18.5	2.4	0.9	-0.5	51.8	61.7	70.7	66.1	19.2
NWW	had.27.7b-k	0.89	4.5	1.1	2	1.3	62.6	30.1	69.3	67.7	71.2
NWW	ple.27.7a	0.22	64.9	0.6	7.6	4.2	23.5	32.6	29.9	4.7	10.8
NWW	whg.27.7a	3.65	50	106.5	98.1	98	78.8	64	2.1	14.8	19.5
NWW	whg.27.7b-ce-k	1.02	-15.9	20.1	14.1	14.1	36	11.7	60.4	50.3	50.3
SWW	hke.27.3a46-8abd	0.97	0.4	22.8	16.9	10.8	63.3	62.2	8.9	33.5	49.7
SWW	ldb.27.8c9a	0.56	1.5	4.4	11.1	-6.9	5.4	4.4	0	0.7	12.2
SWW	meg.27.7b-k8abd	0.72	-0.3	0.5	-0.1	-0.1	16.7	15.6	27.1	22.6	22.6
SWW	meg.27.8c9a	0.88	4.6	62.8	64	-52.5	8.9	9.9	0	1.8	16.1

BS: Baltic Sea; NS: North Sea, NWW: North Western Waters, SWW: South Western Waters

Table 4.1.2.3: Selectivity estimates for Mediterranean stocks summarizing the age-at-50%-selectivity (S_{50}) for the current selectivity-at-age (Cur), the optimised selectivity curves (Crank, Shift) and S_{50} corresponding to age-at-50%-maturity (A_{mat}). In addition, the age at which the total biomass of an unfished cohort (F = 0) attains a maximum (A_{opt}) as well as the plus group (= maximum age) assumed in the assessment model are provided for reference.

Region	Area	Stock	Age-at-50% Selectivity (S50)					Plus
			Cur	Crank	Shift	A_{mat}	A_{opt}	Group
MED	WM	HKE.01_05_06_07	0.6	1.3	4.0	1.5	4	5
MED	WM	HKE.08_09_10_11	0.2	0.4	5.5	1.4	6	7
MED	WM	MUR.05	1.0	0.8	0.7	0.6	4	5
MED	WM	MUT.01	1.6	2.4	3.0	0.6	3	4
MED	WM	MUT.06	1.1	1.3	3.0	0.6	3	4
MED	WM	MUT.07	0.8	1.3	1.8	0.6	3	4
MED	WM	MUT.09	1.0	1.4	1.7	0.6	3	4
MED	WM	MUT.10	1.1	1.5	3.0	0.6	3	4
MED	CEM	HKE.17_18	1.2	2.4	7.0	3.1	19	20
MED	CEM	HKE.19	0.2	1.7	5.6	1.7	6	7
MED	CEM	HKE.20	0.9	1.6	2.8	1.4	3	4
MED	CEM	MUT.17_18	1.1	1.5	2.5	0.6	3	4
MED	CEM	MUT.22	0.5	0.4	1.1	0.3	2	5

MED: Mediterranean Sea

Table 4.1.2.4: Predictions for Mediterranean stocks summarizing the yield change (%) relative to the current selectivity under current *F* (blue: positive; red: negative; colour intensity indicates magnitude of effect) and the associated percentage of juvenile fish in the catch (%) (from red, via orange and yellow to green: high to low values) for the scenarios fishing according to scientific advice under current selectivity (F_{adv}) and the optimised selectivity curves at current *F*. For reference, over-fishing ($F_{2020} > F_{adv}$) and "under-fishing" ($F_{2020} < F_{adv}$) is also presented (red: overfishing; green: underfishing).

Area	Stock	F_{2019}/	Yield Change (%)				Juveniles in catch (%)				
		F_{adv}	F_{adv}	Crank	Shift	A_{mat}	Cur	F_{adv}	Crank	Shift	A_{mat}
WM	HKE.01_05_06_07	4.2	25.5	88.3	294	67.8	86.3	65.1	18.5	0.2	44.8
WM	HKE.08_09_10_11	3.62	11.7	6.1	129.7	37.1	78.6	63.8	58.7	0	16.1
WM	MUR.05	1.05	-1	0.6	1	1	0	0.6	0.2	0	0
WM	MUT.01	1.66	8.4	35.3	43.9	-23.9	0	0	0	0	0
WM	MUT.06	4.62	19	24.8	67.8	-51	0	0	0	0	0.5
WM	MUT.07	1.78	5.1	28.8	27.3	-5.7	13.2	10.1	0	0.2	24.6
WM	MUT.09	2.32	-5.8	6.2	5	-12.3	2.9	4.7	0	0.1	11.9
WM	MUT.10	1.36	8.8	25.1	47.5	-31.5	1.3	11.4	0	0	5.1
CEM	HKE.17_18	2.88	10.4	16.7	34.9	18.1	89.9	73.3	40.3	0.3	42
CEM	HKE.19	3.31	20.8	17.9	166.6	54	78.7	67.3	55.2	1.1	46.2
CEM	HKE.20	2.67	28.3	49.4	99.3	31.1	63.3	47.4	11	2.2	38
CEM	MUT.17_18	2.75	-2.2	17.3	21.6	-11.8	2.3	7.5	0	0	7.2
CEM	MUT.22	0.34	22.3	0.4	0.6	0.4	15.9	17.9	16.1	14	16.4

WM: Western Mediterranean Sea CEM: Central Mediterranean Sea

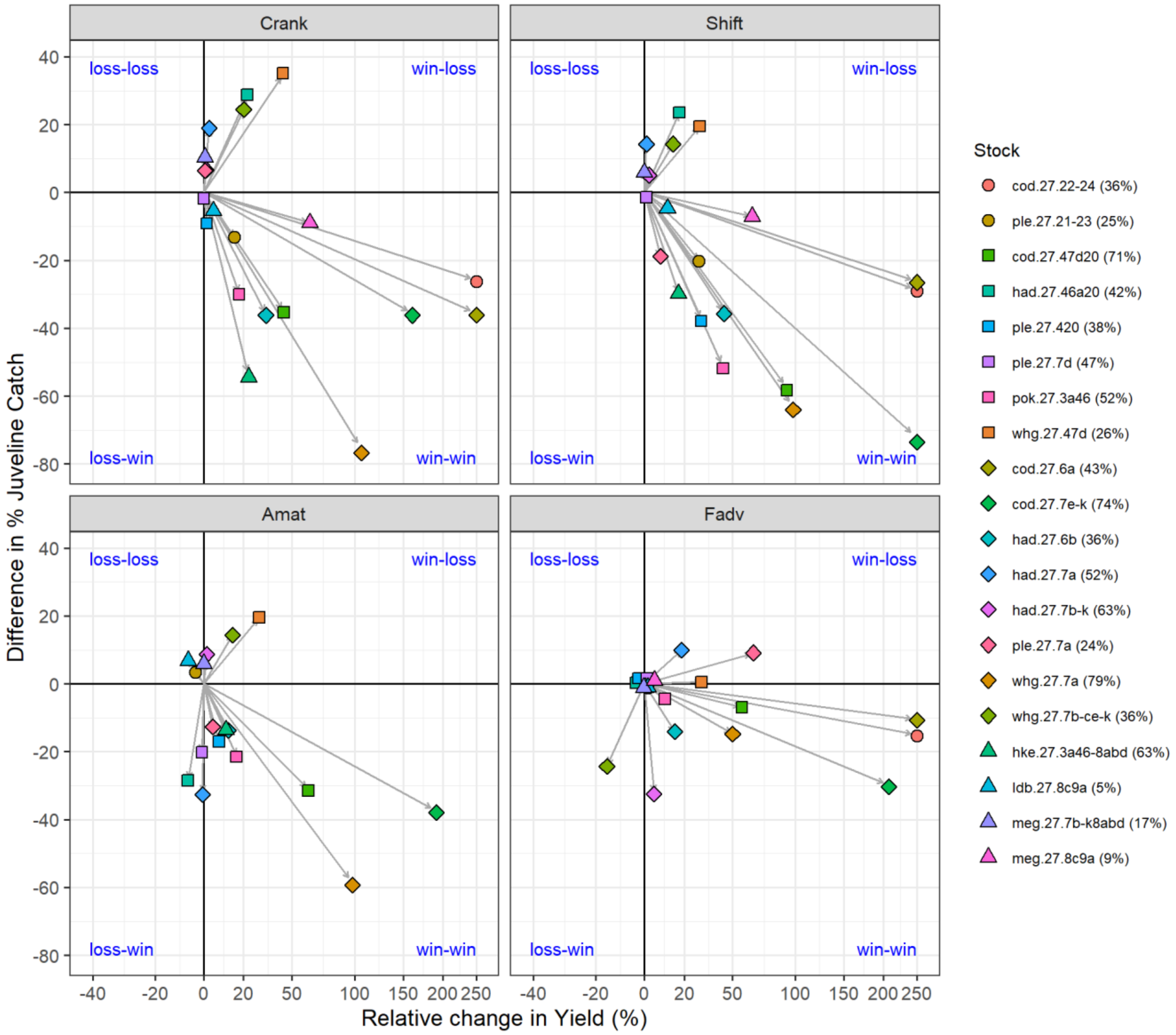

Figure 4.1.2.1: *Summary phase plots for Northeast Atlantic stocks (n = 20) showing the yield change (%) of the four scenarios (Crank, Shift, A_{mat} and F_{adv}) relative to the current selectivity under current F (x-axis) and the differences to the current percentage of juvenile fish in the catch (%). Percentage values in the legend denote the percentage of juvenile fish in the catch (%) under current F and selectivity and symbol shapes denote the four regions. The four quadrants highlight the "wins" and "losses". Bottom- right (win-win): increase in yield and reduction in juvenile catch; Top-Right (win-loss) increase in yield but increase in juvenile catch, Bottom-Left (loss-win) decrease in yield but reduction in juvenile catch; Top-Left (loss-loss) decrease in yield and increase in juvenile catch. Arrows show the predicted direction of change under each scenario from the status quo (current F and selectivity) at the crosshair (0,0).*

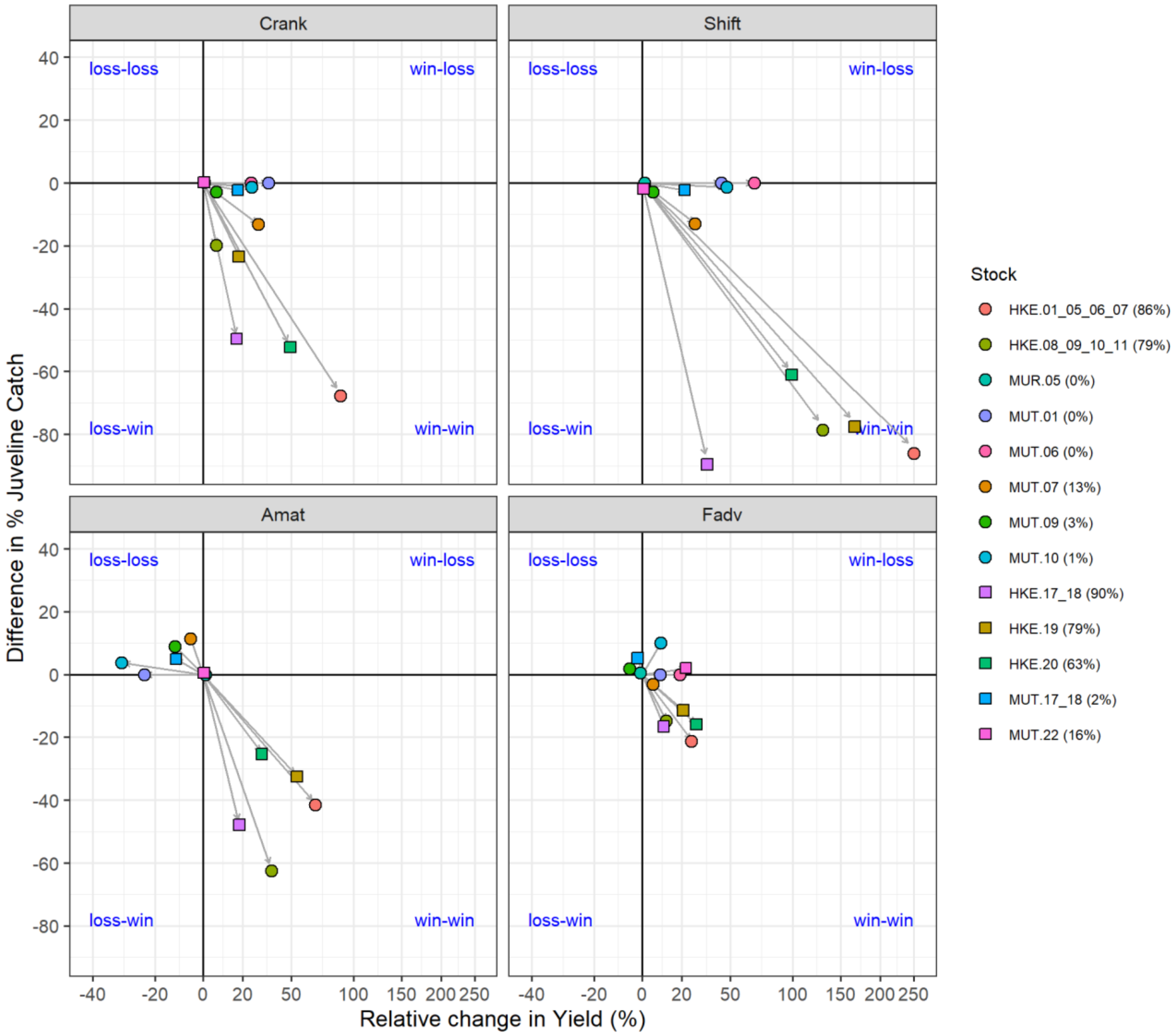

Figure 4.1.2.2: *Summary phase plots for Mediterranean stocks (n = 13) showing the yield change (%) of the for the four scenarios (Crank, Shift, A_{mat} and F_{adv}) relative to the current selectivity under current F (x-axis) and the differences difference to the current percentage of juvenile fish in the catch Percentage values in the legend denote the percentage of juvenile fish in the catch (%) under current F and selectivity and symbol shapes denote the four regions. The four quadrants highlight the "wins" and "losses". Bottom-right (win-win): increase in yield and reduction in juvenile catch; Top-Right (win-loss) increase in yield but increase in juvenile catch, Bottom-Left (loss-win) decrease in yield but reduction in juvenile catch; Top-Left (loss-loss) decrease in yield and increase in juvenile catch. Arrows show the predicted direction of change under each scenario from the status quo (current F and selectivity) at the crosshair (0,0).*

From the results in the tables 4.1.2.1-4.1.2.4 and figures 4.1.2.1-4.1.2.2. the following can be seen:

- In general, any improvement in selectivity will (in the long term) most strongly benefit stocks characterized by greater growth overfishing, which are typically large-bodied and late-maturing (e.g., hake stocks in the Mediterranean, cod);
- A selectivity improvement that achieves a higher protection of juveniles is often producing a higher increase in yield;
- Exceptions are some haddock and whiting stocks in the Northeast Atlantic, where optimisations in yield were associated with a decrease in S_{50}, leading to increased

proportion of juveniles in the catch. Here, the potential yield optimization was typically small in terms of both relative and absolute gains in yield when compared to the current situation.

- Any long-term increase in yields linked to a change in selectivity will imply, in general, a short-term loss in yield, but this short-term loss is similar under F_{adv} scenario. Those short-term losses will be compensated by the long-term gains (i.e. long term gains are larger than short term losses);
- The "shift" scenario typically comes with higher yield gains compared to the other three scenarios, with only few exceptions, such as red mullet in GSA07 and GSA09, cod in 6a, hake in SWW, and some whiting and haddock stocks);
- The "crank" scenario allows to achieve better results in terms of reduction of juvenile catches, with only few exceptions, such as cod in 6a, whiting in 7a, and hake and megrim in SWW;
- For few ICES stocks, neither the "crank" nor the "shift" scenario leads to a reduction in the proportion of juveniles in the catch and these proportions even increase.
- The results described above are general considerations, and for specific stocks the reader should refer to the stock-by-stock results (in the tables 4.1.2.1-4.1.2.4 and figures 4.1.2.1-4.1.2.2 and in the Appendix 3).

4.2 Potential gain in terms of yield and proportion juveniles in the catch from optimising selectivity at current F, by fleet (ToR 3)

This section provides insights into the performance of fleet-based selectivity scenarios for the different stocks with fleet disaggregated data. Performance is presented in terms of (a) yield change relative to the current selection pattern, and (b) the percentage of juvenile species in the catch. Both metrics are calculated for equilibrium states of the stock.

4.2.1. COMPARISON OF OPTIMIZED SELECTIVITY WITH SELECTIVITY ESTIMATES BY FLEET

4.2.1.1. Stocks with ICES advice

The performance of individual fleets against the optimal selectivity scenarios is provided in Table 4.2.1.2 (Yield) and Table 4.2.1.3. (% juveniles in the catch). Fishing with only beam trawls would lead to higher yields for North Sea whiting than both optimized scenarios and fishing. Current F for North Sea whiting is 50% of the F_{MSY} and current selectivity (S_{50} = 3 years) is late when compared to the relatively early maturation (a_{50} = 0.9), so that in this specific case yield could be increased by selection with a wider age range and with a different selectivity curve shape that is closer to beam trawl, but was not captured by the "crank" or "shift" scenarios. Similarly, trammel nets would lead to slightly higher yields for English Channel plaice than both optimized scenarios, while fishing with only set gillnets would lead to higher yields for North Sea saithe than the "crank" scenario. Only for megrim in the Southwestern Waters, otter trawl fisheries would lead to slightly higher yields compared to the status quo scenarios. In all other cases OTB gives lower yields than current selectivity of the all gears combined. By contrast, fleets operating with gillnets, longlines and other passive gear as well as beam trawls result in higher yields for most of the stocks considered compared to the status quo selectivity pattern, except for gillnets for North Sea haddock and beam trawl for North Sea plaice, where yields are lower. For the seine nets, the yield gains and losses are variable.

In terms of the proportion of juveniles in the catch, in two cases, North Sea haddock and Irish Sea haddock, the optimized scenarios perform worse than each of the fleet-specific scenarios as well as the current all-fleet scenario. In the cases of North Sea plaice and North Sea whiting the optimized scenarios result in quite high proportions of juveniles in the catch; for plaice only OTB performs worse and for whiting both seine and beam trawl perform worse. Compared to the current selectivity of all fleets combined, OTB performs better for North Sea plaice but worse for the two haddock stocks in North-western Waters. For Eastern Channel plaice, beam trawl leads to lower proportions of juveniles in the catch than is currently the case for all fleets. Gill nets are a large improvement for North Sea saithe compared to the current mixed-fleet situation.

Table 4.2.1.1: Selectivity estimates for Northeast Atlantic stocks summarizing the age-at-50%-selectivity (S_{50}) by Gear type. OTB: bottom otter trawls; DRB: Towed dredges; GNS: Set gillnets; GTR: Trammel nets; LLS: Set longlines; MWT: Midwater Trawl; PAS: Passive gears; SEI: Seine nets; TBB: Beam trawls.

Area	Stock	OTB	DRB	GNS	GTR	LLS	MWT	PAS	SEI	TBB
BS	cod.27.22-24	2.38		3.17				3.14		
BS	ple.27.21-23	2.26						3.25		
NS	cod.27.47d20	1.86		2.41		2.29			2.08	1.57
NS	had.27.46a20	1.97		5.19					1.88	
NS	ple.27.420	2.03							1.95	1.28
NS	ple.27.7d	1.89	2.13		2.1				2.08	2.26
NS	pok.27.3a46	3.7		7.4						
NS	whg.27.47d	2.64							3.7	1.16
NWW	cod.27.6a	2.11								
NWW	had.27.6b	1.72								
NWW	had.27.7a	0.9					2.86		2.52	
NWW	ple.27.7a	1.73								1.8
SWW	meg.27.7b-k8abd	3.32								3.25

Table 4.2.1.2: Prediction for the Northeast Atlantic stocks summarizing the yield change (%) relative to the current selectivity under current *F* (blue: positive; red: negative; colour intensity indicates magnitude of effect) comparing the optimized (Crank, Shift, A_{mat}) selectivity curves to the prediction for fleet-specific selectivity curves at current *F* .

Area	Stock	Crank	Shift	A_{mat}	OTB	DRB	GNS	GTR	LLS	MWT	PAS	SEI	TBB
BS	cod.27.22-24	322.9	402.1	-98.5	-48.4		63.3				54.5		
BS	ple.27.21-23	14.9	28.3	-3.9	-0.2						11		
NS	cod.27.47d20	44.5	92.4	61.8	-1.5		33.7		35.5			25.6	25.5
NS	had.27.46a20	22	17.3	-7.1	-0.1		-2.3					1.9	
NS	ple.27.420	1.3	29.8	7.2	-1.2							-17.8	-3.8
NS	ple.27.7d	0	0.8	-0.9	-11.8	-7.4		2.3				-7.9	3
NS	pok.27.3a46	17.6	43.5	16.2	-0.8		33.2						
NS	whg.27.47d	43.9	28.9	28.9	-6.7							13.5	57
NWW	cod.27.6a	362.1	315.2	-58.6	-6.1								

NWW	had.27.6b	33	44.2	12	-15.1								
NWW	had.27.7a	2.4	0.9	-0.5	-19.9					-8.1		-4	
NWW	ple.27.7a	0.6	7.6	4.2	-6.6								1.2
SWW	meg.27.7b-k8abd	0.5	-0.1	-0.1	0.3								4

OTB: bottom otter trawls; DRB: Towed dredges; GNS: Set gillnets; GTR: Trammel nets; LLS: Set longlines; MWT: Midwater Trawl; PAS: Passive gears; SEI: Seine nets; TBB: Beam trawls.

Table 4.2.1.3: Prediction for the Northeast Atlantic stocks summarizing associated percentage of juvenile fish in the catch (%) (from red, via orange and yellow to green: high to low values) under current *F* comparing optimised selectivity to the predictions for the current selectivity (all fleets) and fleet-specific selectivity curves.

Area	Stock	Cur	Crank	Shift	Amat	OTB	DRB	GNS	GTR	LLS	MWT	PAS	SEI	TBB
BS	cod.27.22-24	36.2	9.9	7.1	50	36.7		37.2				38.6		
BS	ple.27.21-23	24.8	11.7	4.6	28.1	25.2						15.5		
NS	cod.27.47d20	71.2	35.9	12.9	39.7	72		62.1		66.1			67.6	80.1
NS	had.27.46a20	41.5	70.3	65.1	13	38.3		40.7					40.7	
NS	ple.27.420	37.9	28.8	0	20.9	27.3							35.2	42.8
NS	ple.27.7d	47.1	45.3	45.7	26.9	51.9	37.8		36.9				44.4	32.6
NS	pok.27.3a46	52.5	22.5	0.7	31	53.6		22.4						
NS	whg.27.47d	25.7	60.8	45.2	45.2	28.1							67.7	64.2
NWW	cod.27.6a	42.7	6.6	16.2	46.5	42.2								
NWW	had.27.6b	36.2	0	0.5	22.5	46.2								
NWW	had.27.7a	51.8	70.7	66.1	19.2	60.3					2.3		3.7	
NWW	ple.27.7a	23.5	29.9	4.7	10.8	25.8								23.3
SWW	meg.27.7b-k8abd	16.7	27.1	22.6	22.6	15.4								18.1

4.2.1.2 Stocks with STECF-GFCM advice

The performance of individual fleets against the optimal selectivity scenarios is provided in Table 4.2.1.5 (Yield) and Table 4.2.1.6. (% juveniles in the catch). As expected, none of the single fleets would lead to higher yields than the optimized selectivity scenarios. However, remarkable differences exist between fleets. Those difference are mainly related to the S_{50} values of the fleets (Table 4.2.1.4.). For none of the stocks considered in this analysis, otter trawl fisheries would lead to higher yields compared to the status quo scenarios. In contrast, fleets operating with gillnets result in higher yields for all of the stocks considered compared to the status quo selectivity pattern. For the trammel netters, the yield gains and losses are variable, while the longline fleet would lead to a remarkable gain in the yield of hake.

Similar trends are found for the ratio of juveniles in the catch. None of the fleet-specific scenarios perform better than the optimized selectivity scenarios. The otter trawl fleet performs less well than the status quo scenarios with relatively more juveniles in the catch, especially for the hake stocks. In contrast, the passive gears result in a lower percentage of juveniles in the catch compared to the status quo scenario. Only in case of MUT.10, the selectivity pattern of the gillnetters is a disadvantage compared to the current selectivity of the fleet.

Table 4.2.1.4: Selectivity estimates for Mediterranean stocks summarizing the age-at-50%-selectivity (S50) by Gear type. GNS: Set gillnets; GTR: Trammel nets; LLS: Set longlines; OTB: bottom otter trawls.

Area	Stock	GNS	GTR	LLS	OTB
WM	HKE.01_05_06_07	1.14		2.9	0.39
WM	HKE.08_09_10_11	2.1	0.97		0.15
WM	MUT.01		1.94		1.48
WM	MUT.07				0.77
WM	MUT.09		3.24		1.01
WM	MUT.10	3.01	1.2		1.19

Table 4.2.1.5: Prediction for the Mediterranean stocks summarizing the yield change (%) relative to the current selectivity under current *F* (blue: positive; red: negative; colour intensity indicates magnitude of effect) comparing the optimised selectivity curves to the prediction for fleet-specific selectivity curves at current *F.*

Area	Stock	Crank	Shift	A_{mat}	GNS	GTR	LLS	OTB
WM	HKE.01_05_06_07	88.3	294	67.8	35.2		197	-11.5
WM	HKE.08_09_10_11	6.1	129.7	37.1	56.3	-28.8		-13.5
WM	MUT.01	35.3	43.9	-23.9		11.5		-5.8
WM	MUT.07	28.8	27.3	-5.7				-0.2
WM	MUT.09	6.2	5	-12.3		-17.3		-0.5
WM	MUT.10	25.1	47.5	-31.5	29.2	5.9		-9.1

Table 4.2.1.6: Prediction for the Mediterranean stocks summarizing associated percentage of juvenile fish in the catch (%) (from red, via orange and yellow to green: high to low values) under current *F* comparing optimised selectivity to the predictions for the current selectivity (all fleets) and fleet-specific selectivity curves

Area	Stock	Cur	Crank	Shift	A_{mat}	GNS	GTR	LLS	OTB
WM	HKE.01_05_06_07	86.3	18.5	0.2	44.8	48.1		3.1	91.6
WM	HKE.08_09_10_11	78.6	58.7	0	16.1	16.9	51.8		82.5
WM	MUT.01	0	0	0	0				
WM	MUT.07	13.2	0	0.2	24.6				13.3
WM	MUT.09	2.9	0	0.1	11.9				3.5
WM	MUT.10	1.3	0	0	5.1	30.5	0.1		25.7

4.2.2 JACKKNIFE ANALYSES

The Jackknife analysis completes the fleet-specific approach by taking out one fleet at a time by subtracting the partial fleet F_a from the total F_a of all fleets and scaling up the remaining F_a to match the current F for all fleets. The Jackknife analysis therefore presents evaluation of the partial selectivity impact for each of the excluded fleets. In cases where a fishery is mainly dominated by a single fleet, both catches and percentage juveniles in the catch are similar to the status quo scenario if fleets other than the dominant fleet are removed. For those cases, significant changes in selectivity patterns can only be achieved by removing the dominant fleet.

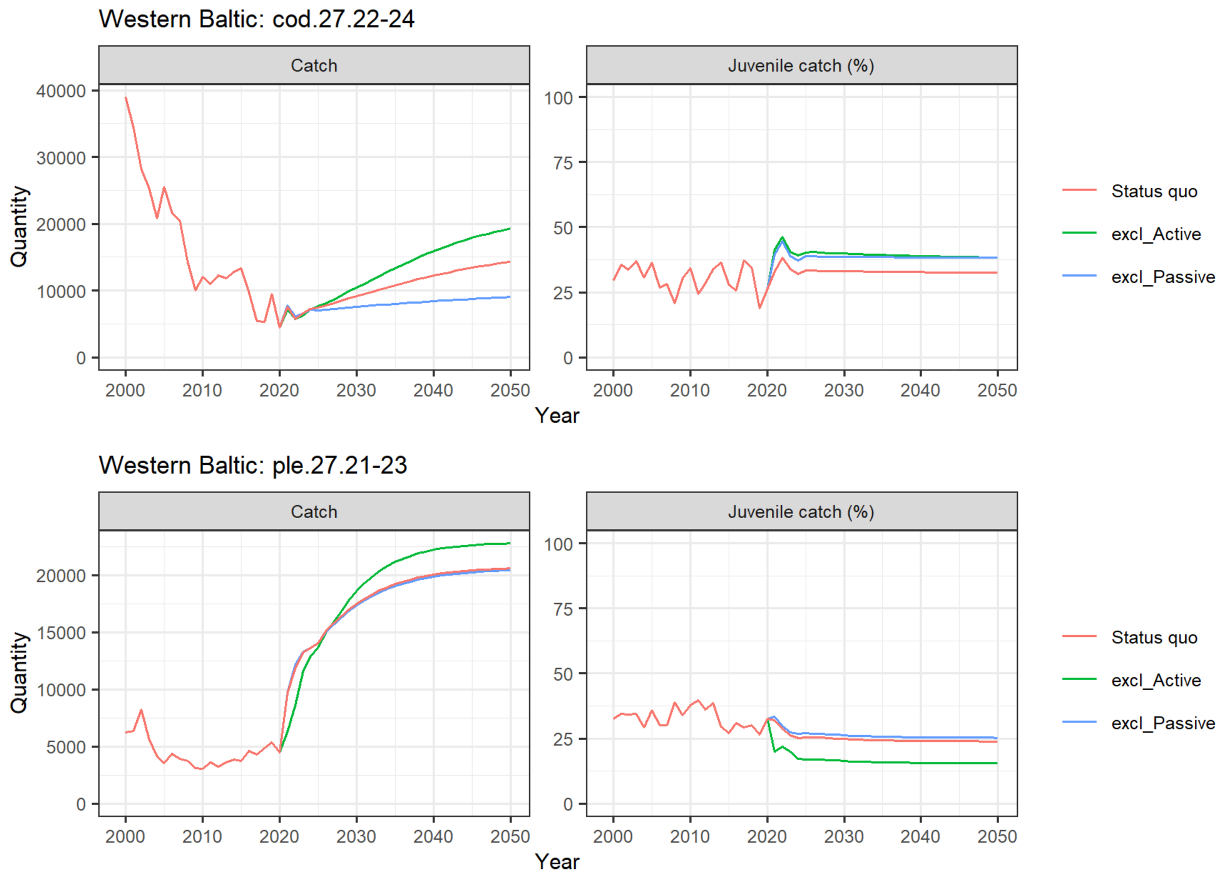

Fig. 4.2.2.1: Jackknife of Northeast Atlantic stocks in the Western Baltic Sea under current *F*. Projections of catch (left) and percentage of juveniles in the catch (right) of status quo and when particular fleet segments are omitted.

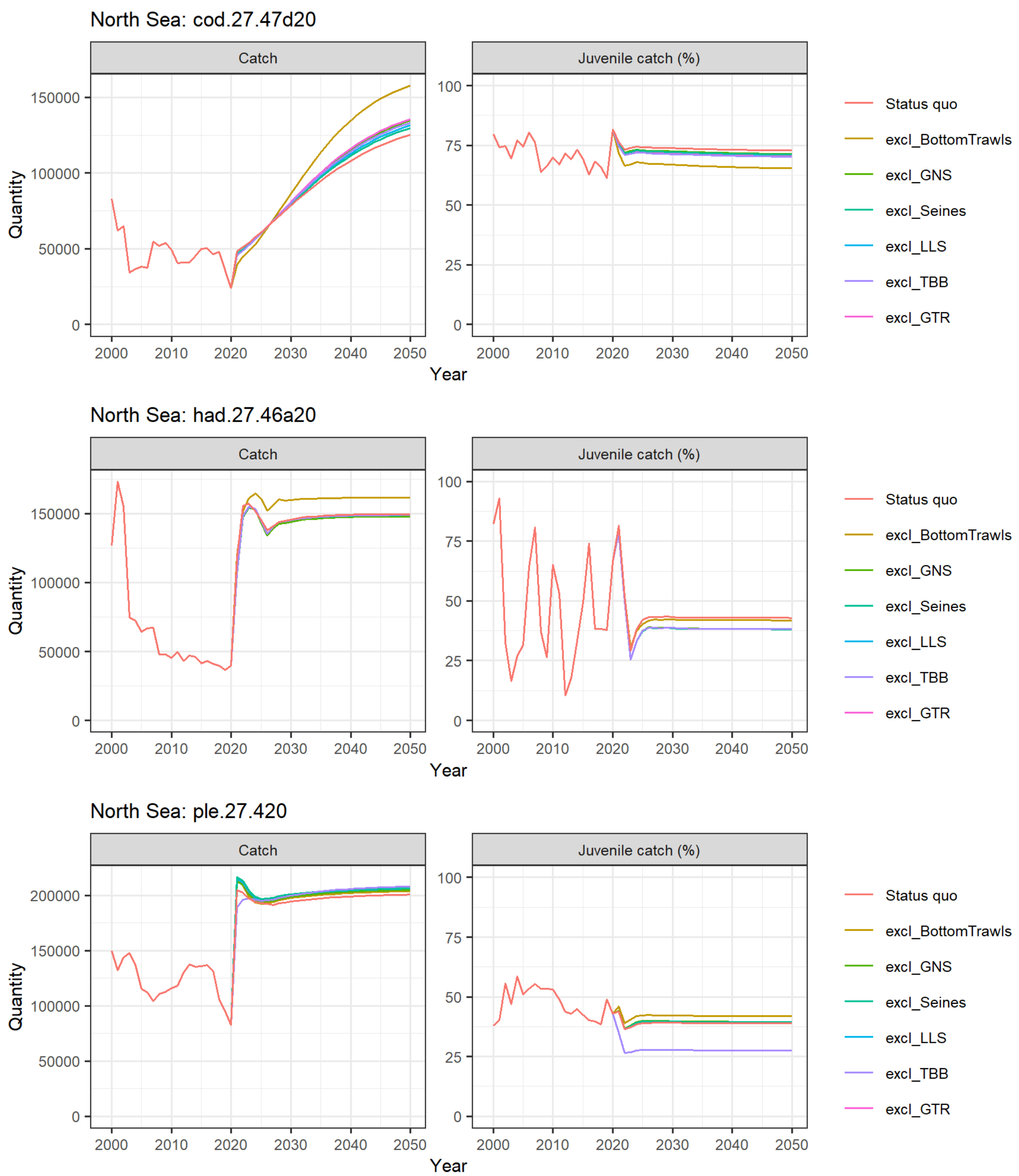

Fig. 4.2.2.2: Jackknife of Northeast Atlantic stocks in the Greater North Sea under current *F*. Projections of catch (left) and percentage of juveniles in the catch (right) of status quo and when particular fleet segments are omitted.

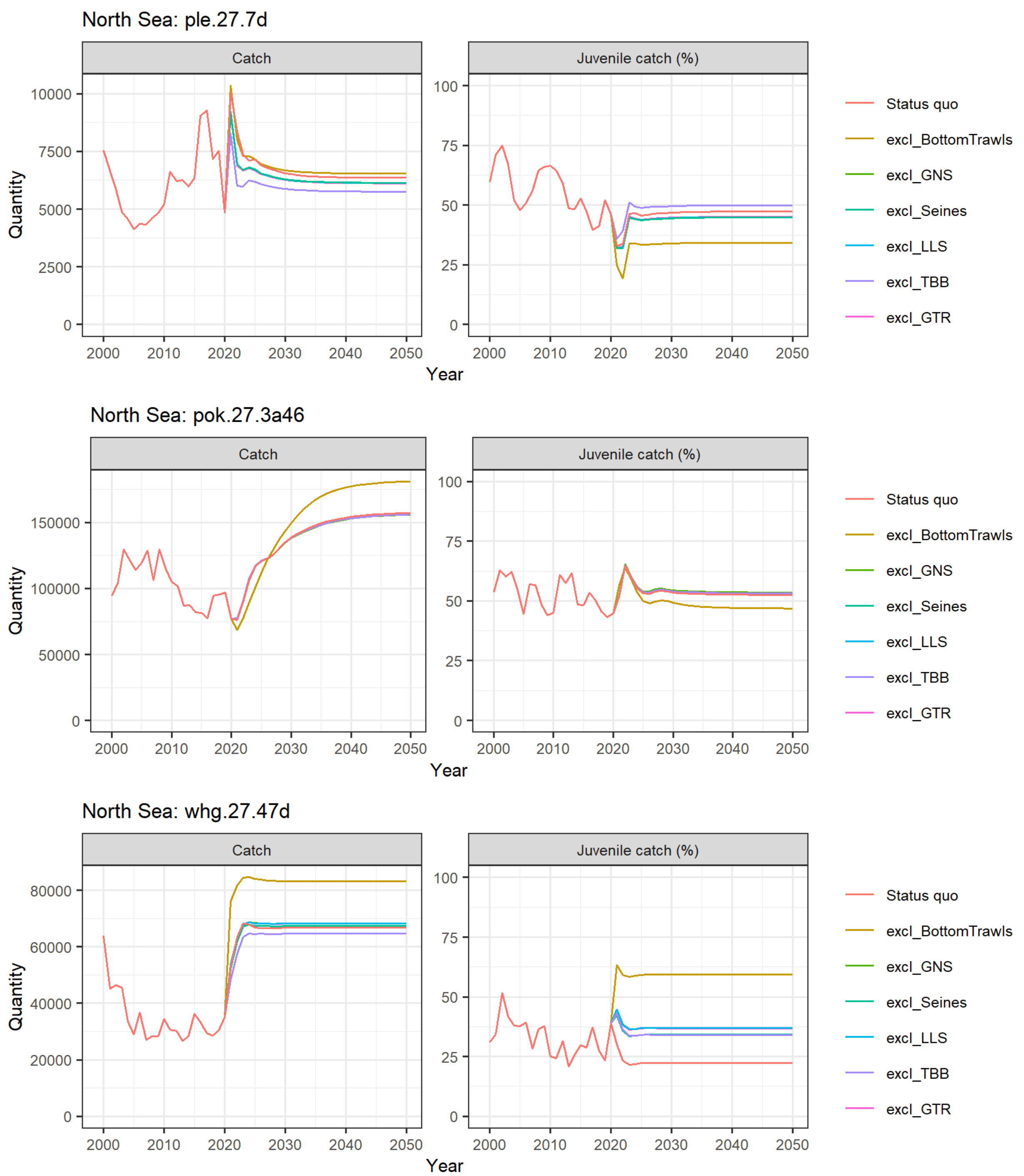

Fig. 4.2.2.2: (cont.): Jackknife of Northeast Atlantic stocks in the Greater North Sea under current F (cont.). Projections of catch (left) and percentage of juveniles in the catch (right) of status quo and when particular fleet segments are omitted.

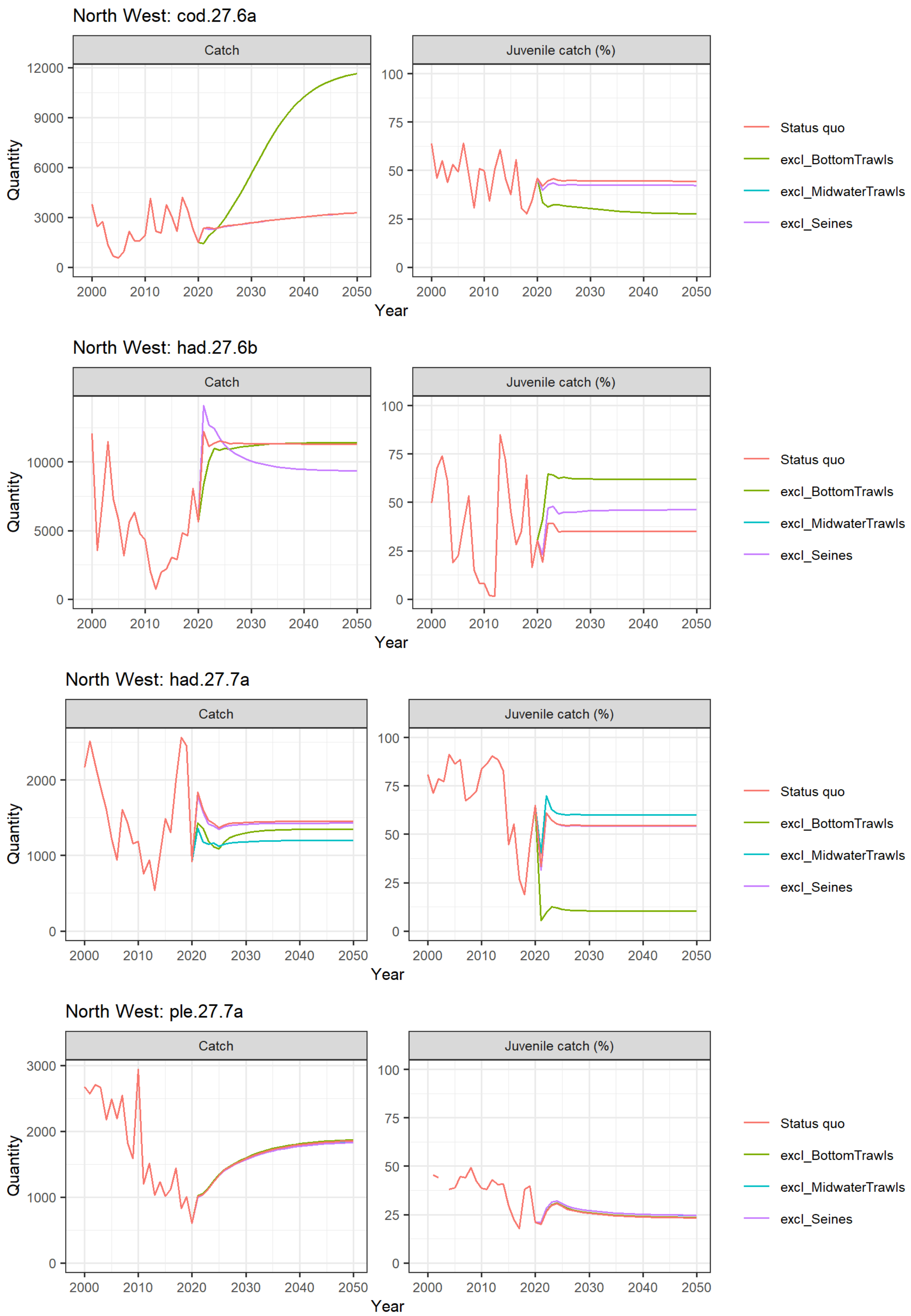

Fig. 4.2.2.3: Jackknife of Northeast Atlantic stocks in North Western waters under current *F*. Projections of catch (left) and percentage of juveniles in the catch (right) of status quo and when particular fleet segments are omitted.

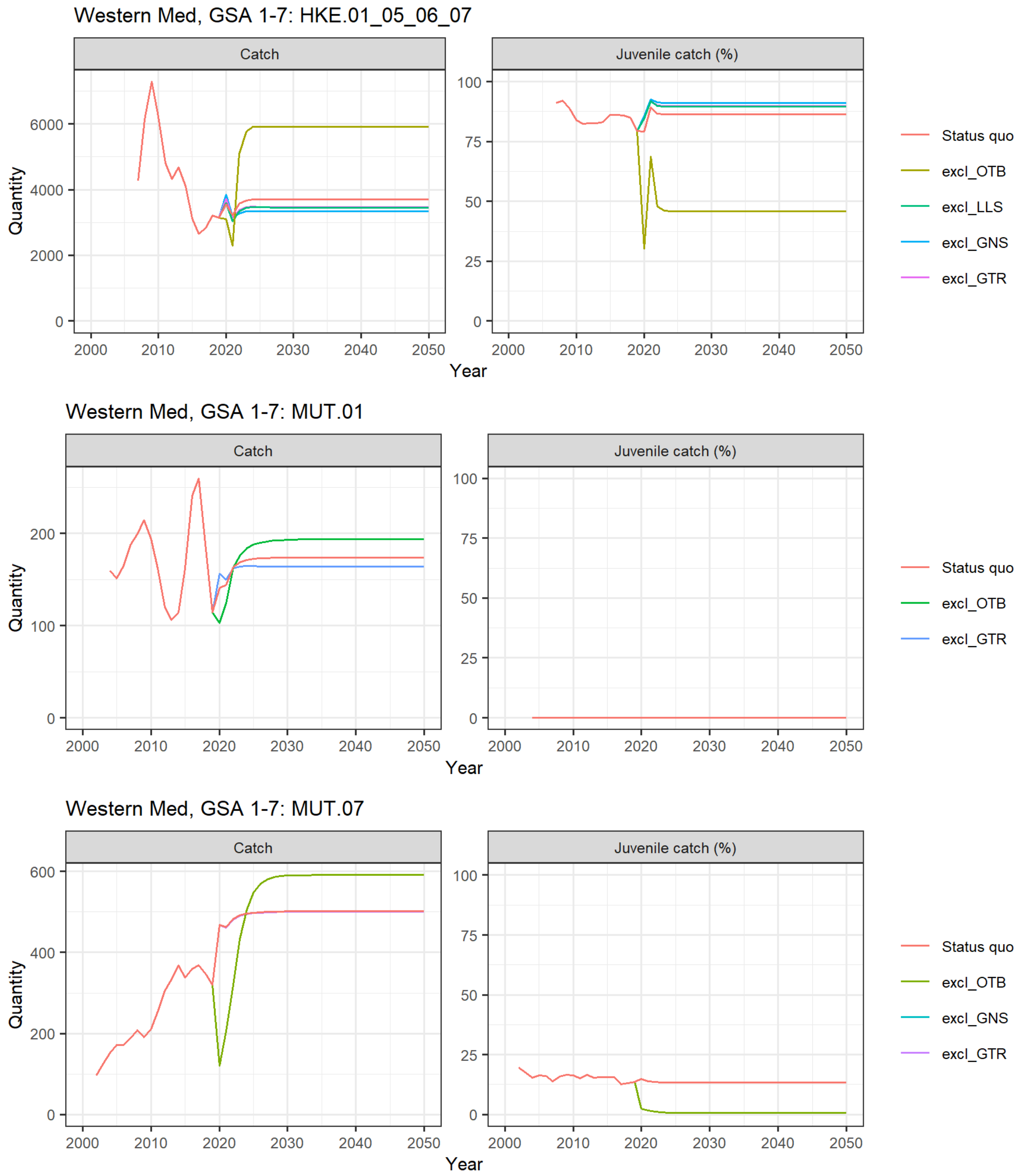

Fig. 4.2.2.4: Jackknife of Western Mediterranean stock in GSA 1-7 under current *F*. Projections of catch (left) and percentage of juveniles in the catch (right) of status quo and when particular fleet segments are omitted.

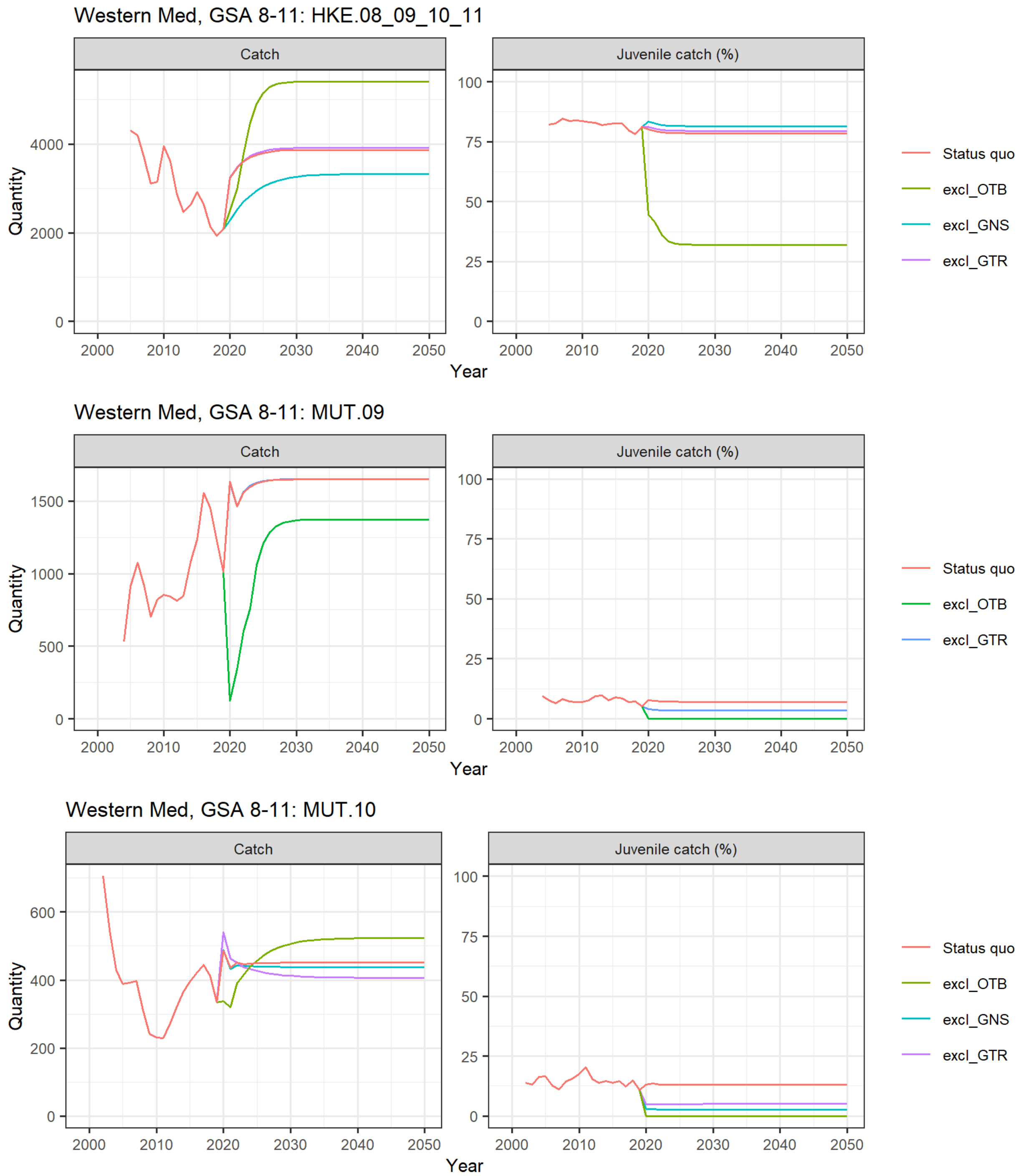

Fig. 4.2.2.5: Jackknife of Western Mediterranean stock in GSA 8-11 under current F. Projections of catch (left) and percentage of juveniles in the catch (right) of status quo and when particular fleet segments are omitted.

4.2.3. SUMMARY ToR 3

From the results shown in sections 4.2.1 and 4.2.2 the following can be seen:

- Otter bottom trawl (OTB) selectivity has negative effects in terms of yield loss when compared to the status quo selectivity of all fleets combined.
- Active gears in general appear to perform worse in terms of juvenile catches and SSB. In the Northeast Atlantic, especially beam trawls often have high proportions of juveniles in the

catch, with the only exception of plaice in the English Channel. In the Western Mediterranean Sea, OTB selectivity is associated with very high proportions (>80%) of juvenile hakes in the catches.

- The Jackknife analysis showed that excluding OTB would be mostly beneficial to stocks of larger bodied cods and hakes in terms of both increase in yield and protection of juveniles.
- The negative partial impact on cods differed among regions and was least in the North Sea and most severe in the case of cod.27.6a (West of Scotland) in North-Western Waters (NWW), which is currently assessed to be below B_{lim} (ToR 3). In the Western Mediterranean Sea, the predicted yield gains from excluding OTB for hakes would exceed the only few hundred tons long term yield loss of a mullet stock in GSA 9 by several thousand tons.
- In general, the results from ToR 3 suggest that largest improvements in yield and juvenile protection can made through optimising the gear selectivity of bottom trawl gears, allocating less effort to fishing with those gears or shifting the effort to areas/season where the impacts on juveniles can be minimized.

4.3 Combined effects of fishing mortality rate and selectivity pattern on yield and SSB (ToR 4 a)

Isopleths show the trade-offs between S_{50} and F with respect to relative yield and SSB (stocks for which Beverton-Holt stock-recruitment relationship was assumed) or YPR and SPR (stocks for which no specific S-R relationship was assumed).

From the results in the figures 4.3.1.-4.3.6 the following can be seen:

- In most cases it is seen that improvement in selectivity (increase in S_{50}) would lead to higher yield (or YPR) and SSB (or SPR). All cod stocks in the North-East Atlantic (cod.27.22-24, cod.27.47d20, cod.27.6a, cod.27.7e-k) are overfished, and yield values at current fishing mortality and selectivity are only 5-20% of the maximum possible yield, and SSB is <5% of the virgin spawning biomass (Figures 4.3.1-4.3.3). These large-bodied species stocks show the largest potential increase in yield from improvement of selectivity. Stocks that are heavily overexploited (e.g., cod.27.7e-k) would gain more if selectivity is increased simultaneously with decreased fishing mortality. In addition, such an approach would mean that reduction in F could be less severe when simultaneously both selectivity and F are manipulated.

- Optimisation of selectivity has often larger positive effects on yield than on SSB. For example, for plaice in Baltic Sea (ple.27.21-23, Figure 4.3.1), cod in North Sea (cod.27.47d20, Figure 4.3.2) and haddock in North-Western Waters (had.27.6bm Figure 4.3.3), improvement in selectivity would lead to higher yield but the improvement in SSB level is minor. Same can be seen in the Mediterranean hake stocks, where SPR levels at current F and selectivity are <5% for HKE.01_05_06_07 and HKE.17_18, and <10% for and HKE.08_09_10_11 and HKE.19 (Figures 4.3.5-4.3.6). Especially for the two hake stocks that have SPR <5%, decrease in F with improved selectivity is needed to see significant changes in SPR level. In many cases, a decrease in F combined with an increase in the age-at-selectivity is needed to see large changes in SSB. However, an increase in SSB albeit not as large as yields when selectivity is improved, has a multitude of positive effect, both for the fisheries through an increase in CPUE and average individual size of the fish caught, for the stock as it increases its resilience to climate change and for the ecosystem as larger biomass and size diversity in general increase ecosystem functionality and services.

- Small bodied and fast-growing species which are described by high natural mortality values for young ages (e.g., whiting and red mullet stocks) have less to benefit from the increase in selectivity at current fishing mortality. For example, increasing selectivity for whiting in North-western waters (whg.27.7b-ce-k, Figure 4.3.3) and North Sea (whg.27.47d, Figure 4.3.2) would lead to decreasing yield instead of commonly seen increase in yield due to improvement in selectivity (e.g., NEA cod stocks).

- Isopleths for fast-growing red mullets in the Mediterranean show that improvement in selectivity would lead to higher yield (close to the maximum relative yield), and also improve the SSB level (Figures 4.3.5-4.3.6). Exceptions to this are MUR.05 and MUT.22 which are the only red mullet stocks in the Mediterranean that are not overexploited ($F<F_{MSY}$). In case of MUR.05, improvement in selectivity would lead to decreased yield, however when combining selectivity increase with minor F increase, max yield can be reached. In case of MUT.22 increased selectivity does not affect the yield, for higher yield F needs to be increased.

- Increase in SSB in response to improved selectivity and decreased F is more predictable and consistent across species compared to responses in yield to changes in selectivity and F.

- Stocks that are underexploited ($F<F_{MSY}$) e.g., North Sea whitings and Irish Sea plaice would not produce higher yield with increasing S_{50} or decreasing F.

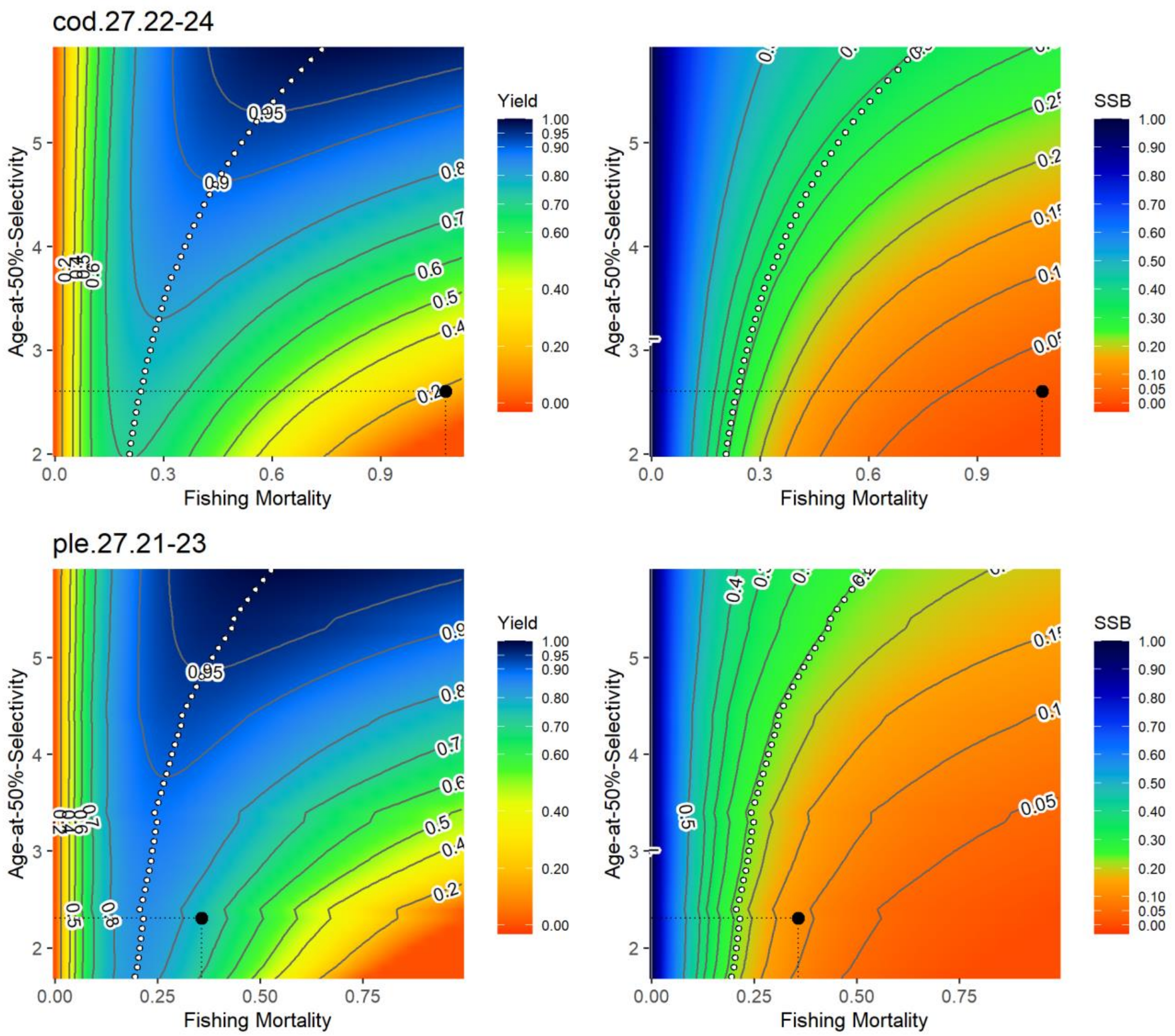

Figure 4.3.1: *Isopleths for Northeast Atlantic stocks in the Western Baltic Sea. Equilibrium yield (left) and SSB (right) under varying age-at-50%-selectivity ("shifting") and fishing mortality rate F. The black dot represents the estimate under current selectivity and F, and white dots show the dynamic F_{MSY} estimates as a function of changes in selectivity.*

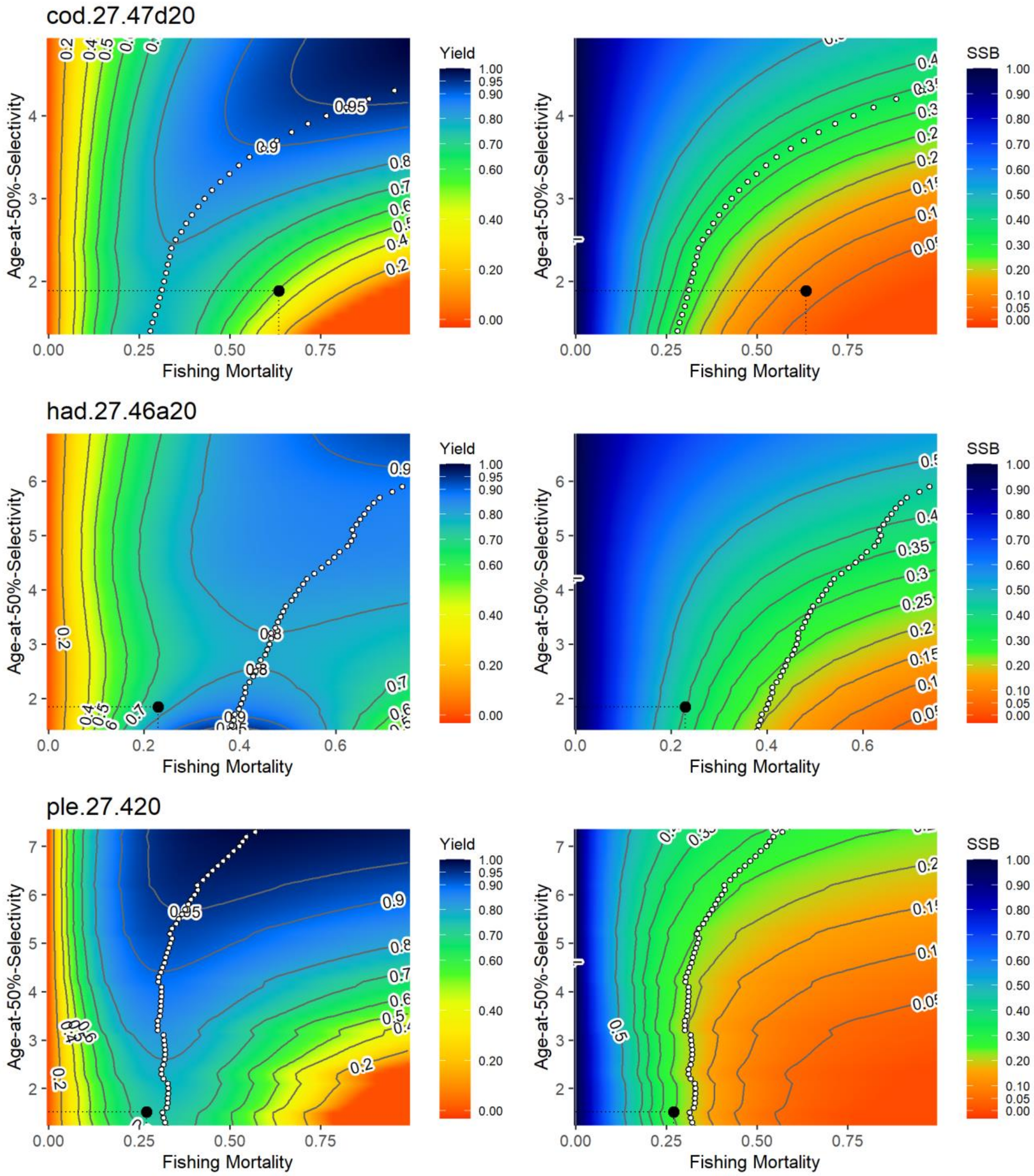

Figure 4.3.2: *Isopleths for Northeast Atlantic stocks in the Greater North Sea. Equilibrium yield (left) and SSB (right) under varying age-at-50%-selectivity ("shifting") and fishing mortality rate F. The black dot represents the estimate under current selectivity and F, and small white dots show the dynamic F_{MSY} estimates as a function of changes in selectivity.*

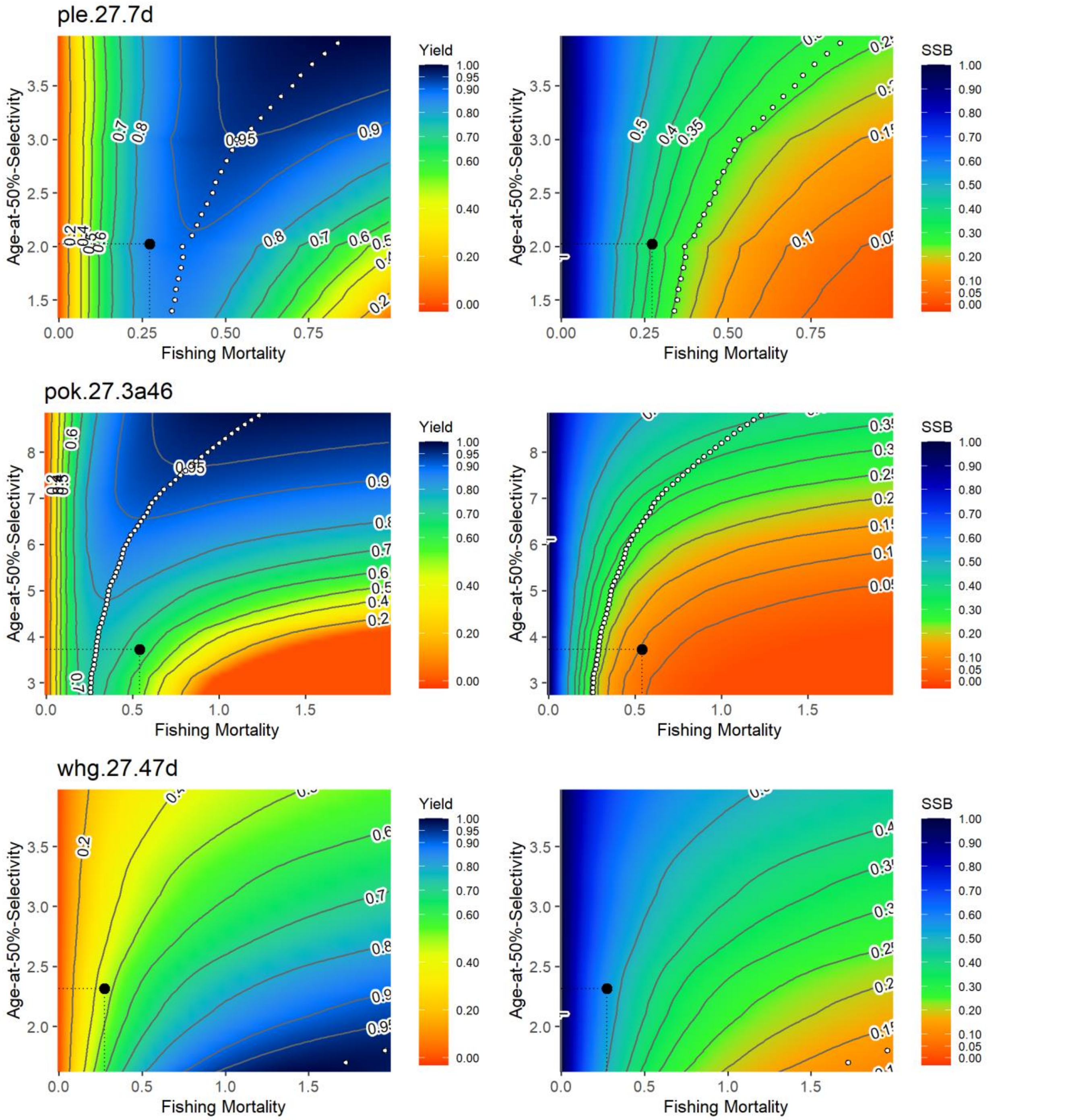

Figure 4.3.2 (cont.): *Isopleths for Northeast Atlantic stocks in the Greater North Sea. Equilibrium yield (left) and SSB (right) under varying age-at-50%-selectivity ("shifting") and fishing mortality rate F. The black dot represents the estimate under current selectivity and F, and white dots show the dynamic F_{MSY} estimates as a function of changes in selectivity.*

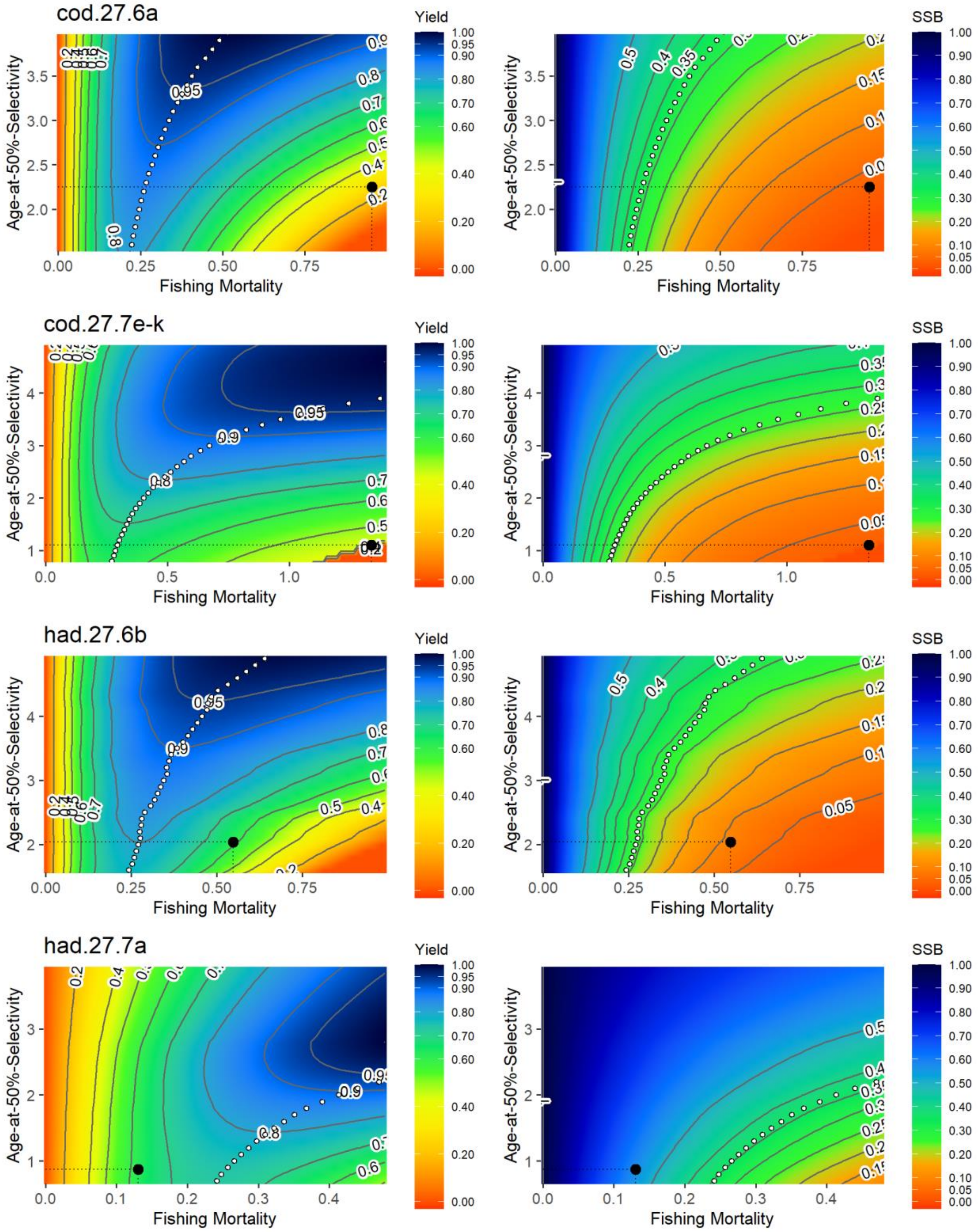

Figure 4.3.3: *Isopleths for Northeast Atlantic stocks in North Western Waters. Equilibrium yield (left) and SSB (right) under varying age-at-50%-selectivity ("shifting") and fishing mortality rate F. The black dot represents the estimate under current selectivity and F, and white dots show the dynamic F_{MSY} estimates as a function of changes in selectivity.*

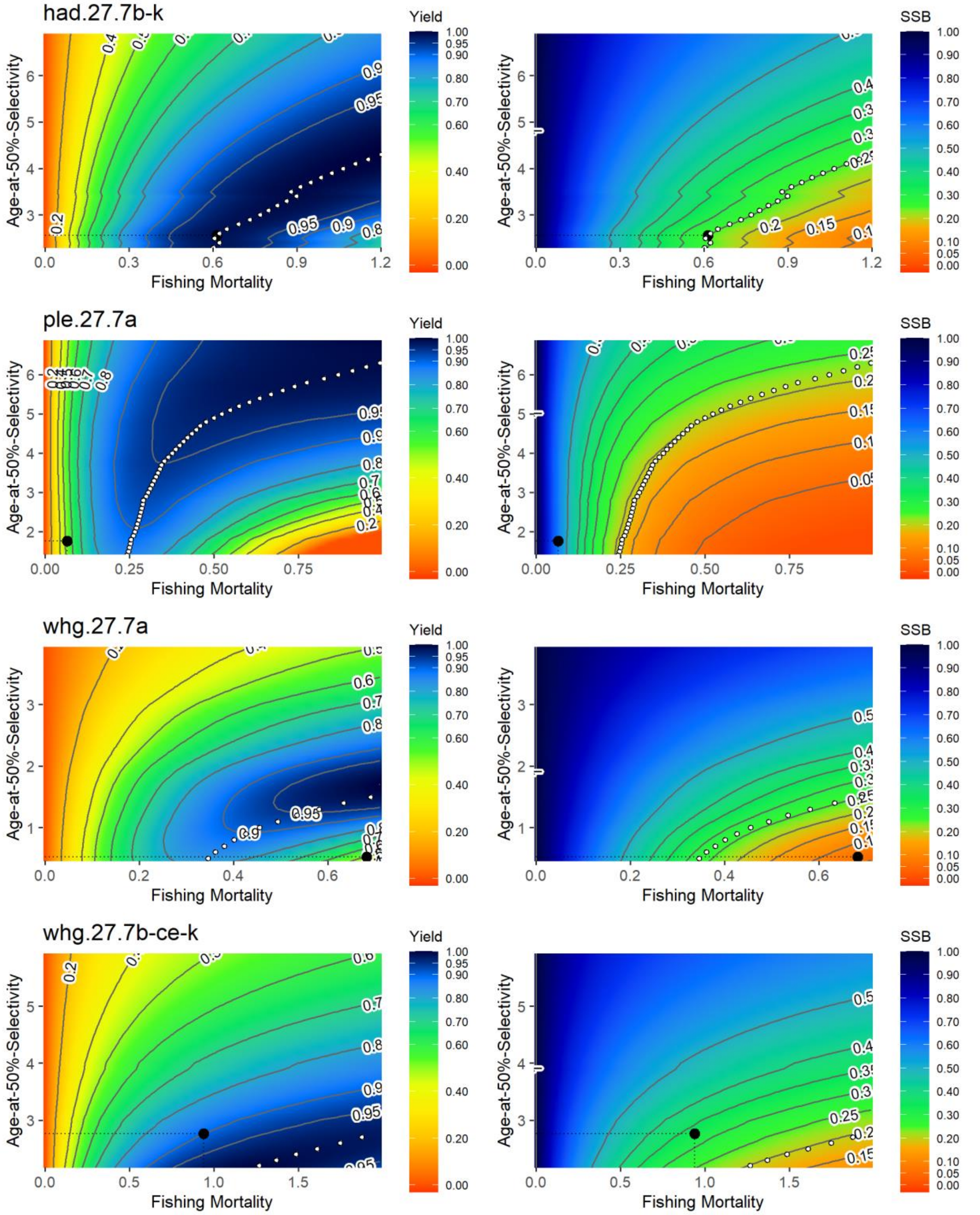

Figure 4.3.3 (cont.): *Isopleths for Northeast Atlantic stocks in the North Western Waters. Equilibrium yield (left) and SSB (right) under varying age-at-50%-selectivity ("shifting") and fishing mortality rate F. The black dot represents the estimate under current selectivity and F, and small white dots show the dynamic F_{MSY} estimates as a function of changes in selectivity.*

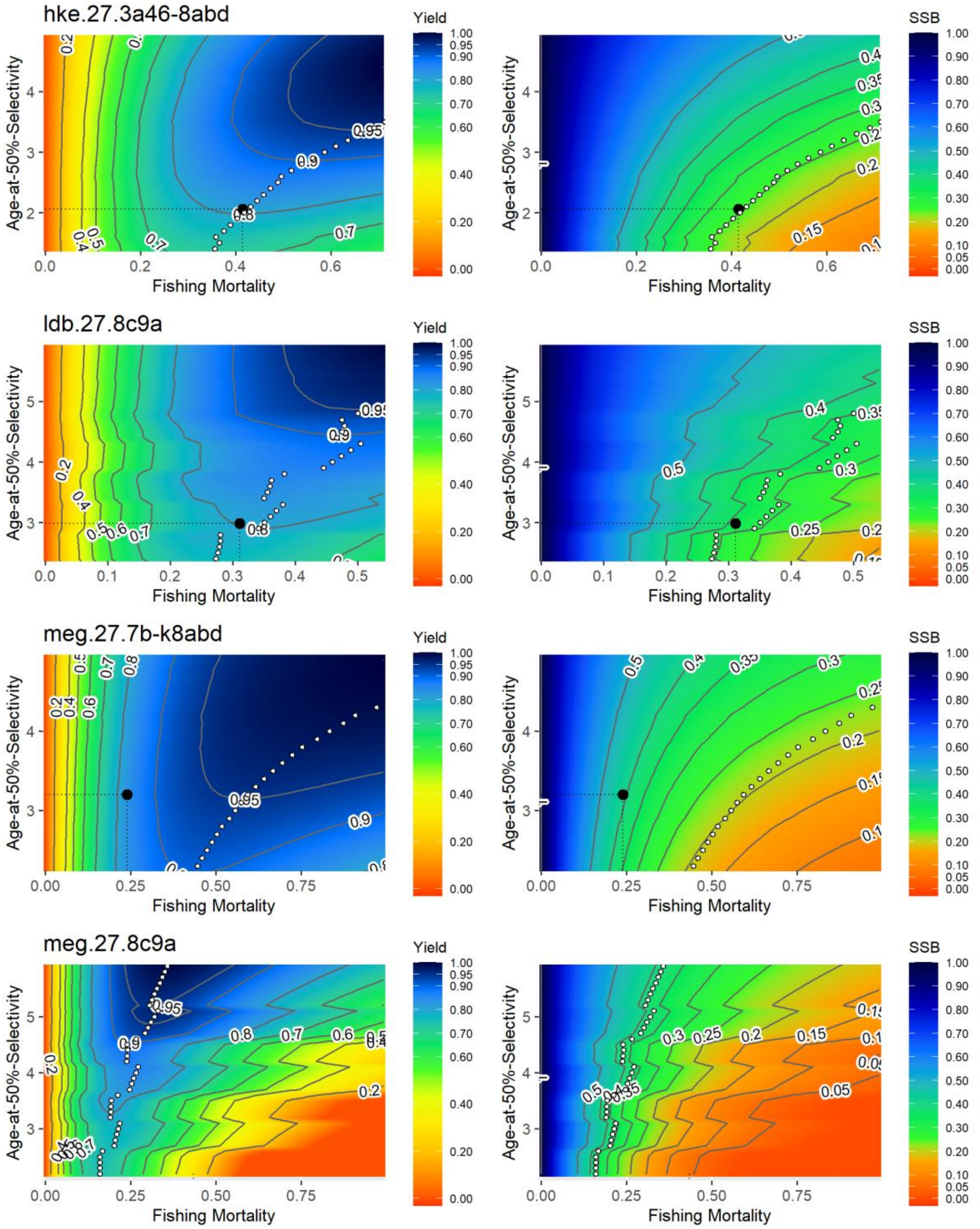

Figure 4.3.4: *Isopleths for Northeast Atlantic stocks in South Western Waters. Equilibrium yield (left) and SSB (right) under varying age-at-50%-selectivity ("shifting") and fishing mortality rate F. The black dot represents the estimate under current selectivity and F, and small white dots show the dynamic F_{MSY} estimates as a function of changes in selectivity.*

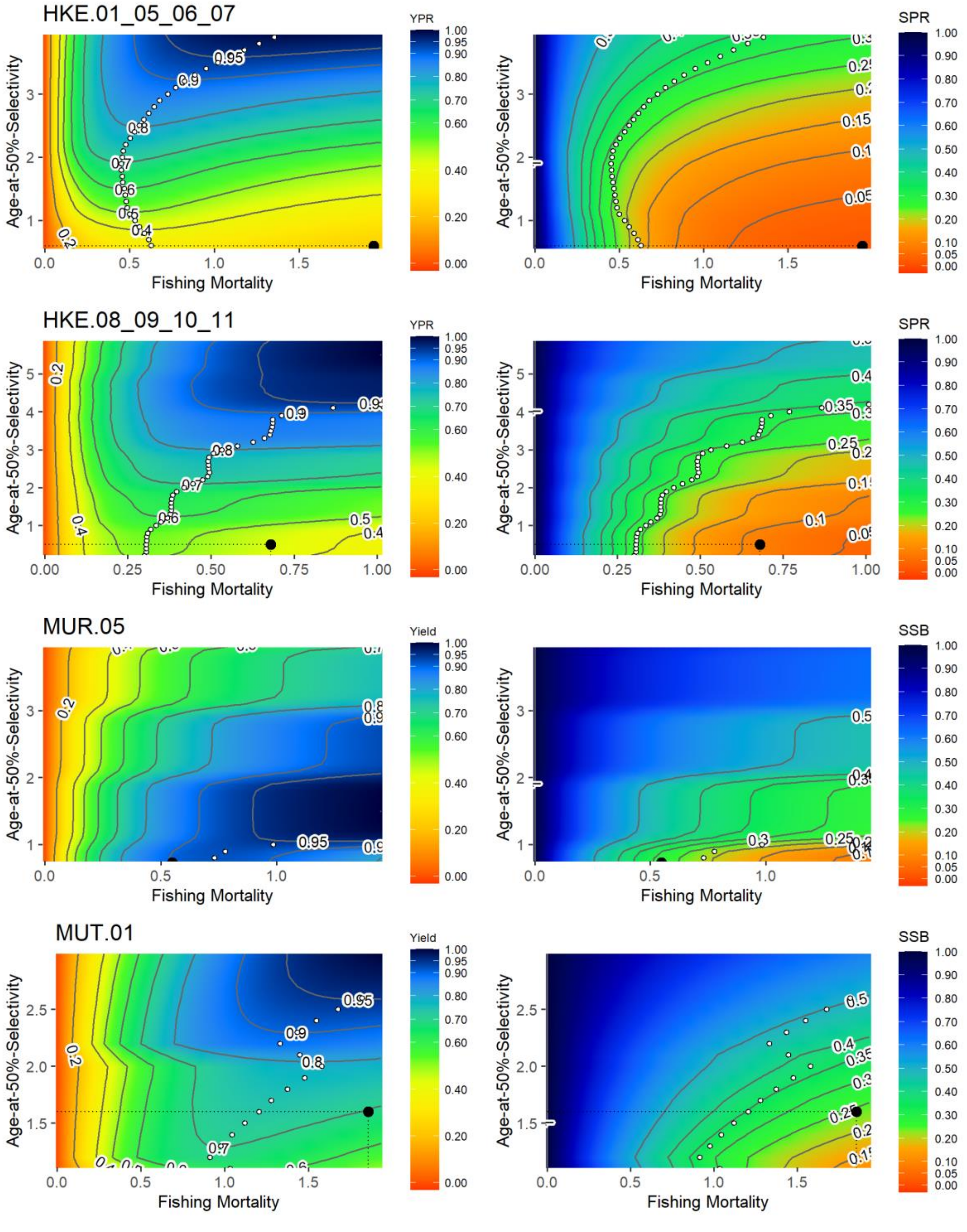

Figure 4.3.5: *Isopleths for Western Mediterranean stocks. Equilibrium yield (left) and SSB (right) under varying age-at-50%-selectivity ("shifting") and fishing mortality rate F. The black dot represents the estimate under current selectivity and F, and small white dots show the dynamic F_{MSY} estimates as a function of changes in selectivity. Note that in the absence of a stock recruitment relationship for hakes Yield and SSB are expressed as per-recruit YPR and SPR, respectively, with white dots representing F_{max}.*

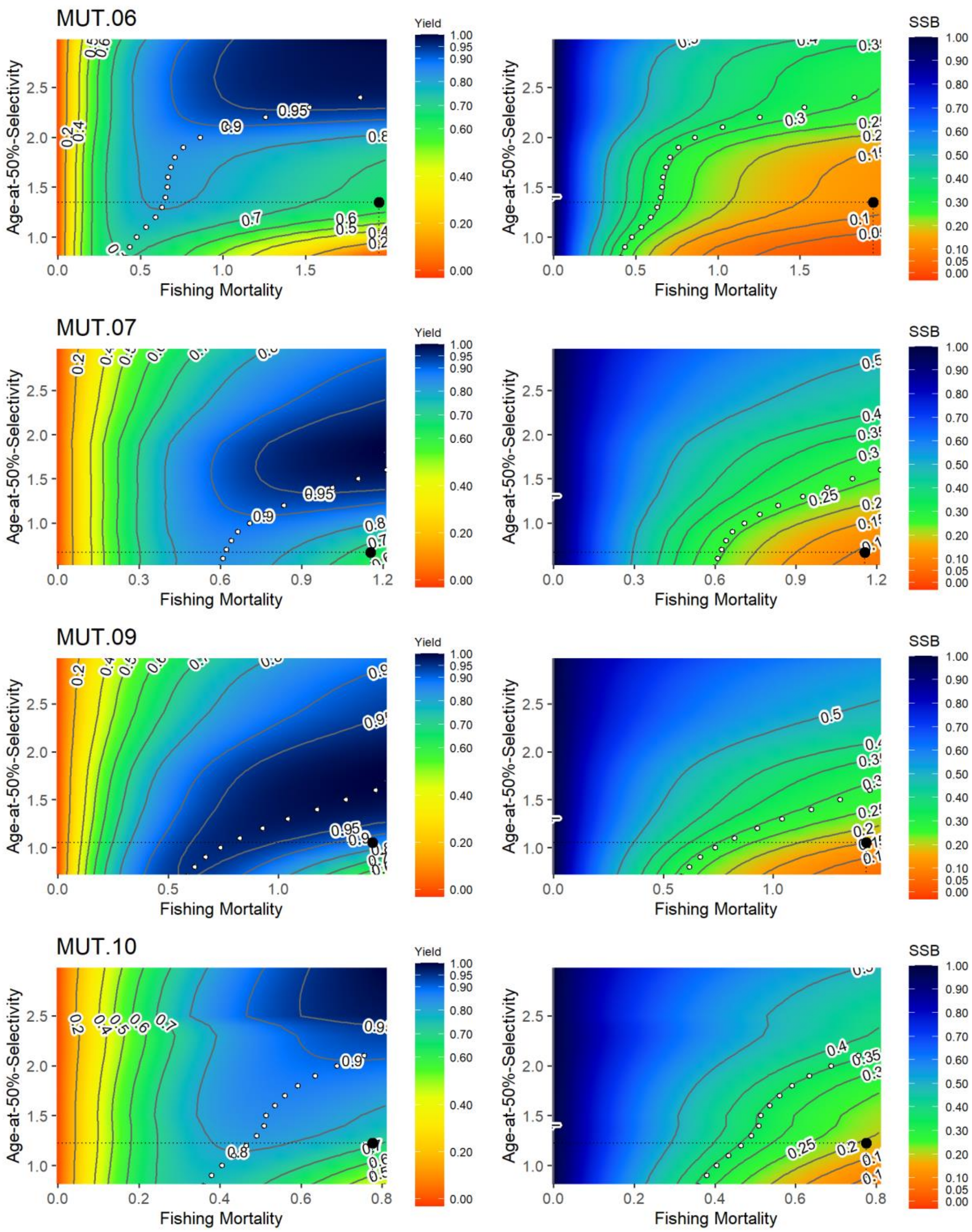

Figure 4.3.5 (cont.): *Isopleths for Western Mediterranean stocks. Equilibrium yield (left) and SSB (right) under varying age-at-50%-selectivity ("shifting") and fishing mortality rate F. The black dot represents the estimate under current selectivity and F, and small white dots show the dynamic F_{MSY} estimates as a function of changes in selectivity.*

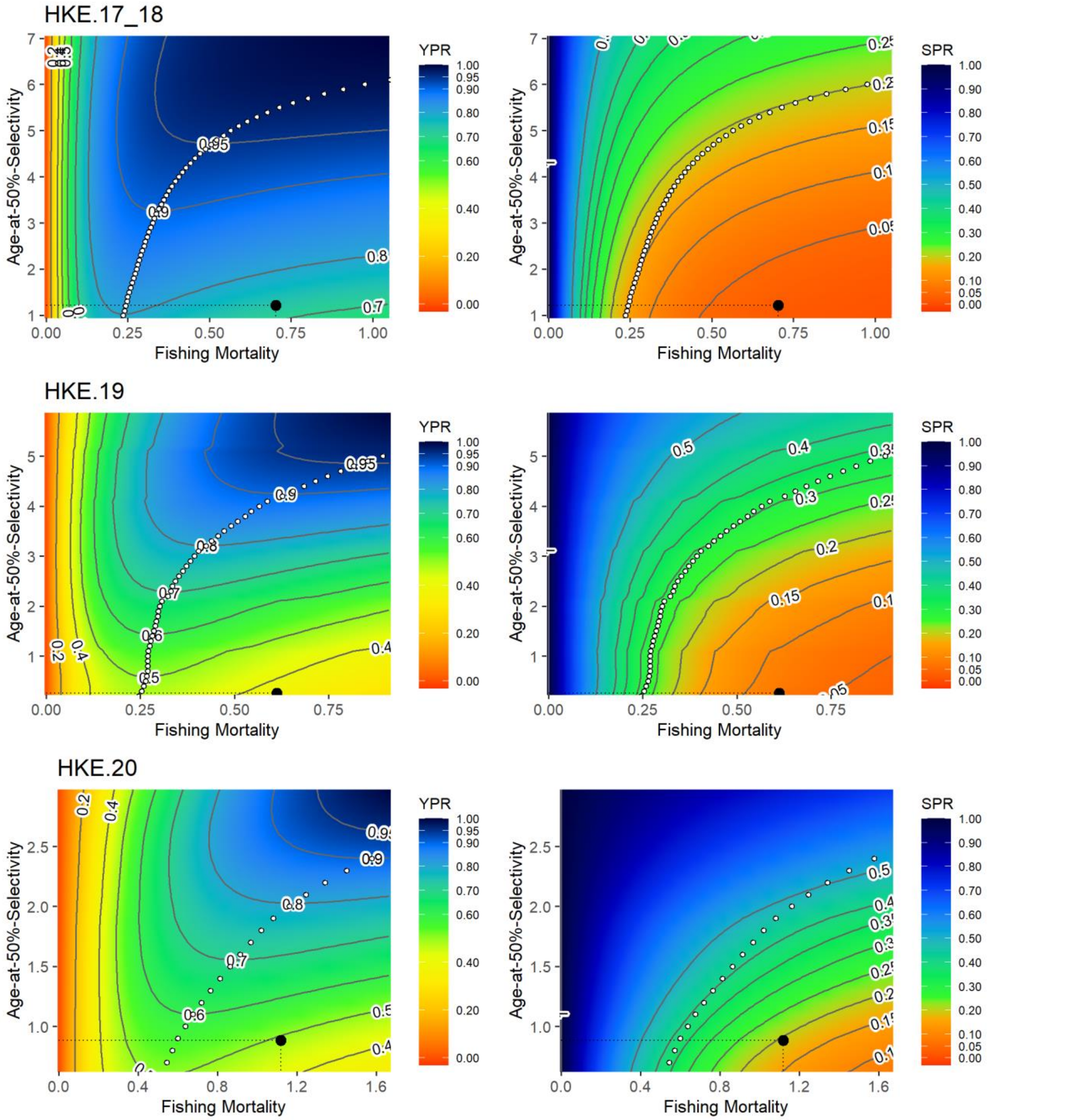

Figure 4.3.6: *Isopleths for Eastern Mediterranean stocks. Equilibrium yield-per-recruit YPR (left) and spawning biomass per recruit SPR (right) under varying age-at-50%-selectivity ("shifting") and fishing mortality rate F in the absence of a stock recruitment relationship for hakes. The black dot represents the estimate under current selectivity and F, and small open circles show the dynamic* F_{max} *estimates as a function of changes in selectivity.*

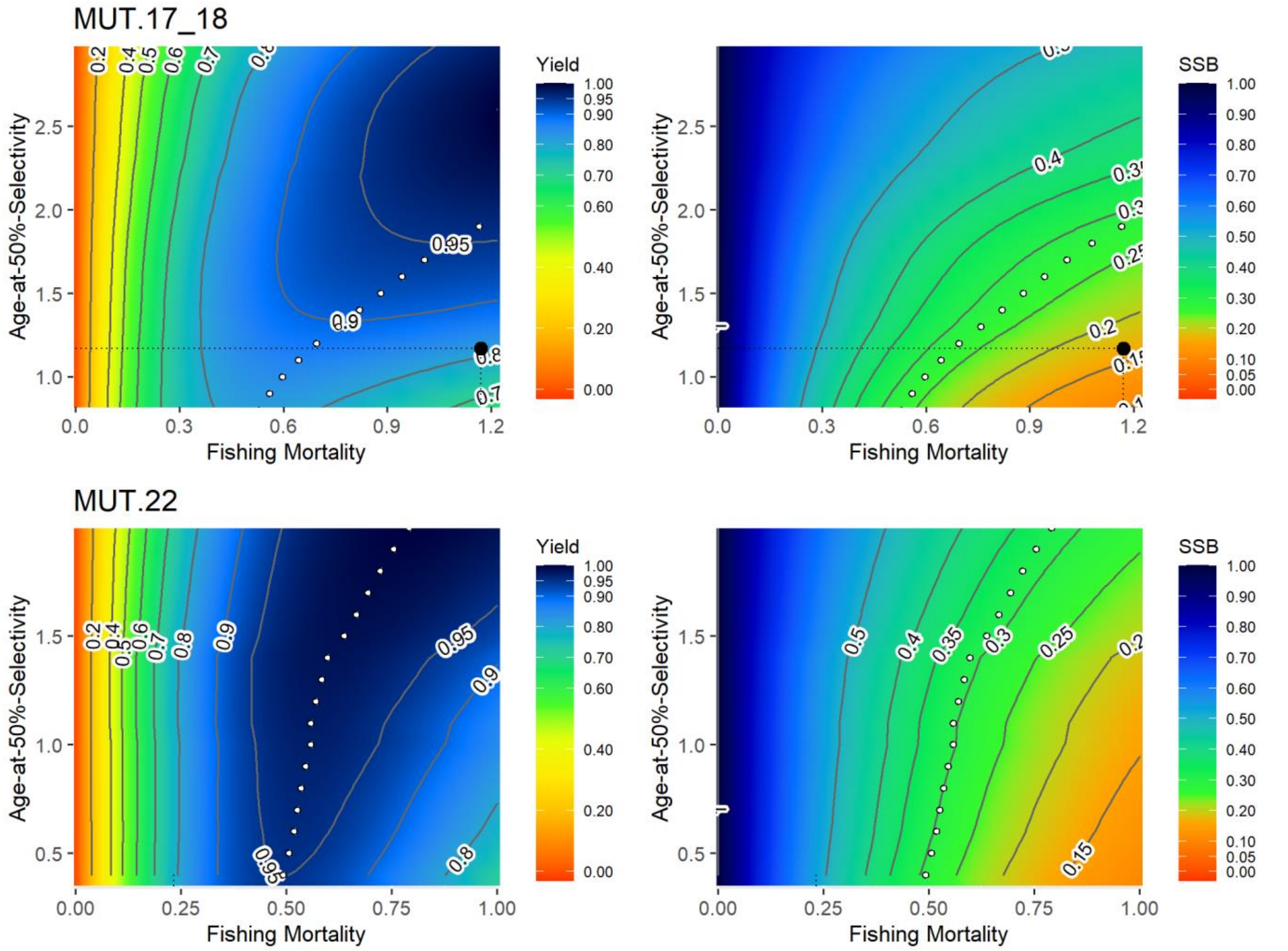

Figure 4.3.6 (cont.): *Isopleths for Eastern Mediterranean stocks. Equilibrium yield-per-recruit YPR (left) and spawning biomass per recruit SPR (right) under varying age-at-50%-selectivity ("shifting") and fishing mortality rate F in the absence of a stock recruitment relationship for hakes. The black dot represents the estimate under current selectivity and F, and small open circles show the dynamic* F_{max} *estimates as a function of changes in selectivity.*

4.4 Practical issues regarding the attainment of the biologically optimal selection pattern in the context of mixed fisheries and multi-gear fisheries (ToR 4b)

4.4.1 PRACTICAL ISSUES IN MIXED FISHERIES – QUALITATIVE CONSIDERATIONS

The majority of mixed species fisheries that exist in EU waters are characterised by having towed gear fisheries where a range of mesh sizes are used to select a range of species often with differing biologically characteristics. Generally, the mesh sizes are designed principally to catch the most valuable species in the fishery (e.g. *Nephrops*), and in practice, the choice of gear is often a short-term compromise to discourage the retention of small fish rather than one based on biological suitability (e.g. maturity).

An example of highly mixed fisheries that can be used to illustrate these practical issues is in the Celtic Sea. A range of species are targeted with different gears in the Celtic Sea, many with high levels of catches of juveniles combined with a highly depleted cod stock, which is caught in most Celtic Sea fisheries. Celtic Sea fisheries can be split into active and passive gears. Otter trawl fisheries take place for mixed gadoids (cod, haddock, whiting, hake), *Nephrops*, anglerfish, megrim, rays as well as cephalopods (cuttlefish and squid). Beam trawl fisheries target flatfish (plaice, sole, turbot), anglerfishes, megrim and cephalopods (cuttlefish and squid) while gillnet fisheries target flatfish, hake, pollack, cod, anglerfishes as well as some crustacean species. Beam trawling occurs for flatfish and skates and rays. The fisheries are mainly prosecuted by French, Irish, and English vessels with additional Belgian beam trawl fisheries and Spanish trawl and net fisheries along the shelf edge.

For many years in the Celtic Sea there has been large but sporadic recruitment for the gadoid stocks and high levels of exploitation resulting in significant fluctuations in the stocks. More recently, recruitment has been well below the long-term average for cod and whiting while haddock and hake have experienced above average recruitment in 2018 and 2019. These fluctuations and particularly the overexploitation of the cod stock have created issues for the towed gear fisheries in the Celtic Sea, particularly for cod which is caught in many fisheries but which from a gear perspective is a difficult species to improve selectivity for without increasing mesh size to a level that would potentially render many of the current towed gear fisheries economically unviable. STECF EWG 13-04 indicated that as a general rule for gadoid species, for every 3.3 cm increase in S_{50} a 10mm increase in mesh size is needed. Such an increase would mean increasing the baseline mesh size in the Celtic Sea in the mixed gadoid fisheries in the Celtic Sea from the current 100mm to ~150mm-180mm. Such a mesh size would be incompatible in the current fishery, which targets haddock, hake, megrim and anglerfish and even increasing mesh size in a stepwise manner would result in very high short- to-medium-term losses. A gradual increase in mesh size would reduce fishing mortality to F_{MSY} levels for cod without losses for other associated species such as haddock and whiting. In this case, specific gear alterations, such as the use of raised fishing line gear can help to reduce the cod catch while maintaining the catch of haddock, hake and whiting but would need to be seen in combination with other measures such as spatial/temporal closures.

In the Celtic Sea *Nephrops* fishery, the central issue remains that the mesh size used in the *Nephrops* fishery is optimal for *Nephrops* but not for the bycatch species and definitely not for cod. The introduction of selectivity devices such as square mesh panels has helped to reduce the catches of juvenile haddock, whiting and hake but not for large-bodied species such as cod. There is a readymade solution to this in the form of sorting grids which are effective at releasing most of the bycatch species (including cod) from *Nephrops* trawls but there is a marked reluctance for fishermen to use such devices because they exclude most of the bycatch of other species such as anglerfish as well as cod, which are an economically valuable part of the catch. In effect, while the fishery targets *Nephrops*, the bycatch is considered economically valuable enough for fishers to resist change and adopt highly selective gears that turn the fishery into a single species fishery with little or no bycatch. This is in contrast to the *Nephrops* fishery in the Skagerrak and Kattegat where due to the poor state of the cod stock in these waters, Swedish fishers were forced by legislation to adopt the use of sorting grids in their fishery in order to keep fishing. The fishery was essentially turned into a single species fishery and overtime the loss of bycatch has diminished as an issue. Therefore, in the Celtic Sea *Nephrops* fishery significant improvements in the selection patterns could be attained by converting the fishery into a single species fishery though the adoption of sorting grids. On the other hand, *Nephrops* fishery is a relatively modern target fisheries, which is a direct consequence of the large historical depletion of top predators as gadoids. In the Skagerrak and Kattegat, a substantial fishery for *Nephrops* has developed that uses baited pots, i.e., creel fishery, which has minimal bycatch of gadoids and other fish or, when caught, bycaught fish can be released unharmed. The transformation of the current target *Nephrops* fishery with trawlers to alternative methods as creel can constitute a way forward to reduce the catches of juvenile gadoids, noting there are undoubtedly barriers to such a transition as acknowledged by Suuronen et al., 2012. These include:

- lack of familiarity with cost-effective and practical alternatives;
- incompatibility of vessels with alternative gear;
- risk of losing marketable catch;
- concerns with safety at sea by using unfamiliar gears or strategies;
- high investment costs;
- lack of capital or restricted access to capital;

Many of these barriers are relevant to the Celtic Sea fishery, nonetheless there is scope to give serious consideration to such a shift as a partial solution to the mixed fishery issues that exist.

The beam trawl fishery in the Celtic Sea prosecuted by Belgian, Irish and UK vessels, has slightly different practical issues centred around cod. The gear used is designed to target sole with a small mesh codend of 80mm. Previous selectivity experiments have shown that increasing the mesh size above 80mm will result in high losses of sole catch. However, in reality, sole makes up only a small but valuable part of the catch with the bycatch of megrim, anglerfish and rays being important components of the overall catch. The beam trawl fleet also catches a small but not insignificant amount of cod. The current mesh size used is unselective for all of these bycatch species. Unlike the *Nephrops* fishery, there is no readymade gear-based solution to reduce cod catches given the design and operation of beam trawl gear. Therefore, in this particular fishery, with no obvious gear-based solution, improving selection patterns could only be achieved through other technical measures such as spatial/temporal closures or significant reductions in fishing effort.

Implemented measures for the recovery of cod stocks include closed seasons, closed areas and gear specifications. The selectivity measures, applied especially to the Baltic, North Sea and NWW mixed trawl fishery aimed mainly at improving the size selectivity. Also spawning closures for Baltic cod stocks were already implemented since the late 1990s. The reduction in MCRS for Baltic cod stocks introduced in 2015 aimed to reduce the volume of cod catches below MLS/MCRS and hence discards. However, it was not expected to change the actual catch profile and thus not affect selectivity for Baltic cod. The F_{rec}/F_{bar} indicator suggests a trend of improving selectivity with less fishing pressure on juvenile cod and an improved exploitation pattern. However, EWG 20-02 could not identify whether this is related to changes in technical measures or reflects changes in fishing patterns.

In the South-western waters, there are also multiple mixed fisheries. In these fisheries, European hake is the most valuable species landed by the French and Spanish fleets in terms of tonnes (8%) and value (10%). Cornou et al. (2021) indicate that in the Bay of Biscay for example, European hake is targeted by demersal and pelagic trawlers together with a mix of other fish species. For these two fleets, with respective codend mesh size of 70-80mm and 100mm, hake represents 34% and 84% respectively of the total catch weight (among which 5 and 8% are unwanted catches of juveniles). This species is also targeted by gill nets where it represents between 42% and 97% of the total catch depending on vessel length (smaller or larger than 15m, respectively). Among these catches, 3% to 12% are unwanted catches. Fleets for which hake is a major component of the catch generate relatively low levels of unwanted catches since their mesh size and fishing strategies are adapted to target individuals above MCRS. In these fisheries, the selection pattern is closer to the optimal.

Hake is also caught as bycatch with trammel nets targeting sole (6% of the total catch among which between 43% and 60% are unwanted catch) as well as with trawls targeting sole (9 % of the total catch weight among which 4% are unwanted catch). Similar to the Celtic Sea, the main issue in that mixed fishery is the *Nephrops* trawl fleet which catches significant quantities of hake below MCRS since *Nephrops* and juvenile of hake are found on the same fishing grounds of the "Grande Vasière". Hake represent 14% of the *Nephrops* trawlers catch, of which 16% are discarded. *Nephrops* is the target species but bycatch species such as hake constitute significant part of the fishers' gross income. In this fishery the mesh size is set to maximise the catch of *Nephrops* rather than hake. As in the Celtic Sea *Nephrops* fishery, there are technical solutions available to reduce the level of bycatch but there is a reluctance to uptake the most effective of these selectivity devices due to the resulting loss of marketable hake catch.

Another way to catch *Nephrops* without hake by-catch is by using creels. However, in practice such an option faces technical, cultural, economic and spatial issues. Indeed, trawl vessels are designed to tow gear and the equipment, layout and space on board are not suitable to store and handle passive gear in a secure way. Furthermore, skippers and crews have no experience in fishing for *Nephrops* with creels*.* Culturally, the shift from a metier to another cannot be instantaneous. The market in France for *Nephrops* is structured according to trawl caught and not creel caught. Therefore, not only the fishing sector would have to adapt their operations, but the processing sector would also have to adapt (but see the Skagerrak-Kattegat example above where the switch has happened rather quickly).

Additionally, the "Grande Vasière" area is exploited by other towed gear metiers such as demersal and pelagic trawl targeting gadoids, which generate spatial conflicts between metiers. For all these reasons, and despite several creel tests in the Grande Vasière, the *Nephrops* trawl fleet adopted technical measures to improve its selectivity and reduce juvenile hake bycatch. For instance, the codend diamond mesh size increased from 55mm to 70mm in 1999, and then in 2005 a 100mm square mesh panel aiming at hake juvenile escapement was added to the legislation (STECF, 2020a). Since 2011 and to keep reducing discards, the *Nephrops* fleet has to choose among 3 selective devices, which are 80mm codend or bottom 62mm square mesh panel or a rigid grid. During the last decade, many selectivity projects were carried out to promote the adoption of selective trawl devices on a voluntary basis in order to cope with the implementation of the landing obligation. In mixed fisheries such as the hake/*Nephrops* one, the challenge of reducing discards to reach F_{MSY} is mainly due to the differences of species behaviour, morphology and MCRS. *Nephrops* has a MCRS of 9cm, a passive behaviour and crustacean morphology. Hake has a MCRS of 27 cm TL, an active behaviour and a round fish shape. From a technical point of view, gear selectivity should consider all these differences to reach the best trade-off leading to the highest escapement of juvenile hake while catching *Nephrops* above MCRS.

Summarizing:

- As currently applied, technical measures, can in principle, adjust exploitation pattern and rate, but it is likely that the anticipated impacts of these measures have not been fully realised due to inability or unwillingness to deploy as intended, the fact that they are often compromises in mixed fishery situations and due to enforcement difficulties. Gear-based measures tend to increase short-term costs, through short-term losses and/or equipment costs and they are generally borne by the individual business without compensation. This incentivises fishers to circumvent technical measures, a response to minimise short term losses. Even with the new Technical Measures regulation in place, these practical issues have hindered thus far the attainment of selection patterns closer to the optimal patterns.
- The improvement of selectivity must include an improvement on fishing strategies and spatial/temporal measures in conjunction with gear selection characteristics to improve compliance with the landing obligation under the reformed CFP. To reach this objective a collaborative approach is essential, including fisher associations and the stakeholders.
- The Celtic Sea and South-western waters examples described above, demonstrate the complexity in improving selection patterns in mixed species and multi-gear fisheries. In each of these mixed fisheries, the possible solutions are different and include a combination of gear-based and spatial/temporal measures along with changes in fishing patterns and possible reductions in fishing effort. Making all such changes at once might be politically, culturally and economically difficult.

4.4.2 PRACTICAL ISSUES IN MIXED FISHERIES – QUANTITATIVE CONSIDERATIONS

A study has been recently conducted at the scale of the North Sea Ecoregion, in order to analyze the effect of technical regulations on several stocks at the same time (Outrequin 2021, Outrequin et al. in prep.). In this study, the impact of fishing on targeted stocks was analyzed focusing on the case of benthic and demersal resources, and thus taking into account the 9 main stocks harvested by mixed fisheries. The FLBEIA model (Garcia et al., 2017), which here considers all the fleets performing in the North Sea, was used to run scenarios of modifications of the three main fishing gears, namely: the large mesh otter trawl (TR1), the small mesh otter trawl (TR2), and the small mesh beam trawl (BT2). As the results of this study clearly illustrate a way selectivity could be improved in practice, we summarize here the outputs of a scenario where a large increase in mesh sizes is implemented, in addition to the use of selectivity devices (details in Table 4.4.2.1). Such a scenario leads to a large increase of the mean age at first catch (Table 4.4.2.1.). On average for all the considered stocks and for the whole fishery, this increase is around 0.9 year. Gear modification doesn’t change stocks selectivity equally, some stocks benefit more than others of such changes.

Table 4.4.2.1: Summary of the modification scenario implemented and consequences on the related age at first catch for the main stocks.

		Scenarios	
		Current	Selectivity improved
Gears modified (mesh size & selective devices)	TR1	100mm	140mm
	TR2	70mm	140mm
	BT2	80mm	T90 de 100mm and square mesh top panel
		Age at first catch (S_{50})	
Stocks	Cod.27.47d20 (Cod)	2.1	3.0
	Had.27.46a20 (Haddock)	2.0	4.3
	Ple.27.7d (Eastern-Channel Plaice)	2.3	2,.6
	Ple.27.420 (North Sea Plaice)	1.4	2.4
	Pok.27.3a46 (Saithe)	3.4	4.4
	Sol.27.4 (North Sea Sole)	1.7	3.3
	Tur.27.4 (Turbot)	2.4	2.6
	Whg.27.47d (Whiting)	3.2	3.4
	Wit.27.3a47d (Witch)	4.2	4.7

Long-term effects of an increase in the selectivity of the main gears used in the North Sea show that, in such a mixed fishery, the mesh size increase may lead to a large reduction of the fishing impact, and to a better use of marine resources.

An important reduction of discards is observed, while landings and biomass are increased (Figure 4.4.2.1). In this scenario, on average for the 9 studied stocks, the relative biomass B/Bo increases from 37% to 52%, landings gain 21%, while discards are reduced by half. The highest benefits are observed for cod (biomass increases by 72%, and landings are multiplied by 8) and the lowest for whiting (biomass +19%, and a decrease in landings).

Simulations also showed that the current level of total landings could be maintained with larger mesh sizes and half of the current effort, then leading to a more than doubling of the biomass compared to the current situation. These results are beneficial in an economic and ecologic perspective. In particular, the fishing effort is hugely reduced, while more biomass would result in higher CPUE. Demographic structures contain more old individuals, so stocks become more resistant and resilient to the environment. There is as well a positive side effect on fleets not concerned by the modification implemented. The entire North-Sea fishery (mixed-fishery and others) could benefit from the modification of the concerned gears (otter trawl, demersal seine, and beam trawl). For example, long-liners would catch more fish, especially more cod.

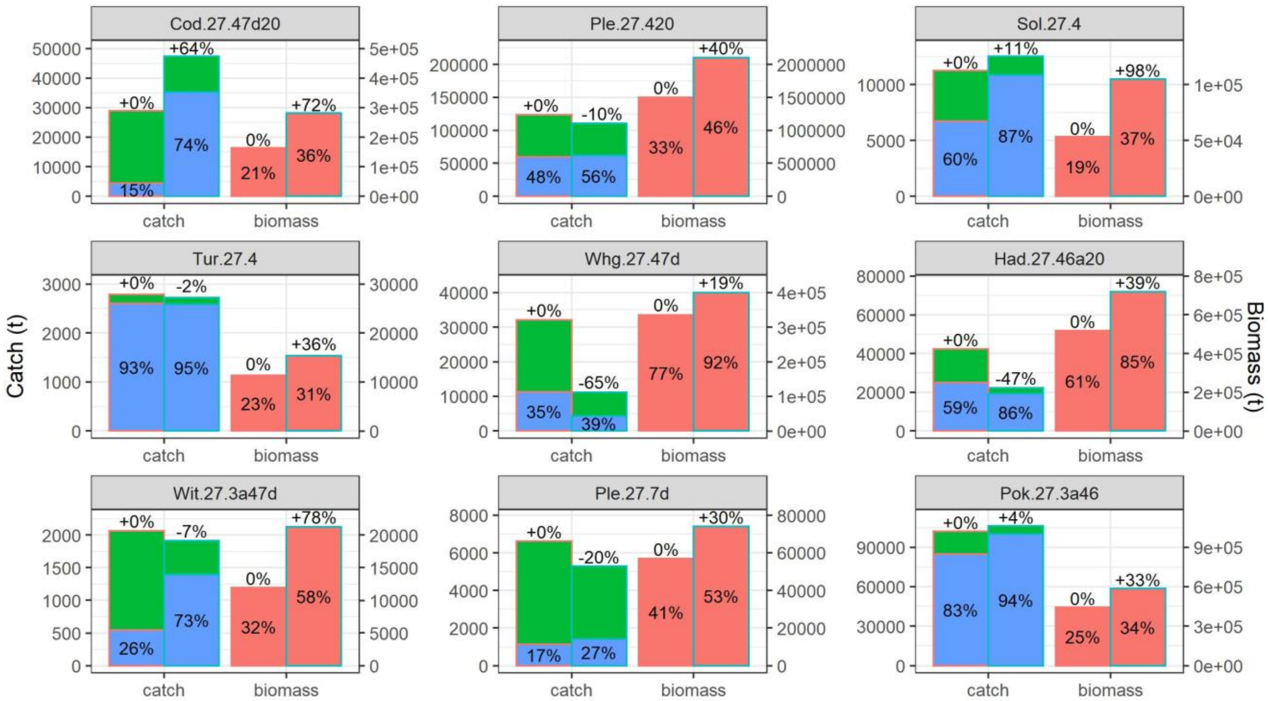

Figure 4.4.2.1: *Catch and biomass at the equilibrium in the two different scenarios for the 9 stocks. Figures in the blue bar corresponds to the proportion of landings in catch, green corresponds to discards, and in the red bar to the relative biomass B/Bo. Bar on the left corresponds to "current gear" scenario, and on the right side to the "modification gear" scenario. Values above bars correspond to gain (catch and biomass) of the current scenario (left of the paired bars) compared to the "modification gear" scenario (right of the paired bars).*

5 DISCUSSION

5.1 Caveats of the approach for interpreting the analysis

Throughout the analyses conducted by the EWG, the tacit assumption was that increased SSB is proportionally related to increased reproductive potential. This may not always be the case, for example, if adults cannibalise on young individuals (e.g. in hake).

However, this could also be compensated by the fact that biomass of large fish may contribute more to reproductive potential than biomass of smaller (adult) fish (e.g., in cod; BOFFFF effect as described by Hixon et al., 2014). Hixon et al. (2014) reviewed the evidence that in numerous fish species, weight-specific annual fecundity increases with female age and/or size; egg quality or larval quality may also increase with female age and/or size. Furthermore, older and/or larger females may have more extensive spawning seasons, providing a bet-hedging life-history strategy helping to ensure that some larvae are spawned at times of favourable environmental conditions (Hixon et al., 2014). Larger and/or older females may thus contribute more to reproductive potential and hence recruitment. Improved selectivity (increased S_{50}) leads to a size structure in the population with more fish that are older and thus larger. If larger fish have a more than proportionally larger reproductive output than smaller adults, this contributes to an increased benefit of improved selection (increased S_{50}). On the other hand, one could argue that increased S_{50} leads to increased fishing pressure on the large individuals of the stock. There are studies suggesting to reduce the fishing pressure on large individuals since they contribute more than proportionally to the reproduction success of a stock (e.g. Birkeland and Dayton, 2005). Several stocks show a dome-shaped selectivity pattern of the population. In these cases, the fishing pressure is reduced on the largest individuals of the population. The effects of cannibalism and BOFFFFs were not considered in the analyses of the EWG.

Another effect that was not considered is the "Rosa Lee" effect. This is the effect that, when size-selective fishing removes faster-growing individuals at higher rates than slower-growing fish, the surviving populations will become dominated by slower-growing individuals (Lee, 1912). When this "Rosa Lee" phenomenon is ignored, bias occurs in catch and stock projections. A simulation study based on cod-like population dynamics (Kraak et al., 2019a) showed that when the L50 was increased from 30 to 40 cm, the catches of undersized fish were overestimated by 150%. That means that the actual benefits of increased S_{50} in terms of reduced proportions of juveniles in the catch may be (much) greater than the predictions of our analyses indicate. However, this study also found that increased S_{50} has the negative side effect that it reduces mean length-at-age, especially among older fish and especially in populations with slow mean growth (Kraak et al., 2019a). If the BOFFFF effects relate to length itself (rather than age), increased gear selectivity would thus result in a negative effect on reproductive potential and hence recruitment. Again, these effects were not considered in the analyses of the EWG.

Projections are subject to the assumptions made in the assessment model and may be particularly sensitive to assumptions on the selection pattern and *M*. Note that such assumptions based on average conditions in most recent years may be appropriate for assessments and short-term forecasts, but may be not necessarily hold for long-term forecasts. As such, the long-term projections should not be interpreted as likely future states, but in the context of estimating baselines analogous to reference point estimations in the assessment process. For example, in some models the selection of older fish is a-priori assumed to be flat-topped. This may not reflect reality but there might be insufficient information in the data to allow the model to estimate selection patterns for each age independently. Similarly, in the majority of cases, there is no empirical data available to support the assumption of M. Often these assumptions are based on extrapolations from a limited number of stocks for which empirical data are available but there is invariably a large amount of variation in these data, resulting in large uncertainty about the assumptions. Misspecifications of M and selectivity are well known to introduce considerable uncertainty in stock assessments and can bias short-term forecasts. Similar to reference point estimation (e.g. F_{MSY}), such bias can be aggravated in long-term forecasts and may produce unrealistically high equilibrium biomass if M or selectivity are incorrectly specified. The results presented here should therefore be interpreted with caution. In general, the present results are informative about the direction of change in yield, juvenile catches, etc. but the absolute changes may be under- or over-estimated.

The use of S_{50} as a 'selectivity metric' in this report should be treated with care, considering its limitations to quantify the underlying selectivity pattern across all ages. S_{50} is only one of the five parameters used to construct often dome-shaped selectivity curves in FLSelex (the other four being S_{95}, S_{max}, D_{cv}, D_{min}), and while it is typically the most influential parameter of a selectivity curve with regards to yield outcomes (Vasilakopoulos et al. 2016), different equilibrium yields could still emerge from potential changes in the shape of the selectivity curve that would leave S_{50} unchanged. Moreover, in some cases (e.g. saddle-shaped selectivity curves; Sampson and Scott, 2012), S_{50} could be even considered a poor indicator of selectivity. S_{50} was deemed adequate to summarize selectivity in the context of the simulated projections to equilibrium employed here, which were designed to illustrate how far different stocks lie from an optimal selectivity. However, it would be precarious to only use S_{50} to track interannual changes in the actual selectivity, as estimated from annual stock assessments. This is due to the shape of the selectivity curve typically exhibiting variations from year to year, hence making the consistency and comparability of the annual S_{50} values problematic. Of course, this is not an issue for stocks assessed under a constant selectivity assumption (e.g. using separable stock assessment models), but in these cases it is anyway impossible to track selectivity changes based on the stock assessment outputs. Therefore, for monitoring purposes, an F-based selectivity metric would be more adequate (e.g. F_{rec}/F_{bar} employed by STECF, 2020a, or F_{juv}/F_{apical} employed here).

Also, a change in the ecosystem might lead to an SSB-recruit relationship which does not follow Beverton-Holt or hockey-stick but instead is characterized by several years of very low recruitment independent of SSB. A change in fishing rate or pattern might only have minor influence in these cases and might not automatically lead to a recovery of the stock as described by the calculations done by the EWG. Examples for this is the eastern Baltic cod stock (ICES, 2021d).

In an attempt to convert selectivity-at-length from gear experiments to selectivity-at-age (see Annex), it was found that this may lead to a distorted view of selectivity. An example is shown for 50 mm diamond-mesh codend in Figure 5.1. The reason is that selectivity does of course not change in discrete time steps, but instead rather continuously (as a function of size).

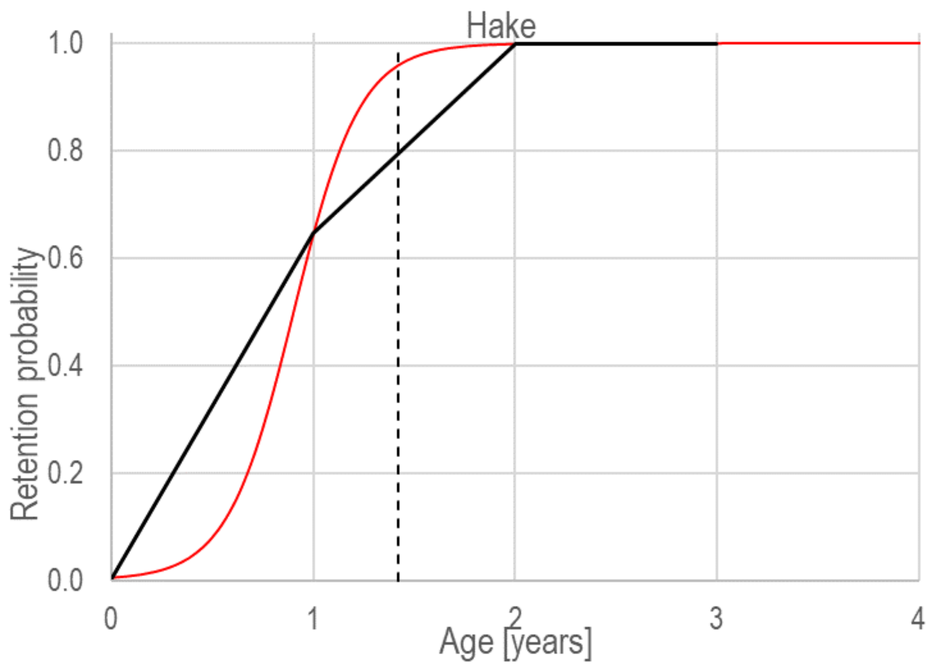

Figure 5.1: *Comparison between size selection (red curve) and age selection (black curve).*

5.2 General practical issues regarding the attainment of the biologically optimal selection pattern

As the analyses from Tors 1-3 show, optimal selection patterns have not been achieved for many stocks across EU fisheries. This is partially due to challenges of implementing technical measures in mixed fisheries where towed gears are the predominant gears used. There are many reasons for this as have been described previously by STECF EWGs 12-20, 13-04 and 15-05.

Like other management tools employed to manage fisheries, technical measures suffer from implementation error (i.e. the expected benefits are not realised in practice because they are often poorly enforced). From a political perspective, technical measures often form part of a negotiation strategy, potentially leading to a dilution of the final measures agreed. This can often be driven by perceived negative impacts (losses of marketable catches) in the fishery and the desire of managers to broker a deal, even though the measures agreed may be sub-optimal in terms of achieving longer-term management objectives relating to optimising exploitation patterns.

Different types of technical measures are used in different ways. They have been mainly used to protect juveniles and improve the selectivity of fishing gears, reducing the amount of fish that is discarded. Historically, the measures have focused on individual stocks but in recent years they have been used to reduce the impact of fishing on multiple aspects of the marine ecosystem, including habitats and non-commercial species. In European waters, technical measures changes have focused on the bottom trawl fisheries, as most of the discard choke situations affect these fleets and there are difficulties in improving selectivity. Over the last few decades commercial vessels have implemented more selective trawl gears, including a variety of selectivity devices and changes in mesh size and geometry in the codends.

A further implementation problem is that the majority of gear-related technical measures are developed by national laboratories and research groups on the basis of relatively short experimental trials. As a consequence, measures tend to be evaluated under idealised conditions where the key design features are controlled and monitored. This potentially leads to issues when they are implemented into the fishery with an over-optimistic outlook of their potential benefits given the multiple factors that affect selectivity (e.g. tow time, environmental conditions, gear and vessel construction). These experiments ultimately can only ever provide short-term point estimates of selectivity.

Additionally, often selectivity measures are introduced in response to a single species conservation issue where the stock prognosis is poor and is typically characterised as having high discards. This is often confounded by the fact that the overexploited stock tends to have a truncated age structure with few old fish in the stock and are caught in mixed fisheries. This means that the fishery relies heavily on young fish, and any increase in selectivity by whatever means results in significant losses of marketable fish. The perception that a proportion of catch will be lost in the short-term leads to be a strong negative incentive to deploy tactics that mitigate these losses and has led to a technological race by the industry to develop and deploy technical fixes to circumvent the regulations and minimise such losses (STECF, 2012, 2013). In response, regulations are subsequently amended as a result, and led to ever increasing complexity in the regulations, and elevated difficulties in terms of monitoring, controlling and enforcement (STECF, 2012, 2013).

Another practical issue that has been highlighted in the past by STECF is related to the use of minimum conservation reference sizes (MCRS) and catch composition rules. These are and continue to be used widely in technical measures legislation. They are assumed to act as a coercive incentive to avoid areas with high concentrations of juveniles or unwanted species. However, there is no clear evidence to suggest that this is the case. Intuitively these make sense as technical measures but in practice they have encouraged discarding where they have not been correctly aligned (MCRSs with gear selectivity characteristics or catch composition with species composition in the fishing ground) or if there is economic advantage to fishing in areas with high abundance of juveniles in order to catch the larger individuals in the population. In the past, STECF noted that fleets complied with catch composition regulations simply by discarding components of the catch in order to balance the retained catch with the composition rules, negating any benefits in terms of controlling fishing mortality. The predominant reaction to both catch-composition rules and minimum landing sizes was, before the landing obligation, to comply through discarding, particularly if moving to other areas would result in a reduction in potential revenue (i.e. movement to an area with fewer marketable fish). With the landing obligation, this is less of an issue, although the use of catch composition rules is still embedded in the current Technical Measures Regulation so the incentive to discard has not necessarily diminished.

5.3 Three major benefits to convince stakeholders

Convincing stakeholders is obviously the first step required to move towards better size-selectivity patterns in European fisheries. The results presented here clearly demonstrate that improving selectivity appears unavoidable to reach the current objectives of the CFP and would lead to three major types of benefits:

1 Improving selectivity is a powerful way to reach sustainability (F_{MSY}) more easily. In particular for stocks that are currently strongly overfished, decreasing the fishing pressure to F_{MSY}, based on the current selectivity pattern, is a well-known difficult issue in fisheries management. It generally implies severe (and socially difficult) reductions in fleet capacities and may lead to large short-term losses in landings. In contrast, results presented here clearly illustrate how improving selectivity may increase the value of F_{MSY} (see the above yield isopleths analyses), making it a less difficult target to reach. Therefore, for managers and as well for fishers, fishing effort AND selectivity should be considered as management tools that deserve to be used to implement in practice the CFP objective of exploiting all stocks according to the MSY approach. In the medium term, this means that scientific advice should consider various options, calculating TACs according to various selectivity patterns related to size-based technical regulations. In practice, there is no doubt that for some stocks improving selectivity would be the only way to reach the F_{MSY} target (for example cod 27.7e-k).

2 Results obtained during the EWG confirm that protecting juveniles requires more selective fisheries. This protection is a requirement of the current TMR which stipulate in article 3.2a that "Technical measures shall […] provide protection for juveniles", specifying that this can be achieved based on minimum conservation reference sizes (article 13), mesh size specifications (article 15), closed or restricted areas (article 17), and real-time closures or moving-on provisions (article 19). Simulations conducted during the EWG clearly demonstrate that the current selectivity patterns lead to high juvenile catches and large mortality rates on juveniles for most of the studied stocks, while optimizing the selectivity according to the scenarios explored for ToRs 1 and 2 would result in a huge drop for both these parameters. In other words, to effectively implement the current regulation there is no alternative (except closing fisheries) than increasing drastically ages at first catch.

3 It is possible to maintain or even increase landings while having much less impact on the biomass of the targeted species, which is also a requirement of the CFP, and more specifically of the ecosystem approach to fisheries management. Indeed, the basic CFP regulation stipulates, in article 2 dedicated to its objectives, "The CFP shall implement the ecosystem-based approach to fisheries management so as to ensure that negative impacts of fishing activities on the marine ecosystem are minimized". Obviously, the targeted stocks are part of the ecosystems and reducing their biomass affects the structure and functioning of marine food webs. Implicitly, the objective of "minimizing the impact of fishing" means that we may continue fishing but with as little impact as possible. From that point of view, simulations conducted during the EWG clearly showed that the current selectivity patterns lead to large reductions in stock biomass and SSB, even in the case of the implementation of the F_{MSY} approach. Thus, residual SSB were estimated to be between 20% and 35 % of the unexploited SSB, depending on stocks, which probably have cascading effects on many other if not all biological compartments of the ecosystem. Conversely, improving selectivity would lead to a large reduction of the fishing impacts on SSB, which encompasses large fish which play a key role in the functioning of marine ecosystems. Here too, there is no doubt that seriously considering the objectives to reduce adverse ecosystem impacts of fishing implies to improve the size-based selectivity applied to targeted stocks. From this point of view, the EWG notes that an optimized selectivity leads to Y(F) curves which become very flat, with a wide range of fishing mortality producing very similar yields, but with very different impacts on the stocks biomass. In such a situation, reaching the new F_{MSY}, associated with the optimized selectivity, may involve large fishing efforts and thus lead to unprofitable fisheries, while inducing higher impacts than those required by the ecosystem approach. Conversely, a lower fishing effort, associated with lower production costs, would allow almost equivalent catches and reduced impacts.

In other words, from the perspective of an Ecosystem approach of fisheries management (AEFM) optimal selectivity should be associated with more conservative targets than F_{MSY}. An F_{low} value (the fishing mortality which provides 90% of the MSY) would for example be a much more suitable target for sustainability, as a proxy for F_{MEY} (the fishing mortality allowing the maximum economic yield, i.e. say an optimized profitability of fisheries), and as a powerful way to reduce the impact of fishing on targeted stocks, compared to the F_{MSY} objective.

The EWG also underlines that rebuilding healthy ecosystems, characterized by less impacted stocks, is becoming an objective of particular importance in the context of climate change. In particular, large predator fish, that are commonly caught by little-selective bottom gears, are playing a key role in the stability and resilience of marine food webs. From that point of view, going beyond the current F_{MSY} target, which is based on little-selective gears or fishing practices, and adopting more precautionary targets for fisheries management (such as e.g. F_{MEY} or proxy) while optimizing mesh sizes, appears to be the most effective pathway for adaptation of the fishing management rules to climate change.

5.4 Three main management tools to improve selectivity

Just increasing the current minimum conservation reference sizes (MCRS) would probably be insufficient to improve fisheries selectivity, with the high risk to just lead to larger discards or unwanted catches, without any decrease in small fish catches. In contrast (or in addition), three main management tools can be used to improve selectivity. The first two are the regulation of the mesh sizes of fishing gears and elimination of particular gears. For example, results of Outrequin et al. (2021 and in prep.) presented above clearly illustrate the point, demonstrating that the implementation of larger mesh sizes in the North Sea, at least for the main gears, would result in larger landings, larger remaining biomass and less discards (see section 4.4.2.). More generally, the effects of such a change in mesh size, on yields and SSBs, has also been presented above based on the "shift" simulations.

The major alternative or additional way to implement an improvement in selectivity would be based on spatial management, by closing definitively or temporarily areas where small fishes occur. This is what "crank" scenarios were assumed to simulate. However, it is important to stress that in spatio-temporal measures, important factors influencing the population-selectivity model are the spatial distribution of fishing mortality as well as the movement of fish between subpopulations (Sampson and Scott, 2011). Spatial measures applied to protect juveniles of species with high movement rate from protected to non-protected areas would in general be less effective.

5.5 A gradual change?

Of course, fishers cannot be asked to change their fishing gears progressively from year to year, changing mesh sizes step by step, as this would imply to buy new gears each time, thus leading to high and probably unsustainable costs. Therefore, for a given fisher, any gear selectivity improvement has to be envisaged by a large and long-term if not unique step. From this perspective, it is commonly admitted that all fishers have to change their selectivity pattern simultaneously. Otherwise, the spared fishes issued from large mesh-sized gears would be caught by the small-mesh size ones, thus leading to a situation where innovative virtuous fishermen would suffer losses, while conservative fisherman will benefit from additional catches.

However, two mechanisms can contradict such a vision, where changes do not have to be implemented gradually. The first is the use of spatial management where areas encompassing large quantities of small fish would be progressively protected, thus leading to a gradual change that would simultaneously and equally affect all fishers. The second mechanism would be based on a change of the quota distribution system, in order to incentivize virtuous fishermen who would agree to use larger mesh sizes. In this perspective, article 17 of the CFP regulation stipulates that quotas can be distributed by MS among fishers taking into account their environmental or social performances. We can thus imagine a situation where individual catch quotas would at least be maintained for virtuous fishers, while the short-term losses induced by overall larger mesh sizes would be supported by the others.

It can also be noted that in some fisheries, a gradual increase in 2-3 years should be feasible because this is the life time of the gear. In such a case, the regulations should define who must change first, possibly putting in place accompanying measures, and in particular a complement in the allocation of quotas as mentioned above.

5.6 Results-based management

Results-based management (RBM) describes a framework where outcomes can be demonstrated by industry and verified by managers on behalf of society, thus reversing the burden of proof to the industry (Fitzpatrick et al. 2011). In the context of RBM a fishery is managed by its outputs, giving more liberty to fishers to choose how, where and when to fish, instead of having detailed and prescriptive top-down rules. In practice, there would be still some general objectives and standards in place (e.g. avoid overfishing), but a regionalized approach would set the specific measures in a fishery/area to meet these objectives.

Previous work on selectivity and technical measures by the dedicated STECF EWGs (STECF 2012; 2013; 2015; 2017) has always acknowledged the need to facilitate RBM. This EWG is also contributing to that direction. The inclusion of different selectivity scenarios on a stock-by-stock and fleet-by-fleet basis provides a range of choices to the local industries. Moreover, the isopleths parameterized here for specific stocks featuring both F and selectivity as explanatory variables, map the effects of different management strategies on the stock size and yield, illustrating a greater range of possible exploitation regimes (i.e. combinations of F and selectivity) than the current system focusing solely on regulating F. These isopleths also assist the decisions by the industry on the exact way they want to move towards regimes with higher yields through changes in F and selectivity. Combining the information coming from multiple stock-specific isopleths of sympatric stocks could further inform the decisions on changing the exploitation regime, by illustrating the gains and losses to be expected for the mixed fishery as a whole.

The move towards results-based management, has, as yet, to a large extent failed to be implemented. The main reason is that the required comprehensive monitoring, control and enforcement and quantification of the catch (e.g. through "fully documented fisheries", FDF or electronic monitoring, EM) have not been widely established. Because the discard ban is not enforced, the costs of overfishing the quotas are still largely external to the fishing business. The new TMR is still largely very prescriptive micromanagement but also allows for bottom-up results-based management in the form of the explicit allowances for national management plans and pilots. Unfortunately, the momentum and drive towards FDF that was present in the first half of the past decade, through pilot projects (van Helmond et al. 2015; Needle et al. 2015; Mortensen et al. 2017), seem to have halted. Most joint recommendations and exemption requests from member states are not accompanied by proposals for extensive monitoring, control and enforcement and quantification of the catch (e.g. ToR 6.5 in STECF, 2021b). According to van Helmond et al. (2020), managers and industry are often reluctant to the uptake of EM. Improved understanding of the fisher's concerns, for example intrusion of privacy, liability and costs, and better exploration of the benefits may enhance implementation on a larger scale (van Helmond et al., 2020).

Much research has been carried out on bottom-up spatio-temporal approaches. Fishers could use digital platforms to be informed on the spatial distribution of wanted and unwanted catches. The information in these tools could consist of long-term, scientifically processed data such as in the tool from Calderwood et al. (2020). They could also be based on real-time information that is shared by the fishers (Bergsson & Plet-Hansen, 2016; Bergsson et al., 2017; Eliasen and Bichel, 2016; Needle et al., 2015) or sent from the fishers to scientists or managers and back. This information can be used for real-time closures and move-on rules. Examples of success include the science-industry collaborative program that runs since 2010 in the US Georges Bank scallop fishery (O'Keefe & DeCelles, 2013). Vessels share near real-time location information about flounder bycatch amounts. Scientists compile the information, identify bycatch hotspots, and provide daily advisories to vessels on the fishing grounds. Another example is the Shorebased Whiting Cooperative (SWC, formed in 2012) at the US west coast; information on location and catch is processed and distributed back to the members in near real-time, in the form of high-resolution maps, enabling them to make fine-scale decisions (Holland and Martin, 2019; McQuaw, 2019). Similarly, in the US northwest Atlantic mid-water trawl fishery targeting Atlantic herring and Atlantic mackerel, a voluntary bycatch avoidance program exists, as a partnership between industry, state government, and university, through near real-time information sharing of catches on a spatial grid (Bethoney et al., 2013, 2017). Closer to home, in the Celtic Sea, the UK runs an industry-science collaboration project with a real-time self-reporting scheme to avoid bycatch of spurdog, whose zero (or low) TAC potentially chokes the fishery (Hetherington, 2014); here maps with grid cells and traffic-light colours are produced and sent back to participating fishers.

ICES (2020b) reviewed the current availability of innovative gear. For an increased adoption of selective gear, it is necessary to involve the industry. Involvement creates a feeling of ownership which increases compliance levels (Kraak and Hart, 2019b). Fitzpatrick et al. (2019) found that some fishers are interested in more selective gears and spatial and temporal closures and that fishers found it important to "integrate fishers' local ecological knowledge into discard plans". The results-based setup of the 2008-2015 cod plan had promoted bottom-up initiatives aimed at attaining set targets with measures that were more suited to local conditions (Kraak et al., 2013). This experience showed that given the right stimulus, the industry can rapidly develop and deploy fishing tactics, including gear and behavioural changes, when there are specific objectives and strong drivers to do so. Reid et al. (2019) reviewed bottom-up results-based approaches, looking at trials where fishers tried to reduce their unwanted catches by whatever (legal) means they thought best. In some cases, they were able to reduce unwanted catches, in others they were less successful. O'Neill et al. (2019) reviewed ways to encourage and support fishers to design, develop and test selective gears that will avoid unwanted catches. They also examined the success of science-industry collaborations and emphasised the benefits of a flexible regulatory environment.

Just before the adoption of the new TMR, Eliasen et al. (2019) discussed the role that fishers can play by actively participating in the development of gears and contributing to the scientific documentation of their selectivity. They concluded that "a more flexible system of gear development and evaluation would be possible by a) involvement of fishers in proposing gear adjustments, self-sampling and documenting results according to scientific protocols […] and b) […] faster approval of gear use under a regionalised technical regulation regime with yearly adjustments of management plan". The latter echoes the STECF (2017) advice. Nevertheless, appropriate incentives for behavioural change, perhaps in the form of a carrot or a stick, should also be established. Else fishers will not adopt behaviour that is costly to them in the short term (Hardin, 1968) in terms of reduced catches and higher costs (buying new gear etc.). One way of doing this is the internalisation of the costs to the resource and the ecosystem into the individual fishing business; fishers will then try to avoid these costs. And this internalisation, in turn, requires comprehensive monitoring, control and enforcement and quantification of the catch.

5.7 Progress in evaluating the technical measures regulation and future steps

Already in 2008, the EC had initiated renewal of the TMR that was in force (EC, 1998) through a proposal for a new regulation (COM, 2008). This proposal called for clearer, simpler rules and a regional approach. However, the EC did not follow through with this proposal. In 2012, the EC established a STECF EWG to assist in the development of technical measures and to investigate possible new approaches to regulating technical measures in the context of a reformed CFP. This group met multiple times (STECF, 2012, 2013, 2015, 2017). Two lines of avenue that were recommended by these groups were (i) moving towards results-based management (STECF 2012, 2013), and (ii) linking exploitation pattern and yield through a harvest-control-rule type approach (STECF, 2013). Regarding the second point, the EWG (STECF, 2013) started exploring how technical measures as drivers for changes in selectivity pattern can be formally integrated into multiannual management plans, along with existing measures, such as TACs, whereby positive adjustments in exploitation pattern could result in increased fishing opportunities. This could potentially be achieved by directly linking exploitation pattern and yield through a harvest-control-rule type approach, e.g. in the catch advice, where the fishing mortality rate implying maximum sustainable yield (F_{MSY}) is recalculated to consider changes in exploitation pattern. This would have the benefit of giving a transparent association, all else being equal, between improving selectivity and improved fishing opportunities thereby creating an obvious incentive to improve selectivity. STECF has also called for the development of suitable selectivity metrics to track the effect of technical measures on exploited fish stocks (e.g., STECF, 2015). Candidate metrics were tested in a study (Vasilakopoulos et al., 2020) and the most suitable indicator appeared to be F_{rec}/F_{bar} (the ratio between the fishing mortality rate on the fish at the age of recruitment to the fishery and the mean fishing mortality rate over a range of adult ages). In the meanwhile, the new TMR was adopted and came into force in 2019 (EU, 2019). In 2020, to advise the EC in the context of their reporting obligation according to article 31 of the regulation, the EWG (STECF, 2020a) provided time series of the F_{rec}/F_{bar} indicator for each of the stocks in Annex XIV of the regulation and attempted to relate the changes in the indicator to changes in technical measures. STECF PLEN 20-03 (STECF, 2020d), however, concluded that, although temporal trends in selectivity were found, the extent to which such changes can be attributed to implementation of technical measures cannot be deduced. As explained in the introduction, DGMARE in consultation with STECF about how to proceed to prepare for the next evaluation, which is due in 2023, decided to request advice from the EWG in a stepwise approach. The step for the current EWG is stipulated in the current ToRs. The ToRs 1-3 quantify by stock and also by fleet how far removed the current fishing patterns are from optimal selectivity patterns. ToR 4 demonstrates in which directions fisheries can move, in terms of fishing mortality rate and selectivity pattern, towards optimal yield and SSB and also discusses what the major obstacles are in practice, especially in the context of mixed fisheries with multiple gears. In mixed fisheries, optimized selectivity can obviously not be reached simultaneously and tradeoffs need to be defined. Therefore, the EWG considers that the next steps should focus on these obstacles, perhaps in dedicated case studies with priority on the fisheries that are currently furthest removed from sustainability. Work will be needed including simulating and assessing various scenarios. The current EWG report gives guidance (i) that sustainability can best be achieved by a combination of reducing fishing mortality and improving selectivity, (ii) that three options are available to change selectivity, namely gear/mesh changes, elimination of particular gears and spatiotemporal measures; (iii) that the first two should best be implemented gradually (because of the cost of buying gear) but that the latter can be implemented more immediately; and (iv) which fisheries and fleets are farthest removed from sustainable exploitation (in terms of differences between current and optimised patterns). Focus should be on how to create the right incentives that lead to the uptake of more selective gear and spatio-temporal effort allocation shifts. As noted above, much research has been done of this; these insights need to be linked to the actual cases that require most urgent change. The demonstration through the isopleths in ToR 4 of how higher yields and SSB can be achieved through a combination of reduced fishing mortality rate and improved selectivity, can be seen as a first step towards the establishment of harvest control rules and catch advice in which the catch options do not only feature several options of fishing mortality rate but also several options of selectivity pattern and combinations thereof.

6 CONCLUSIONS

ToRs 1-3 quantify by stock and by fleet how far the current fishing patterns are removed from the optimal selectivity patterns. ToR "4a" demonstrates in which direction fisheries can move, in terms of fishing mortality rate and selectivity pattern, to reach optimal yield and SSB. ToR "4b" discusses the major obstacles in practice, especially in the context of mixed fisheries with multiple gears. For species-specific and fleet-specific results, the figures and tables in the results section of the report need to be consulted. Here, some general conclusions are phrased, sometimes mentioning specific examples. For species-specific and fleet-specific conclusions, the results section has to be consulted.

- In general, any improvement in selectivity will (in the long term) most strongly benefit stocks characterized by greater growth overfishing, which are typically large-bodied and late-maturing (e.g., hake stocks in the Mediterranean, cod) (ToRs 1-2).
- A selectivity improvement that achieves a higher protection of juveniles often produces a higher increase in long-term yield (ToRs 1-2).
- Exceptions are some haddock and whiting stocks in the Northeast Atlantic, where optimisations in yield were associated with a decrease in S_{50}, leading to increased proportion of juveniles in the catch (ToRs 1-2).
- Any long-term increase in yield linked to a change in selectivity will imply, in general, a short-term loss in yield, but this short-term loss is generally similar to the short-term loss that would result from reducing current F to the F levels in accordance with the scientific advice under current selectivity. Those short-term losses will be more than compensated by the long-term gains (ToRs 1-2).
- The "shift" scenario typically comes with higher yield gains compared to the "crank" scenario, with only few exceptions, such as red mullet in GSA07 and GSA09, cod in 6a, hake in SWW, and some whiting and haddock stocks (ToRs 1-2).
- The "crank" scenario generally gives better results in terms of reduction of juvenile catches, with only few exceptions, such as cod in 6a, whiting in 7a, and hake and megrim in SWW (ToRs 1-2).

- Active gears in general perform worse in terms of juvenile catches and SSB (ToR 3).
- Otter bottom trawl (OTB) selectivity has negative effects in terms of yield loss when compared to the status quo selectivity of all fleets combined (ToR 3).
- In the Northeast Atlantic, beam trawls often have high proportions of juveniles in the catch, with the exception of plaice in the English Channel.
- In the Western Mediterranean Sea, OTB selectivity is associated with very high proportions (>80%) of juvenile hakes in the catches (ToR 3).
- Jackknife analysis excluding OTB would be mostly beneficial to stocks of larger bodied gadoids in terms of both increase in yield and protection of juveniles (ToR 3).
- In general, the results from ToR 3 suggest that largest improvements in yield and juvenile protection can made through optimising the gear selectivity of bottom trawl gears, allocating less effort to fishing with those gears or shifting the effort to areas/season where the impacts on juveniles can be minimized.

- Stocks that are heavily overexploited (e.g., all cod and Mediterranean hake stocks) would gain substantially in both yield and SSB if selectivity is increased simultaneously with decreased fishing mortality (ToR "4a").
- Simultaneously increasing the selectivity and decreasing F would demand smaller changes compared to only manipulating only one parameter. This may increase the incentive (or rather decrease the disincentive) for change (ToR 4).
- Increased selectivity has often larger effects on yield than on SSB. In many cases, a decrease in F combined with increased selectivity is needed to see large changes in SSB (ToR "4a"). However, an increase in SSB has a multitude of positive effects, both for the fisheries through an increase in CPUE and average individual size of the fish caught, for the stock as it increases its resilience to climate change and for the ecosystem as larger biomass and size diversity in general increase ecosystem functionality, resilience and services.
- Small-bodied and fast-growing species, which are commonly assumed to have high natural mortality of younger age classes (e.g., whiting stocks), have less to benefit in terms of yield from the increase in selectivity at current fishing mortality. In some cases, increased selectivity would lead to decreasing yield, but it would always result in larger SSB (ToR "4a").

- Stocks that are currently underexploited ($F< F_{MSY}$) (e.g., North Sea whiting and Irish Sea plaice) would not produce higher yield with increasing selectivity or decreasing F (ToR "4a").
- When selectivity is optimised, the yield-F curve usually becomes very flat. In this case, increasing F until F_{MSY} would just add costs for no additional catch (ToR "4a"). Thus, in this case a more conservative target may lead to more profitable and less impacting fisheries.
- In mixed-fishery situations, technical measures are often compromises that tend to increase short-term costs for the industry, through short-term losses, re-designing of vessels and/or equipment costs (ToR "4b").
- The mixed-fisheries multi-gear examples demonstrate the complexity in improving selection patterns. Possible solutions differ case-by-case and include a combination of gear-based and spatial/temporal measures and reductions in fishing effort. Making these changes is politically, culturally and economically difficult (ToR "4b").
- For the improvement of selectivity in mixed fisheries a collaborative approach with stakeholders is essential (ToR "4b").
- Simulations showed that implementation of larger mesh sizes in the North Sea, at least for the main gears, would result in larger landings, larger remaining biomass and less unwanted catches (ToR "4b").

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9 LIST OF ANNEXES

Electronic annexes are published on the meeting's web site on:
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ANNEX: Conversion of selectivity-at-length from gear experiments to selectivity-at-age

To obtain an average size selection for baseline codends used in the Mediterranean bottom trawl fisheries either 40 mm square-mesh (SM40) or 50 mm diamond-mesh (DM50), for hake (HKE) and red mullet (MUT), a dataset from Lucchetti et al. (2021) was used for the analysis. The dataset was further updated with new field results from Sala et al. (2018). See Table 4 for details.

The resulting dataset consisted of 83 experiments for diamond-mesh and 20 for square-mesh for hake while for red mullet we analyzed 79 values for diamond-mesh and 19 for square-mesh. Linear models were found to relate the size selection parameters (L50 and SR) with mesh size for each species and mesh configuration. The models were used to predict L50 and SR values for baseline codends (SM40 and DM50) used in the Mediterranean bottom trawl fisheries. The estimated coefficients of each model are presented in Table 1.

Table 1. Size selection coefficients for hake (HKE) and red mullet (MUT) obtained using the data collected from literature. L50: length of fish that has a 50% probability of being retained or escaping after entering the codend; SR: difference in length between the fish that has a 75 % probability of retention and that with a 25% probability of retention.

Parameter	**Species**	**MC**	**a**	**b**
L50	HKE	DM	-0.135	0.273
	MUT	DM	2.33	0.199
	MUT	SM	3.04	0.247
SR	HKE	DM	-1.05	0.115
	MUT	DM	-4.86	0.176
	MUT	SM	-0.626	0.068

In case of hake, where almost all studies were performed with SM40 codends, instead of producing simple linear model and then predict size selection parameters, for square-mesh codend average values of L50 and SR were calculated (Figure 1). The models in Table 1 were also used to predict size selection parameters for 60 mm diamond-mesh, while values for a 50 mm square-mesh codend was taken from Sala et al. (2018). For red mullet, the selection parameters of all 4 codends (SM40, SM50, DM50, and DM60) were inferred using the models.

Since stock assessment does not use length but age of fish, the L50 and SR values obtained for DM50, SM40, DM60 and SM50 were converted into age for each GSA separately, using the von Bertalanffy growth parameters shown in Table 2.

Selectivity studies use *logit* curve to estimate size selection parameters L50 and SR:

$$r(l, L50, SR) = \frac{exp\left(\frac{\ln(9)}{SR} \times (l - L50)\right)}{1.0 + exp\left(\frac{\ln(9)}{SR} \times (l - L50)\right)} \quad (1)$$

where *l* is fish length, *L50* is the 50% retention length and *SR* is the difference between the 75% retention length and the 25% retention length.

Following the calculation of the age-at-length, we used equation (1) to estimate retention probability for each age class in each GSA separately (Table 3).

It is noteworthy to observe that providing information on age selection (e.g., retention at age class 0, 1, 2, 3, etc.) the curve misrepresents the real size selection. An example is shown for 50 mm diamond-mesh codend in Figure 3.

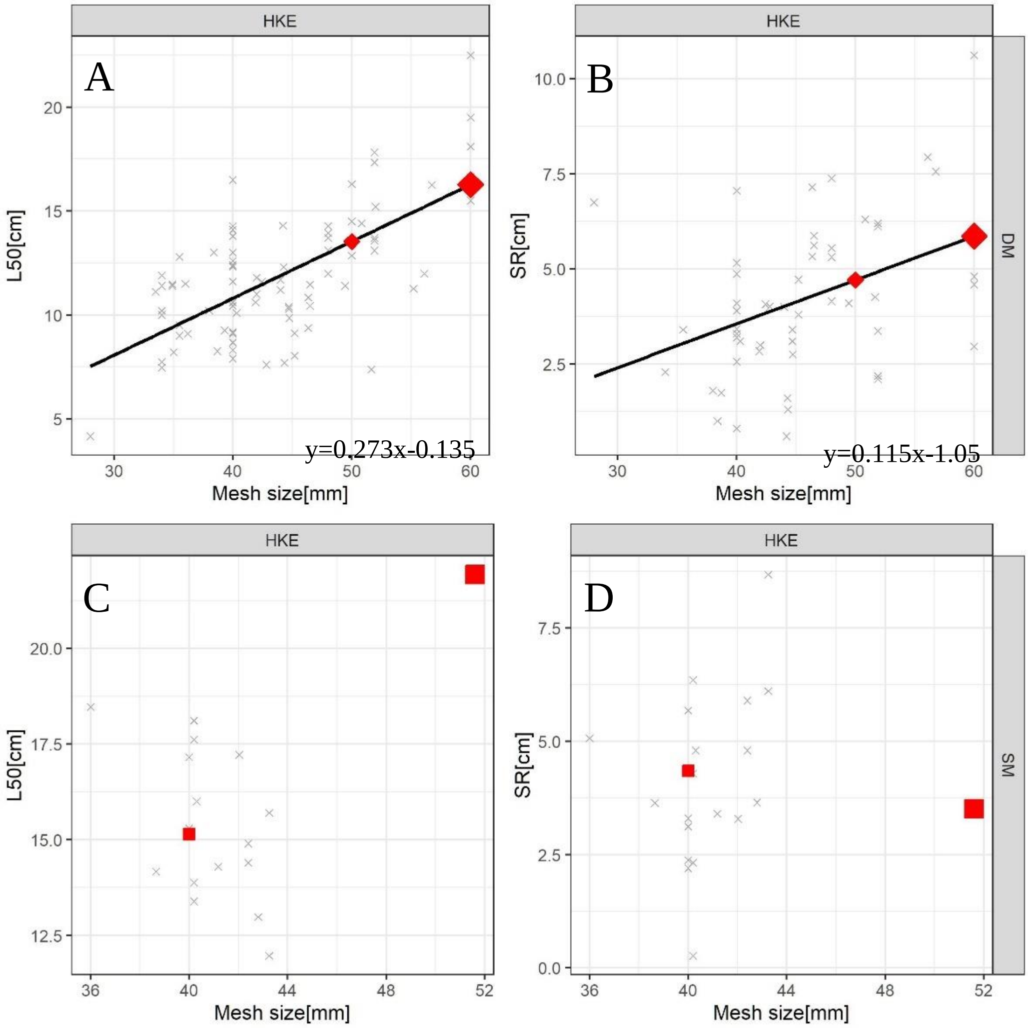

Figure 1. Linear models used to predict L50 (A) and SR (B) values for hake (HKE) in DM50 (small red diamond) and DM60 (large red diamond) codends. Small red squares in (C) and (D) represent the mean L50 and SR, respectively for SM40 codend, while large red squares represent L50 and SR data for SM50 codend obtained from Sala et al. (2018). Small grey crosses represent L50 or SR values obtained in the Med experiments and collated in the paper Lucchetti et al. (2021) and Sala et al. (2018).

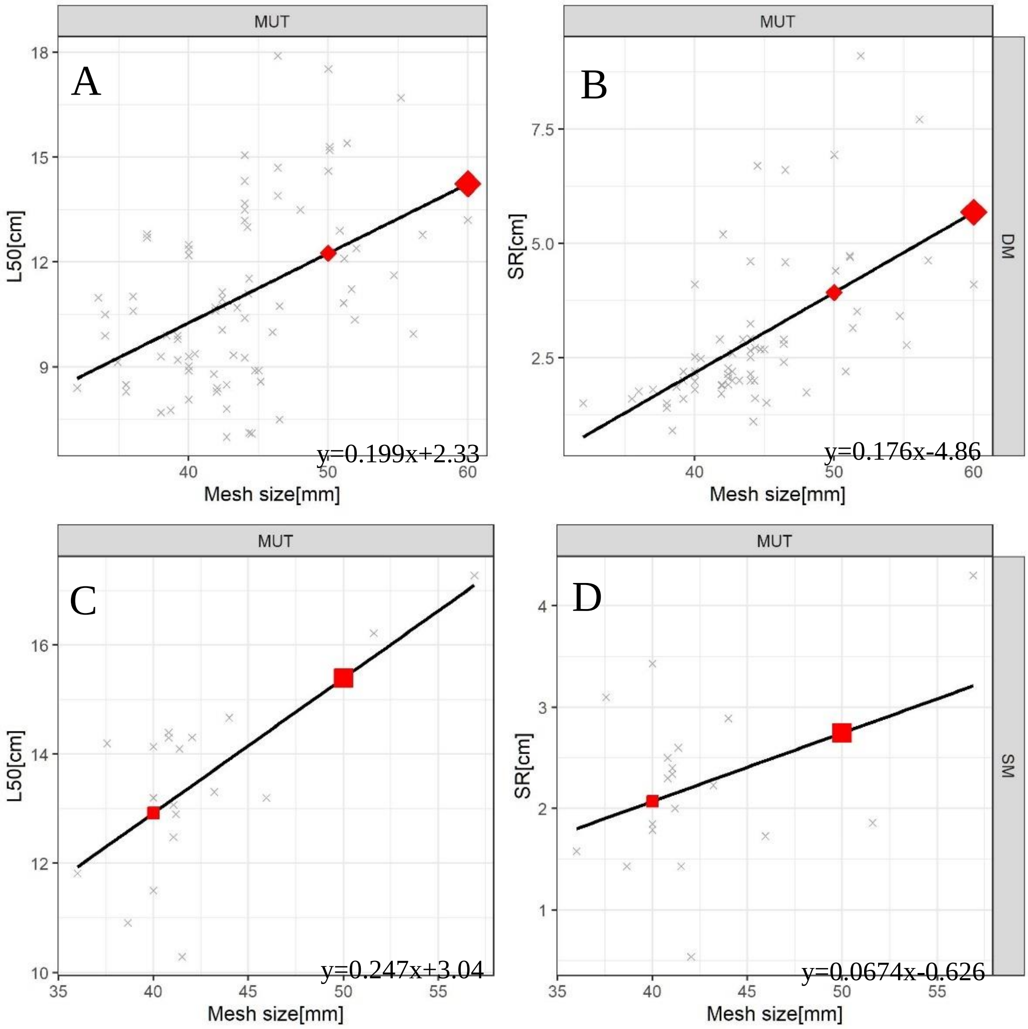

Figure 2. Linear models used to predict L50 (A) and SR (B) values for red mullet (MUT) in DM50 (small red diamond) and DM60 (large red diamond) codends. Small red squares in (C) and (D) represent the modelled L50 and SR, respectively for SM40 codend, while large red squares represent L50 and SR data for SM50 codend. Small grey crosses represent L50 or SR values obtained in the Med experiments and collated in the paper Lucchetti et al. (2021) and Sala et al. (2018).

Table 2. VBGF coefficients (Linf, k,t0) used in the analysis. HKE: Hake, MUT: Red mullet.

Species	GSA	Sex	L_{inf} (cm)	k	t0
HKE	1	Combined	110	0.178	-0.005
MUT	1	Combined	34.5	0.34	0.143
HKE	5	Combined	110	0.178	-0.005
MUR	5	Combined	33.4	0.43	-0.1
HKE	6	Combined	110	0.178	-0.005

Species	GSA	Sex	L_{inf} (cm)	k	t0
MUT	6	Combined	34.5	0.34	0.14
HKE	7	Combined	110	0.178	-0.005
MUT	7	Combined	34.5	0.34	0.14
HKE	8	Females	95	0.16	-0.06
HKE	9	Females	95	0.16	-0.06
MUT	9	Females	26.56	0.545	0.17
HKE	10	Females	95	0.16	-0.06
MUT	10	Females	30	0.243	-0.62
HKE	11	Females	95	0.16	-0.06
MUT	17	Females	29.185	0.247	-0.768
HKE	17	Combined	104	0.12	-0.01
HKE	18	Combined	104	0.12	-0.01
MUT	18	Females	29.185	0.247	-0.768
HKE	19	Females	111	0.1	-0.6
HKE	20	Combined	104	0.12	-0.01
MUT	22	Combined	32.6	0.17	-1.78

Table 3. HKE and MUL retention for each age class. MC: mesh configuration (DM, diamond-; SM, square-mesh); MS: mesh size in the codend; L50: length of fish that has a 50% probability of being retained or escaping after entering the codend; SR: difference in length between the fish that has a 75 % probability of retention and that with a 25% probability of retention; A50: age of fish that has a 50% probability of being retained or escaping after entering the codend; ASR: difference in age between the fish that has a 75 % probability of retention and that with a 25% probability of retention; AX_ret: retention at age X. HKE: Hake, MUT: Red mullet.

Species	MC	MS	GSA	L50	SR	A50	ASR	A0_ret	A1_ret	A2_ret	A3_ret	A4_ret	A5_ret	A6_ret
HKE	DM	50	1	13.53	4.71	0.73	0.27	0.00	0.89	1.00	1.00	1.00	1.00	1.00
HKE	DM	60	1	16.27	5.86	0.89	0.35	0.00	0.66	1.00	1.00	1.00	1.00	1.00

Species	MC	MS	GSA	L50	SR	A50	ASR	A0_ret	A1_ret	A2_ret	A3_ret	A4_ret	A5_ret	A6_ret
HKE	SM	40	1	15.15	4.35	0.83	0.26	0.00	0.81	1.00	1.00	1.00	1.00	1.00
HKE	SM	51.6	1	21.93	3.51	1.24	0.22	0.00	0.08	1.00	1.00	1.00	1.00	1.00
HKE	DM	50	5	13.53	4.71	0.73	0.27	0.00	0.89	1.00	1.00	1.00	1.00	1.00
HKE	DM	60	5	16.27	5.86	0.89	0.35	0.00	0.66	1.00	1.00	1.00	1.00	1.00
HKE	SM	40	5	15.15	4.35	0.83	0.26	0.00	0.81	1.00	1.00	1.00	1.00	1.00
HKE	SM	51.6	5	21.93	3.51	1.24	0.22	0.00	0.08	1.00	1.00	1.00	1.00	1.00
HKE	DM	50	6	13.53	4.71	0.73	0.27	0.00	0.89	1.00	1.00	1.00	1.00	1.00
HKE	DM	60	6	16.27	5.86	0.89	0.35	0.00	0.66	1.00	1.00	1.00	1.00	1.00
HKE	SM	40	6	15.15	4.35	0.83	0.26	0.00	0.81	1.00	1.00	1.00	1.00	1.00
HKE	SM	51.6	6	21.93	3.51	1.24	0.22	0.00	0.08	1.00	1.00	1.00	1.00	1.00
HKE	DM	50	7	13.53	4.71	0.73	0.27	0.00	0.89	1.00	1.00	1.00	1.00	1.00
HKE	DM	60	7	16.27	5.86	0.89	0.35	0.00	0.66	1.00	1.00	1.00	1.00	1.00
HKE	SM	40	7	15.15	4.35	0.83	0.26	0.00	0.81	1.00	1.00	1.00	1.00	1.00
HKE	SM	51.6	7	21.93	3.51	1.24	0.22	0.00	0.08	1.00	1.00	1.00	1.00	1.00
HKE	DM	50	8	13.53	4.71	0.90	0.36	0.00	0.65	1.00	1.00	1.00	1.00	1.00
HKE	DM	60	8	16.27	5.86	1.11	0.47	0.00	0.37	0.98	1.00	1.00	1.00	1.00
HKE	SM	40	8	15.15	4.35	1.03	0.34	0.00	0.46	1.00	1.00	1.00	1.00	1.00

Species	MC	MS	GSA	L50	SR	A50	ASR	A0_ret	A1_ret	A2_ret	A3_ret	A4_ret	A5_ret	A6_ret
HKE	SM	51.6	8	21.93	3.51	1.58	0.30	0.00	0.01	0.95	1.00	1.00	1.00	1.00
HKE	DM	50	9	13.53	4.71	0.90	0.36	0.00	0.65	1.00	1.00	1.00	1.00	1.00
HKE	DM	60	9	16.27	5.86	1.11	0.47	0.00	0.37	0.98	1.00	1.00	1.00	1.00
HKE	SM	40	9	15.15	4.35	1.03	0.34	0.00	0.46	1.00	1.00	1.00	1.00	1.00
HKE	SM	51.6	9	21.93	3.51	1.58	0.30	0.00	0.01	0.95	1.00	1.00	1.00	1.00
HKE	DM	50	10	13.53	4.71	0.90	0.36	0.00	0.65	1.00	1.00	1.00	1.00	1.00
HKE	DM	60	10	16.27	5.86	1.11	0.47	0.00	0.37	0.98	1.00	1.00	1.00	1.00
HKE	SM	40	10	15.15	4.35	1.03	0.34	0.00	0.46	1.00	1.00	1.00	1.00	1.00
HKE	SM	51.6	10	21.93	3.51	1.58	0.30	0.00	0.01	0.95	1.00	1.00	1.00	1.00
HKE	DM	50	11	13.53	4.71	0.90	0.36	0.00	0.65	1.00	1.00	1.00	1.00	1.00
HKE	DM	60	11	16.27	5.86	1.11	0.47	0.00	0.37	0.98	1.00	1.00	1.00	1.00
HKE	SM	40	11	15.15	4.35	1.03	0.34	0.00	0.46	1.00	1.00	1.00	1.00	1.00
HKE	SM	51.6	11	21.93	3.51	1.58	0.30	0.00	0.01	0.95	1.00	1.00	1.00	1.00
HKE	DM	50	17	13.53	4.71	1.15	0.43	0.00	0.32	0.98	1.00	1.00	1.00	1.00
HKE	DM	60	17	16.27	5.86	1.41	0.56	0.00	0.16	0.91	1.00	1.00	1.00	1.00
HKE	SM	40	17	15.15	4.35	1.30	0.41	0.00	0.16	0.97	1.00	1.00	1.00	1.00
HKE	SM	51.6	17	21.93	3.51	1.96	0.36	0.00	0.00	0.56	1.00	1.00	1.00	1.00

Species	MC	MS	GSA	L50	SR	A50	ASR	A0_ret	A1_ret	A2_ret	A3_ret	A4_ret	A5_ret	A6_ret
HKE	DM	50	18	13.53	4.71	1.15	0.43	0.00	0.32	0.98	1.00	1.00	1.00	1.00
HKE	DM	60	18	16.27	5.86	1.41	0.56	0.00	0.16	0.91	1.00	1.00	1.00	1.00
HKE	SM	40	18	15.15	4.35	1.30	0.41	0.00	0.16	0.97	1.00	1.00	1.00	1.00
HKE	SM	51.6	18	21.93	3.51	1.96	0.36	0.00	0.00	0.56	1.00	1.00	1.00	1.00
HKE	DM	50	19	13.53	4.71	0.70	0.48	0.04	0.79	1.00	1.00	1.00	1.00	1.00
HKE	DM	60	19	16.27	5.86	0.98	0.62	0.02	0.51	0.97	1.00	1.00	1.00	1.00
HKE	SM	40	19	15.15	4.35	0.87	0.45	0.01	0.65	0.99	1.00	1.00	1.00	1.00
HKE	SM	51.6	19	21.93	3.51	1.60	0.39	0.00	0.03	0.90	1.00	1.00	1.00	1.00
HKE	DM	50	20	13.53	4.71	1.15	0.43	0.00	0.32	0.98	1.00	1.00	1.00	1.00
HKE	DM	60	20	16.27	5.86	1.41	0.56	0.00	0.16	0.91	1.00	1.00	1.00	1.00
HKE	SM	40	20	15.15	4.35	1.30	0.41	0.00	0.16	0.97	1.00	1.00	1.00	1.00
HKE	SM	51.6	20	21.93	3.51	1.96	0.36	0.00	0.00	0.56	1.00	1.00	1.00	1.00
MUT	DM	50	1	12.25	3.93	1.43	0.52	0.00	0.12	0.90	0.99	1.00	1.00	1.00
MUT	DM	60	1	14.24	5.68	1.71	0.83	0.00	0.11	0.68	0.94	0.99	0.99	1.00
MUT	SM	40	1	12.92	2.07	1.52	0.28	0.00	0.01	0.97	1.00	1.00	1.00	1.00
MUT	SM	50	1	15.39	2.75	1.88	0.42	0.00	0.00	0.65	0.99	1.00	1.00	1.00
MUT	DM	50	6	12.25	3.93	1.43	0.52	0.00	0.12	0.90	0.99	1.00	1.00	1.00

Species	MC	MS	GSA	L50	SR	A50	ASR	A0_ret	A1_ret	A2_ret	A3_ret	A4_ret	A5_ret	A6_ret
MUT	DM	60	6	14.24	5.68	1.71	0.83	0.00	0.11	0.68	0.94	0.99	0.99	1.00
MUT	SM	40	6	12.92	2.07	1.52	0.28	0.00	0.01	0.97	1.00	1.00	1.00	1.00
MUT	SM	50	6	15.39	2.75	1.88	0.42	0.00	0.00	0.65	0.99	1.00	1.00	1.00
MUT	DM	50	7	12.25	3.93	1.43	0.52	0.00	0.12	0.90	0.99	1.00	1.00	1.00
MUT	DM	60	7	14.24	5.68	1.71	0.83	0.00	0.11	0.68	0.94	0.99	0.99	1.00
MUT	SM	40	7	12.92	2.07	1.52	0.28	0.00	0.01	0.97	1.00	1.00	1.00	1.00
MUT	SM	50	7	15.39	2.75	1.88	0.42	0.00	0.00	0.65	0.99	1.00	1.00	1.00
MUT	DM	50	9	12.25	3.93	1.31	0.51	0.00	0.19	0.93	0.99	1.00	1.00	1.00
MUT	DM	60	9	14.24	5.68	1.58	0.86	0.00	0.15	0.73	0.93	0.97	0.98	0.99
MUT	SM	40	9	12.92	2.07	1.39	0.28	0.00	0.03	0.98	1.00	1.00	1.00	1.00
MUT	SM	50	9	15.39	2.75	1.76	0.45	0.00	0.01	0.75	0.99	1.00	1.00	1.00
MUT	DM	50	10	12.25	3.93	1.54	0.91	0.01	0.20	0.74	0.95	0.99	1.00	1.00
MUT	DM	60	10	14.24	5.68	2.03	1.50	0.02	0.15	0.49	0.78	0.91	0.96	0.98
MUT	SM	40	10	12.92	2.07	1.70	0.50	0.00	0.03	0.78	0.99	1.00	1.00	1.00
MUT	SM	50	10	15.39	2.75	2.34	0.78	0.00	0.01	0.27	0.85	0.98	1.00	1.00
MUT	DM	50	17	12.25	3.93	1.44	0.94	0.02	0.25	0.77	0.95	0.99	1.00	1.00
MUT	DM	60	17	14.24	5.68	1.94	1.56	0.03	0.18	0.52	0.79	0.91	0.96	0.97

Species	MC	MS	GSA	L50	SR	A50	ASR	A0_ret	A1_ret	A2_ret	A3_ret	A4_ret	A5_ret	A6_ret
MUT	SM	40	17	12.92	2.07	1.60	0.52	0.00	0.06	0.84	0.99	1.00	1.00	1.00
MUT	SM	50	17	15.39	2.75	2.27	0.81	0.00	0.02	0.32	0.86	0.98	1.00	1.00
MUT	DM	50	18	12.25	3.93	1.44	0.94	0.02	0.25	0.77	0.95	0.99	1.00	1.00
MUT	DM	60	18	14.24	5.68	1.94	1.56	0.03	0.18	0.52	0.79	0.91	0.96	0.97
MUT	SM	40	18	12.92	2.07	1.60	0.52	0.00	0.06	0.84	0.99	1.00	1.00	1.00
MUT	SM	50	18	15.39	2.75	2.27	0.81	0.00	0.02	0.32	0.86	0.98	1.00	1.00
MUT	DM	50	22	12.25	3.93	0.99	1.14	0.11	0.50	0.86	0.96	0.99	1.00	1.00
MUT	DM	60	22	14.24	5.68	1.60	1.84	0.10	0.32	0.62	0.82	0.92	0.96	0.98
MUT	SM	40	22	12.92	2.07	1.19	0.62	0.01	0.34	0.94	1.00	1.00	1.00	1.00
MUT	SM	50	22	15.39	2.75	1.98	0.94	0.00	0.08	0.51	0.90	0.98	1.00	1.00

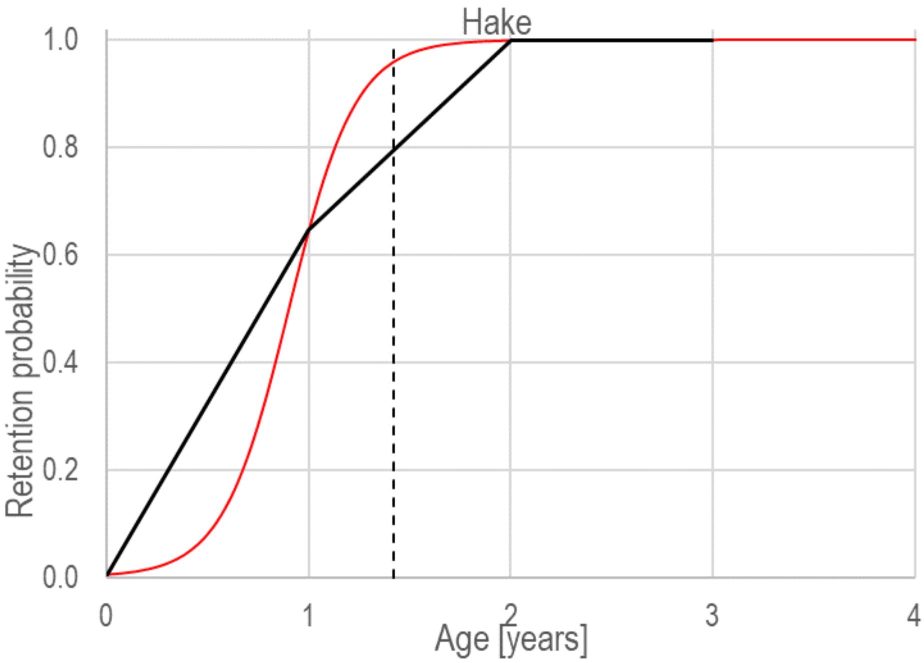

Figure 3. Comparison between size selection (red curve) and age selection (black curve).

Table 4. Mediterranean studies on trawl selectivity. Selectivity parameters collated in Lucchetti et al. (2021) and Sala et al. (2018). For diamond- (DM) and square-mesh (SM) codends; NMS: nominal mesh size in the codend; MMS: measured mesh size in the codend; L50: length of fish that has a 50% probability of being retained or escaping after entering the codend; SR: difference in length between the fish that has a 75 % probability of retention and that with a 25% probability of retention.

References	Species	MC	NMS	MMS	L50	SR
Abella & Serena, 1998	HKE	DM	38	NA	10.2	1.8
Aldebert e Carriers, 1990	HKE	DM	NA	34	11.4	NA
Aldebert e Carriers, 1990	HKE	DM	NA	40	13	NA
Aldebert e Carriers, 1990	HKE	DM	NA	50	16.3	NA
Aldebert e Carriers, 1990	HKE	DM	NA	60	19.5	NA
Aldebert e Carriers, 1990	HKE	DM	NA	40	12.4	NA
Aydin & Tosunoglu, 2010	HKE	DM	44	44.7	10.4	3.1
Aydin & Tosunoglu, 2010	HKE	SM	40	42.4	14.4	4.8
Aydin & Tosunoglu, 2010	HKE	HEX	40	42.6	11	4.3
Aydin & Tosunoglu, 2010	HKE	DM	44	44.7	10.3	3.4
Aydin & Tosunoglu, 2010	HKE	SM	40	42.4	14.9	5.9
Aydin & Tosunoglu, 2010	HKE	HEX	40	42.6	10.6	4.6
Bahamon et al.,2006	HKE	DM	42	40.3	10.1	3.1
Bahamon et al.,2006	HKE	SM	42	40.3	16	4.8
Baino, 1998	HKE	DM	40	NA	8.31	3.2
Baro et al., 2007	HKE	DM	40	NA	8.67	3.9
Baro et al., 2007	HKE	SM	40	NA	15.21	3.12
Baro et al., 2007	HKE	SM	40	NA	17.16	2.38
Belcari et al.,2007	HKE	DM	40	NA	9.17	2.56
Belcari et al.,2007	HKE	DM	60	NA	18.1	10.62
Brčić et al., 2018a	HKE	DM	50	51.9	13.59	2.18
Brčić et al., 2018a	HKE	DM	50	51.9	13.1	2.1

References	Species	MC	NMS	MMS	L50	SR
Brčić et al., 2018a	HKE	DM	50	51.9	17.82	6.2
Brčić et al., 2018a	HKE	DM	50	51.9	17.33	6.12
Brčić et al., 2018a	HKE	SM	40	40.2	13.88	0.27
Brčić et al., 2018a	HKE	SM	40	40.2	13.39	2.32
Brčić et al., 2018a	HKE	SM	40	40.2	18.11	4.29
Brčić et al., 2018a	HKE	SM	40	40.2	17.62	6.35
Brčić et al., 2018b	HKE	DM	50	51.9	13.71	3.37
Burgaud & Dremiere, 1992	HKE	DM	44	NA	11.7	4
Dereli & Aydin, 2016	HKE	DM	44	44.27	12.3	1.6
Dereli & Aydin, 2016	HKE	DM	50	50.82	14.4	6.3
Dereli & Aydin, 2016	HKE	SM	40	41.18	14.3	3.4
Dremiere, 1979	HKE	DM	NA	35.5	12.8	NA
Dremiere, 1979	HKE	DM	NA	34	10.2	NA
Dremiere, 1979	HKE	DM	NA	34.9	11.4	NA
Ferretti & Froglia, 1975	HKE	DM	NA	35.5	9	3.4
Ferretti & Froglia, 1975	HKE	DM	NA	42	11	3
Genç et al., 2018	HKE	T90	44	45.4	12.8	4.6
Genç et al., 2018	HKE	T90	44	45.4	13.2	4
Genç et al., 2018	HKE	T90	40	40.4	12.1	1.7
Gil De Sola Simarro, 1991	HKE	DM	NA	39.3	9.26	NA
Gil De Sola Simarro, 1991	HKE	DM	NA	36.2	9.1	NA
Gil De Sola Simarro, 1994	HKE	DM	NA	35	8.21	NA
Gil De Sola Simarro, 1994	HKE	DM	NA	40	9.11	NA
Gil De Sola Simarro, 1994	HKE	DM	NA	50	12.85	NA
Guijarro & Massuti, 2006	HKE	DM	40	NA	11.6	0.8
Guijarro & Massuti, 2006	HKE	SM	40	NA	15.3	2.2

References	Species	MC	NMS	MMS	L50	SR
Larraneta et al.,1969	HKE	DM	NA	35.5	9.5	NA
Larraneta et al.,1969	HKE	DM	34	NA	11.9	NA
Larraneta et al.,1969	HKE	DM	36	NA	11.5	NA
Larraneta et al.,1969	HKE	DM	40	NA	14.1	NA
Larraneta et al.,1969	HKE	DM	42	NA	11.8	NA
Larraneta et al.,1969	HKE	DM	44	NA	11.2	NA
Larraneta et al.,1969	HKE	DM	48	NA	13.1	NA
Larraneta et al.,1969	HKE	DM	50	NA	14.5	NA
Larraneta et al.,1969	HKE	DM	52	NA	15.2	NA
Lembo et al., 2002	HKE	DM	40	NA	7.9	4.1
Lembo et al., 2002	HKE	DM	60	NA	15.5	4.8
Levi et al.,1971	HKE	DM	NA	35.5	9.5	NA
Lucchetti, 2008	HKE	DM	40	42.8	7.6	4.01
Lucchetti, 2008	HKE	SM	40	42.8	12.98	3.65
M'Rabet, 1994	HKE	DM	40	33.5	11.11	NA
M'Rabet, 1994	HKE	DM	40	34.9	11.48	NA
M'Rabet, 1998	HKE	DM	40	38.4	13	1
M'Rabet, 1998	HKE	DM	48	44.2	14.3	0.6
Ordines et al., 2006	HKE	DM	40	NA	10.6	3.3
Ozbilgin et al., 2005	HKE	DM	40	NA	14.28	3.42
Ordines et al., 2006	HKE	SM	40	NA	15.2	3.3
Petetta et al., 2020	HKE	DM	54	55.2	11.26	21.33
Petetta et al., 2020	HKE	T90	54	55.3	21.26	7.02
Petrakis & Stergiou, 1997	HKE	DM	28	NA	4.16	6.75
Petrakis & Stergiou, 1997	HKE	DM	40	NA	13.79	7.06
Petrakis & Stergiou, 1997	HKE	SM	40	NA	15.1	5.68

References	**Species**	**MC**	**NMS**	**MMS**	**L50**	**SR**
Petrakis et al., 2004	HKE	DM	40	NA	12.6	5.16
Petrakis et al., 2004	HKE	DM	40	NA	12.32	4.87
Petrakis et al., 2004	HKE	DM	40	NA	10.44	4.87
Sala & Luchetti, 2010	HKE	DM	40	45.2	8.03	3.8
Sala & Luchetti, 2010	HKE	DM	40	45.2	9.12	4.72
Sala & Luchetti, 2010	HKE	SM	40	43.25	11.97	6.11
Sala & Luchetti, 2010	HKE	SM	40	43.25	15.7	8.68
Sala & Luchetti, 2010	HKE	DM	40	46.35	10.84	7.15
Sala & Luchetti, 2010	HKE	DM	40	46.35	9.37	5.33
Sala & Luchetti, 2011	HKE	DM	48	46.5	11.45	5.62
Sala & Luchetti, 2011	HKE	DM	48	46.5	10.43	5.87
Sala & Luchetti, 2011	HKE	DM	56	56.75	16.25	7.56
Sala & Luchetti, 2011	HKE	DM	56	56.1	11.99	7.94
Sala et al.,2007	HKE	DM	44	44.73	9.85	2.75
Sala et al.,2007	HKE	DM	44	44.33	7.7	1.3
Sala et al.,2008	HKE	DM	40	38.7	8.26	1.74
Sala et al.,2008	HKE	SM	40	38.65	14.17	3.64
Sarda et al.,2006	HKE	SM	36	NA	18.47	5.07
Sbrana & Reale, 1994	HKE	DM	34	NA	7.74	2.29
Sbrana et al., 1998	HKE	DM	NA	34	7.47	2.29
Soldo, 2004	HKE	DM	48	NA	14.28	4.15
Soldo, 2004	HKE	DM	48	NA	13.94	5.31
Soldo, 2004	HKE	DM	48	NA	13.7	5.55
Soldo, 2004	HKE	DM	48	NA	11.99	7.38
Soldo, 2004	HKE	DM	60	NA	16.64	2.96
Soldo, 2004	HKE	DM	60	NA	16.62	4.59

References	Species	MC	NMS	MMS	L50	SR
Tokaç et al.,2010	HKE	DM	40	42.42	11.59	4.07
Tosunoglou et al., 2008	HKE	DM	50	49.44	11.4	4.1
Tosunoglu et al.,2003	HKE	DM	40	41.9	10.6	2.84
Vives et al.,1966	HKE	DM	34	NA	10	NA
Vives et al.,1966	HKE	DM	40	NA	16.5	NA
Vives et al.,1966	HKE	DM	60	NA	22.5	NA
Ates et al., 2010	MUT	DM	44	43.46	10.70	2.90
Ates et al., 2010	MUT	SM	40	37.55	14.20	3.10
Aydin et al., 2011	MUT	SM	40	40.80	14.40	2.50
Aydin et al., 2011	MUT	SM	40	40.80	14.30	2.30
Aydin et al., 2011	MUT	DM	50	50.10	15.20	4.40
Aydin et al., 2011	MUT	DM	50	50.10	15.30	4.40
Baino, 1998	MUT	DM	40	NA	9.02	1.98
Baro et al., 2007	MUT	DM	40	NA	8.07	2.21
Baro et al., 2007	MUT	SM	40	NA	11.50	1.79
Brcic et al., 2018b	MUT	DM	50	51.90	10.35	9.11
Burgaud & Dremiere, 1992	MUT	DM	32	NA	8.40	1.50
Burgaud & Dremiere, 1992	MUT	DM	40	NA	9.30	4.10
Burgaud & Dremiere, 1992	MUT	DM	44	NA	10.40	2.00
Cicek, 2015	MUT	DM	44	NA	9.27	4.61
Demirci & Akyurt, 2017	MUT	DM	44	NA	13.19	2.51
Demirci & Akyurt, 2017	MUT	DM	50	NA	17.52	6.94
Demirci & Akyurt, 2017	MUT	SM	40	NA	14.14	3.43
Dereli & Aydin, 2016	MUT	DM	44	44.27	11.10	2.00
Dereli & Aydin, 2016	MUT	DM	50	50.82	12.90	2.20
Dereli & Aydin, 2016	MUT	SM	40	41.18	12.90	2.00

References	Species	MC	NMS	MMS	L50	SR
Dereli & Aydin, 2016	MUT	T90	40	42.42	13.60	3.10
Ferretti & Froglia, 1975	MUT	DM	NA	38.00	7.70	1.40
Ferretti & Froglia, 1975	MUT	DM	NA	35.50	8.50	1.60
Ferretti & Froglia, 1975	MUT	DM	NA	42.00	8.30	1.90
Ferretti & Froglia, 1975	MUT	DM	NA	42.70	7.80	2.60
Ferretti & Froglia, 1975	MUT	DM	NA	42.70	8.50	2.00
Ferretti & Froglia, 1975	MUT	DM	NA	42.70	7.00	2.20
Ferretti & Froglia, 1975	MUT	DM	NA	41.80	8.80	2.90
Larraneta et al.,1969	MUT	DM	34	NA	9.90	NA
Larraneta et al.,1969	MUT	DM	36	NA	10.60	NA
Larraneta et al.,1969	MUT	DM	40	NA	12.50	NA
Larraneta et al.,1969	MUT	DM	34	NA	10.50	NA
Larraneta et al.,1969	MUT	DM	46	NA	10.00	NA
Larraneta et al.,1969	MUT	DM	50	NA	14.60	NA
Larraneta et al.,1969	MUT	DM	52	NA	12.40	NA
Lembo et al., 2002	MUT	DM	40	NA	8.90	1.80
Lembo et al., 2002	MUT	DM	60	NA	13.20	4.10
Levi et al.,1971	MUT	DM	NA	35.50	8.30	NA
Livadas, 1988	MUT	DM	34	39.19	9.20	1.60
Livadas, 1988	MUT	DM	34	39.19	9.90	2.20
Livadas, 1988	MUT	DM	34	39.19	9.80	2.00
Livadas, 1988	MUT	DM	40	46.38	14.70	2.90
Livadas, 1988	MUT	DM	40	46.38	13.90	2.80
Livadas, 1988	MUT	DM	40	46.38	17.90	2.40
Lök et al.,1997	MUT	DM	44	NA	13.68	2.92
Lök et al.,1997	MUT	DM	44	NA	15.06	3.24

References	Species	MC	NMS	MMS	L50	SR
Lök et al.,1997	MUT	DM	44	NA	14.32	2.14
M'Rabet, 1994	MUT	DM	40	33.50	10.98	NA
M'Rabet, 1994	MUT	DM	40	34.90	9.14	NA
M'Rabet, 1998	MUT	DM	40	38.40	9.90	0.90
M'Rabet, 1998	MUT	DM	48	44.20	13.00	1.10
Mytilineou et al., 2021	MUT	DM	40	43.20	9.34	2.00
Mytilineou et al., 2021	MUT	SM	40	43.20	13.31	2.23
Mytilineou et al., 2021	MUT	DM	50	51.10	10.83	4.73
Özbilgin et al.,2011	MUT	DM	40	42.40	10.06	2.05
Özbilgin et al.,2011	MUT	DM	40	42.40	11.14	2.14
Özbilgin et al.,2011	MUT	DM	40	42.40	10.76	2.27
Özbilgin et al.,2011	MUT	DM	40	42.40	10.95	1.91
Ozbilgin et al., 2015	MUT	DM	44	44.50	7.10	6.70
Ozbilgin et al., 2015	MUT	SM	40	41.36	14.10	2.60
Ozbilgin et al., 2015	MUT	DM	44	42.03	8.40	5.20
Ozbilgin et al., 2015	MUT	DM	50	51.14	12.10	4.70
Petetta et al., 2020	MUT	DM	54	55.20	16.70	2.78
Petetta et al., 2020	MUT	T90	54	55.30	23.10	11.48
Petrakis et al., 2004	MUT	DM	40	NA	12.37	2.52
Sala & Luchetti, 2011	MUT	DM	48	46.50	10.74	4.59
Sala & Luchetti, 2011	MUT	DM	48	46.50	7.50	6.61
Sala & Luchetti, 2011	MUT	DM	56	56.75	12.78	4.63
Sala & Luchetti, 2011	MUT	DM	56	56.10	9.95	7.72
Sala et al., 2007	MUT	DM	44	44.73	8.90	2.68
Sala et al. ,2007	MUT	DM	44	44.33	7.12	1.61
Sala et al., 2008	MUT	DM	40	38.70	7.76	1.86

References	**Species**	**MC**	**NMS**	**MMS**	**L50**	**SR**
Sala et al., 2008	MUT	SM	40	38.65	10.91	1.43
Sala et al., 2015	MUT	DM	44	45.15	8.58	1.51
Sala et al., 2015	MUT	SM	44	45.95	13.20	1.73
Sala et al., 2015	MUT	DM	54	54.70	11.63	3.41
Sala et al., 2015	MUT	SM	54	56.90	17.28	4.30
Sala et al., 2016	MUT	SM	41	41.05	13.07	2.34
Sala et al., 2016	MUT	SM	41	41.05	12.48	2.40
Sala et al., 2016	MUT	SM	41	41.50	10.29	1.43
Sala et al., 2006	MUT	DM	44	45.00	8.90	2.68
Soldo, 2004	MUT	DM	48	NA	13.49	1.74
Tokaç et al., 1998	MUT	DM	36	NA	11.02	1.76
Tokaç et al., 1998	MUT	DM	40	NA	12.19	2.15
Tokaç et al., 1998	MUT	DM	44	NA	13.50	2.65
Tokaç et al., 1998	MUT	SM	36	NA	11.82	1.58
Tokaç et al., 1998	MUT	SM	40	NA	13.20	1.85
Tokaç et al., 1998	MUT	SM	44	NA	14.67	2.89
Tokaç et al., 2004	MUT	DM	36	37.00	12.70	1.80
Tokaç et al., 2004	MUT	DM	36	37.00	12.80	1.80
Tokaç et al., 2004	MUT	DM	40	41.90	10.70	1.90
Tokaç et al., 2004	MUT	DM	40	41.90	10.70	1.90
Tokaç et al., 2014	MUT	DM	40	40.44	9.38	2.48
Tokaç et al., 2014	MUT	DM	44	44.33	11.53	2.72
Tokaç et al., 2014	MUT	DM	50	51.34	15.40	3.15
Tokaç et al., 2014	MUT	T90	40	40.44	12.65	1.48
Tokaç et al., 2014	MUT	T90	44	44.33	14.80	1.62
Tosunoglu et al.,2003b	MUT	DM	40	41.90	10.60	1.71

References	Species	MC	NMS	MMS	L50	SR
Voliani & Abella, 1998	MUT	DM	38	NA	9.30	1.50
Sala et al. (2018)	MUT	SM	NA	51.6	16.22	1.86
Sala et al. (2018)	MUT	DM	NA	51.65	11.23	3.51
Sala et al. (2018)	MUT	SM	NA	42.03	14.31	0.54
Sala et al. (2018)	HKE	SM	NA	51.6	21.93	3.51
Sala et al. (2018)	HKE	DM	NA	51.65	7.38	4.26
Sala et al. (2018)	HKE	SM	NA	42.03	17.22	3.29

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