Authors’ response to east coast Spanish mackerel assessment review

11 August 2021

We appreciate the time and effort the reviewer dedicated to examining the stock assessment of Australian east coast Spanish mackerel (2021). The reviewer’s report, knowledge of Stock Synthesis software and insightful comments provided valuable information to the stock assessment.

We have incorporated several suggestions made by the reviewer. Those changes are highlighted within the stock assessment report.

A point-by-point response to the reviewer’s comments follows:

Reviewers' Comments to the Authors

Reviewer: “I could not find a summary background discussion in the assessment document of these features of the logbook data or methods that may have been employed to initially filter the data prior to analysis.” (p6, Section 2.2.1b)

Authors: The following description on data-filtering was added to page 11, Section 2.3 Abundance indices, and page 44, Appendix A Section A4 in the main report.

<u>Section 2.3 Abundance indices</u>

From the initial logbook data, a series of filters were applied to obtain the Spanish mackerel data for catch rate standardisation. The filters used criteria relating to species, location, fishing method, fishing date and trip duration. The filtering process was detailed in Appendix A Section A4.

<u>Appendix A A4</u>

Commercial catch data were extracted from the Queensland logbook database. From the initial set of records, the catch rate data was defined through a series of filters.

For the probability model (first component of the standardisation model), the following filters were applied:

- Spanish mackerel (CAAB Code= 37441007) catches per latitude band and day.
- Where multiple latitudes were recorded on a single day, the catch was summed over all records, and the location was set to mean of latitude derived and mean of longitude derived.
- Date between 1 July 1988 and 30 June 2020.
- Location was east coast (between 11.00° S and 28.50° S, >= 142.5 ° E)
- Location excluded records in the far north latitude band 11 (due to lack of available data).

For the catch rate model (second component of the standardisation model), the following filters were applied:

- Line fishers that had at least three years of catching Spanish mackerel.
- Line fishing methods included “Trolling”, “Handline”, and “Line fishing”.
- Where multiple locations were fished on a single day, the catch was summed over all records, and the location was set to mean of latitude and mean of longitude.
- Date between 1 July 1988 and 30 June 2020.
- Duration of the fishing trip was a single day.

- Location was east coast (between 11.00° S and 28.50° S, >= 142.5 ° E).
- Where kilograms of Spanish mackerel caught was greater than zero.

Reviewer: "Despite good efforts in historical catch reconstruction, the number of assumptions shows that historical harvest estimates for Spanish mackerel are uncertain and this uncertainty should be evident in assessment results. The scenarios examined did not include alternative catch history, although it may be that the influence of this is less important than the factors that were examined." (p7, Section2.2.1d)

Authors: The authors agree that it would have been ideal to consider alternative harvest scenarios as part of the sensitivity analyses. We will endeavour to test alternative harvest scenarios again in the next assessment. We note different harvest scenarios were analysed by Campbell et al. (2012) and Welch et al. (2002), showing marginal variations in biomass ratios.

Reviewer: "Until recently, many stock assessments have assumed that steepness is unknown and have used a default generic value, such as 0.75 for marine demersal fish stocks from Shertzer and Conn (2012). It has been common past practice to assume that pelagic species have relatively high reproductive resilience, with many assessments of those assuming steepness of 0.7 or more, and not a small number at or near steepness 1.0 (e.g. Zhu 2012 for bigeye tuna)." (p8, Section 2.2.1d)

Authors: Steepness is an influential parameter and thus, if fixed, should be at a value or range of values that are justified by the stock's biological information and data. We do not believe that using a "generic default value" meets this standard and instead have opted to be informed by estimates of this parameter from stock assessments on the same species or species with similar biology.

Specifically, we have used the most comprehensive and up-to-date meta-analysis available – the FishLife analysis by Thorson (2020), which incorporates stock assessment information from the global RAM legacy database. We would like to emphasise the trade-off involved in obtaining information from this meta-analysis at the genus and family taxonomic levels.

We have chosen to be primarily informed by the genus level steepness values as these are more likely to be relevant biologically. However, we acknowledge that the higher sample size associated with the family level estimates is arguably preferable. The family level steepness value is higher (0.69) and therefore we further investigated scenarios with steepness at 0.7.

This resulted in mixed outcomes depending on setting for natural mortality and the model generally had poor fit to input data, issues with convergence (i.e. unable to find model results), and high recruitment residuals in early years (Table 1).

For scenarios estimating natural mortality, estimated values were less realistic given the age to which east coast Spanish mackerel are known to live. Fixing natural mortality with high steepness generally resulted in poor fit to the data. In particular, the scenario C (fixing M at 0.25) had poor weighting (over-weighting) to age and length composition data.

The overall finding was that the model did not fit well with high steepness given current input data and resulted in less plausible parameter estimates (e.g. very high natural mortality and low sized-based selectivity). Detailed results of additional scenarios are provided in Response Appendix 1 (located at the end of this document).

Table 1 Summary of the Spanish mackerel results from the base case and additional model runs Note: bold italic values indicate parameter estimated from the model; base case standardised catch rate was used for all additional runs; log-likelihood (-lnL) values are not comparable as different Francis weighting was applied to individual scenario; spawning biomass is presented as a ratio relative to an unfished state; and equilibrium annual harvest values are in tonnes.

Scenario	h	M	-lnL	B_{2020}/B_0	Harvest at B_{60}
1 (Base)	0.45	***0.27 (no prior)***	389.547	0.169	557
A	0.7	***0.39 (with prior)***	401.921	0.582	894
B	0.7	***0.18 (with prior)***	426.574	0.122	511
C	0.7	0.25	647.875	0.405	546
D	0.7	0.33	435.955	0.571	727
E	***0.49***	0.25	390.279	0.157	552

We would also like to draw attention to a characteristic of the assessment that may imply the specific value of steepness is less a source of uncertainty than it might at first appear. This is the “bi-modal” (two-valued) nature of the space of possible solutions. Additional sensitivity analysis runs indicate that it is possible for “high steepness” scenarios to result in “low biomass” (~ 20%) outcomes as well as “low steepness” scenarios to end up in “high biomass” (~ 60%) outcomes.

In general, the high biomass scenarios were considered less plausible than the low biomass scenarios because they are either associated with unrealistically high natural mortality, or very large early-year recruitment residuals, or convergence problems or some combination of these.

We also found that when natural mortality was fixed at 0.25 and steepness was estimated, consistent with scenarios in O'Neill et al. (2018), the final estimate for steepness was 0.49 (scenario E, Table 1). In general, scenario E results were similar to the base case model with the spawning biomass ratio B_{2020} at 16% (base case = 17%) and harvest at B_{60} was estimated at 552 tonnes (base case = 557 tonnes).

Based on the information above, we feel the base case results in the report remains a credible scenario.

Reducing uncertainty in future assessments might be more about understanding how much, if any, probability should be associated with the “higher mode” than about steepness setting per se. As well as gauging the realism in natural mortality and MSY values, one way to do this would be through an MCMC analysis in combination with a genuine steepness prior (as opposed to a fixed value).

Reviewer: “The current assessment simply states “Beverton-Holt stock recruitment steepness (h) was fixed at a value of 0.45, based on the meta-analysis of Thorson (2020). Different levels of h were tested as sensitivity analyses.” and “The values of steepness (h) that were explored in this assessment were chosen to align with range of estimated values in O’Neill et al. (2018).” It has been recognised by the authors that this required more explanation, which I was provided separately.” (p8, Section 2.2.1d)

Authors: We acknowledge that further explanation of the choices of base case steepness value was needed and the revised text reads as follows on Section 2.5.2 Model parameters:

“Beverton-Holt stock recruitment steepness (h) was fixed at a value of 0.45, based on the meta-analysis of Thorson (2020). Table 4 of Thorson (2020) lists a steepness value of h=0.69

for the Scombridae family, however Figure 3 of the same paper indicates great variation in steepness at the genus level (*Scomberomorus*). The R package "FishLife" was used to extract the steepness value for the *Scomberomorus* genus (h=0.45) from the meta-analysis described in the paper."

We have explored steepness extensively and concluded that the value used in this assessment is the most appropriate based on current evidence. Future work will refine our understanding of steepness for this stock. In the process of gaining this understanding we will consider how Thorson's meta-analysis has combined information from various sources.

Reviewer: "From my experience with many stock assessments, that low central value for steepness for Spanish mackerel is inconsistent with previous accepted practice, and comparable existing DAF Spanish mackerel assessments. As such, it requires a much-expanded justification within the current assessment document." (p9, Section 2.2.1d)

Authors: The first statement is persuasive and is implied in the "No BS guide to fisheries stock assessment.ppt" on capamresearch.org for an unknown stock recruitment relationship. However, scientific/peer opinion has varied in literature on appropriate upper settings on steepness (Myers et al, 1999), particularly when hyperstability might confound stock assessments. In addition, basing stock assessments on a sole high steepness value might not be risk adverse or contribute to further understanding. More capamresearch.org documentation and guidance is required around this parameter capturing assessment findings more broadly from Australia.

The Australian east coast Spanish mackerel assessment in 2012 (Campbell et al., 2012) used fixed steepness of 0.52 as a base case, which was based on the mode of the empirical prior distribution for the Scombridae family reported by Myers et al. (1999). The steepness estimated in the following stock assessment (O'Neill et al., 2018) ranged between 0.25 and 0.8 over 177 scenarios with median value of 0.41.

For the Torres Strait Spanish mackerel stock, the estimation of steepness in the assessment by O'Neill and Tobin (2016) estimated steepness which varied 0.35–0.59. The estimated steepness values for the most recent stock assessment by Buckworth et al. (2021) had a mean steepness of 0.4 over the six core stock assessment analyses.

It is difficult to give credence to a high sole steepness value. In general, Spanish mackerel data from the east coast, Torres Strait (Buckworth et al., 2021) and Gulf of Carpentaria (Bessell-Browne et al., 2020) cannot match well with the high steepness values noted from overseas on the review paragraph 2 on page 9.

Early publication on the reproductive rates for Scombridae species (mackerel and tuna species) suggested steepness with median h = 0.52, 20th percentile = 0.3 and 80th percentile = 0.72; (Table 1, Myers et al., 1999). Myers et al. (1999) concluded that h will vary with species, natural mortality and age-at-maturity, with the number of annual replacement spawners typically ranging 1–7 per spawner per year. Using Myers et al. (1999) biological generalisation, an expected steepness (h) for Spanish mackerel could range 0.4 to 0.87; noting this range is higher than the values summarised for Scombridae. This value could also vary between stocks or areas.

We believe the different levels of fixed steepness analysed in the report and herein were within the range estimated in existing DAF Spanish mackerel assessments. We acknowledge that more research is required for the selection of base case steepness value and the report has been amended in accordance with the feedback.

Reviewer: "I have SS input files for accepted US base-case assessments for three species in the genus Scomberomorus. Some or all of these may have contributed recruitment series to the RAM Legacy database. These were SEDAR 28 2012 South Atlantic Spanish mackerel, SEDAR 38 2014 Gulf of Mexico king mackerel, and SEDAR 38 2014 South Atlantic king mackerel. These stock assessments used fixed steepness values of 0.8, 0.98 and 0.99 respectively, although those values are not used by subsequent steepness meta-analysis." (p9, Section 2.2.1d)

Authors: We reviewed the three assessments and found that:

- SEDAR (2012) used steepness value fixed at 0.75 for South Atlantic Spanish mackerel,
- The base case model for Gulf of Mexico king mackerel estimated steepness at 0.79 with beta prior of 0.7 (sd = 0.11) (SEDAR, 2014a).
- The base case model for South Atlantic king mackerel estimated steepness at 0.5 with uniform prior (SEDAR, 2014b).

The review panel for the last two assessments recommended to fix steepness at 0.99. This explained why the input files, the reviewer had from these three assessments, had such a high value of 0.99. We also understand why these values were not used by subsequent steepness meta-analysis. The authors believe that there is scientific evidence that lower steepness values were estimated in these assessments prior to panel review, and this aligns with steepness values estimated by Thorson (2020) and our findings, as presented on the previous page.

Reviewer: "In addressing this, it would be useful if assessment documents provided a table that summarises those uncertainties and how the assessment has addressed them." (p10, Section 2.2.1f)

Authors: Authors appreciate reviewer's suggestion and will endeavour to consider in future stock assessment report.

Reviewer: "True sensitivity analysis that alters only one factor from the base-case for the purpose of stock assessment diagnosis was not included and could be considerably expanded through examination of lower and higher weights (potentially via Lambda adjustments) for the various data inputs and assumptions." (p10, Section2.2.1f).

Authors: This comparative approach and full sensitivities tests were completed by Campbell et al. (2012) and O'Neill et al. (2018). We concluded that our model runs can now be more selective and informative. For the next assessment, the project team will suggest sensitivity tests following a factor-by-factor design.

Reviewer: "The document states that this assessment did not include a discount factor to account for uncertainty in recommended target estimates, but this decision was not explained in the document." (p11, Section 2.2.1g)

Authors: Authors added the following sentence to the report in page 17, Section 2.5.5 Forward projection: "This assessment did not include a discount factor to account for uncertainty in recommended target estimates as the Fisheries Queensland Spanish Mackerel Fishery Working Group and fishery management will evaluate whether to apply discount factors to recommended biological catch."

Reviewer: “Any efforts to make use of earlier composition data that may enable extension of recruitment deviation estimation to earlier years is important for this assessment.” (p12, Section 2.2.3)

Authors: Authors note the importance of including earlier age and length composition data and will endeavour reviewing available data and standardise for consideration in the future assessment and this is listed as a recommendation in Stock Assessment Report Section 4.4.1.

Reviewer: “Integration of results over a range of models selected to represent structural and data uncertainty more comprehensively is potentially superior for obtaining values of interest to management and should be considered.” (p13, Section 2.2.4)

Authors: Authors agreed with the reviewer’s comments, and this has been our common approach.

Reviewer: “The plot of fitted spawning output vs recruitment for at least the base-case is of key importance and should be included in a stock assessment document.”

Authors: The plot of the base case model was added in the report, Appendix B, Section B.2.

Reviewer: “Although the previous stock assessment for east coast Spanish mackerel by O’Neill et al. (2018) did not use SS, there may still have been an opportunity to construct a bridging analysis by commencing with a model that attempted to replicate those results – at least for a selected representative case.” (p13, Section 2.2.4)

Authors: Authors consider this a useful exercise. This will be considered by the advisory project team. To note, a bridging analysis (comparing custom and Stock Synthesis models) is scheduled for upcoming Torres Strait Spanish mackerel stock assessment. Results will help inform the east coast stock assessment.

Reviewer: “Evidence for model convergence should be considered and can be based on jittering starting values for estimated parameters. An improvement on this is via MCMC or bootstrap runs, although the additional time required for such procedures is recognized.“ (p14, Section 2.2.4)

Authors: We have explored uncertainty in steepness values by exploring a range of fixed steepness values. We have also explored overall model convergence by applying different starting values for estimated parameters (using jitter function in Stock Synthesis). While we concluded that more plausible results were obtained with lower biomass outcome (i.e., reasonable M and R0 estimates, better performed recruitment deviation), jittering starting values revealed that the model could lead to two distinct solutions based on the allowed upper extent on M. We are not ruling out that there are alternative solutions under more sensitivity runs. MCMC might help report the broader uncertainties in the model. Expansion of model sensitivity runs, jittering and changing the number of parameters estimated may provide further evidence on model convergence and stock scenarios.

Reviewer: “A separate table with likelihood components further broken down into components such as CPUE or composition fit often still allows much insight into model behaviour that is unobtainable otherwise.” (p14, Section 2.2.4)

Authors: The table of negative log likelihoods broken down into components for eight scenarios are provided in Table 2 (details of each scenario are in Table 2.3 of the main report). Authors agree with reviewer’s suggestion and will endeavour to include this in the future stock assessment reports.

Table 2 Breakdown of negative log-likelihood for each scenario. Zero values indicate components that are not applicable to this assessment.

Scenario	**1 (Base)**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
TOTAL	389.55	381.06	394.13	349.14	346.41	370.12	370.85	385.28
Catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equil_catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Survey	-58.35	-60.35	-56.29	-66.80	-69.11	-66.86	-59.75	-70.53
Length_comp	77.78	77.33	76.66	78.18	78.10	79.88	80.43	81.36
Age_comp	379.19	372.61	382.99	347.47	347.06	364.52	360.02	384.10
Recruitment	-9.24	-8.91	-9.53	-10.67	-10.76	-11.16	-10.01	-9.83
InitEQ_Regime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Forecast_Recruitmen	0.04	0.05	0.03	0.02	0.04	0.02	0.03	0.04
Parm_priors	0.13	0.33	0.26	0.94	1.08	3.72	0.13	0.13
Parm_softbounds	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parm_devs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crash_Pen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Reviewer: “As CPUE standardisation is a complex procedure that produces much output on fits to the data and diagnostics that should be examined, I believe that this might be best achieved by the production of a document separate to the stock assessment on that process.” (p14, Section 2.2.4)

Authors: In general, this will be considered for future stock assessment reports.

Amendments made to the report:

1. A paragraph of data filtering process was added in page 11, Section 2.3 Abundance indices and detailed description was added in page 44, Appendix A Section A4.
2. Expanded description of the selection of base case steepness parameter was added in page 16, Section 2.5.2 Model parameters.
3. The plot of fitted spawning output vs recruitment was added in Appendix B Section B.2.
4. Justification of not applying discount factor was added in page 17, Section 2.5.5 Forward Projections.

References

Bessell-Browne, P, MF O’Neill, and JC Langstreth (2020). Stock assessment of the Queensland Gulf of Carpentaria Spanish mackerel (*Scomberomorus commerson*) fishery 2019. Tech. rep. Brisbane: Queensland Department of Agriculture, Fisheries and Forestry.

Buckworth, R.C., O’Neill, M.F., Trappett, A.G., and Langstreth, J.C. (2021). Spanish mackerel stock assessment, with appraisal of environmental drivers. Torres Strait AFMA Project Number: RR2019/0831. Department of Agriculture and Fisheries, Queensland Government.

Campbell, A. B., M. F. O'Neill, J. Staunton-Smith, J. Atfield, and J. Kirkwood (2012). Stock assessment of the Australian East Coast Spanish mackerel (*Scomberomorus commerson*) fishery. Tech. rep. Brisbane: Queensland Department of Agriculture, Fisheries and Forestry.

O'Neill, Michael F., Joanne Langstreth, Sarah M. Buckley, and John Stewart (2018). Stock assessment of Australian east coast Spanish mackerel: Predictions of stock status and reference points. Tech. rep. Brisbane. Queensland Department of Agriculture, Fisheries and Forestry.

O'Neill, M. F., and A. Tobin. (2016). Torres Strait Spanish Mackerel: Stock assessment II, 2015. Torres Strait AFMA Project Number: RR2014/0823. Department of Agriculture and Fisheries, Queensland Government. p 73.

Myers RA, Bowen KG, Barrowman NJ (1999). Maximum reproductive rate of fish at low population sizes. Canadian Journal of Fisheries and Aquatic Sciences 56, 2404-2419.

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SEDAR. (2014a). SEDAR 38 – Gulf of Mexico King Mackerel Stock Assessment Report. SEDAR, North Charleston SC. 465 pp. available online at: https://sedarweb.org/docs/sar/SEDAR_38_Gulf_SAR.pdf

SEDAR. (2014b). SEDAR 38 – South Atlantic King Mackerel Stock Assessment Report. SEDAR, North Charleston SC. 502 pp. available online at: https://sedarweb.org/docs/sar/SEDAR_38_SA_SAR.pdf

Thorson, James T (2020). "Predicting recruitment density dependence and intrinsic growth rate for all fishes worldwide using a data-integrated life-history model". In: *Fish and Fisheries* 21.2, pp. 237–251.

Welch, D. J., S. D. Hoyle, N. A. Gribble, and G. McPherson (2002). Preliminary assessment of the Queensland east coast Spanish mackerel fishery. Tech. rep. Brisbane. Agency for Food, Fibre Sciences, and Queensland Fisheries Service. Department of Primary Industries.

Response Appendix 1

Scenario A - Result warning: natural mortality estimate was biologically very high, and the large early-year recruitment deviations were implausible.

Scenario A was identical to the base case except steepness, *h,* was fixed at 0.70 instead of 0.45 with upper bound of natural mortality was set as 0.5. Note that all outputs are standard Stock Synthesis outputs produced by R4SS package.

Table 3: Stock Synthesis parameter estimates for the scenario A population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Natural mortality	0.39	3	0.01	0.5	0.29	0.02
Length at age 1 (*FL_1*) female	66.62	1	30	90	72	1.42
Length at maximum age (*FLinf*) female	130.14	1	100	180	140	2.40
von Bertalanffy growth parameter (κ) female	0.29	1	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (*FL1*) male	65.73	1	30	85	70	1.30
Length at maximum age (*FLinf*) male	114.24	1	100	200	120	1.32
von Bertalanffy growth parameter (κ) male	0.35	1	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	4	0.01	0.2	0.13	0.00
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.77	1	10	15	13.3	0.25
Commercial selectivity inflection (cm)	81.50	2	30	120	60	0.93
Commercial selectivity width (cm)	11.40	2	0	20	0.5	1.32

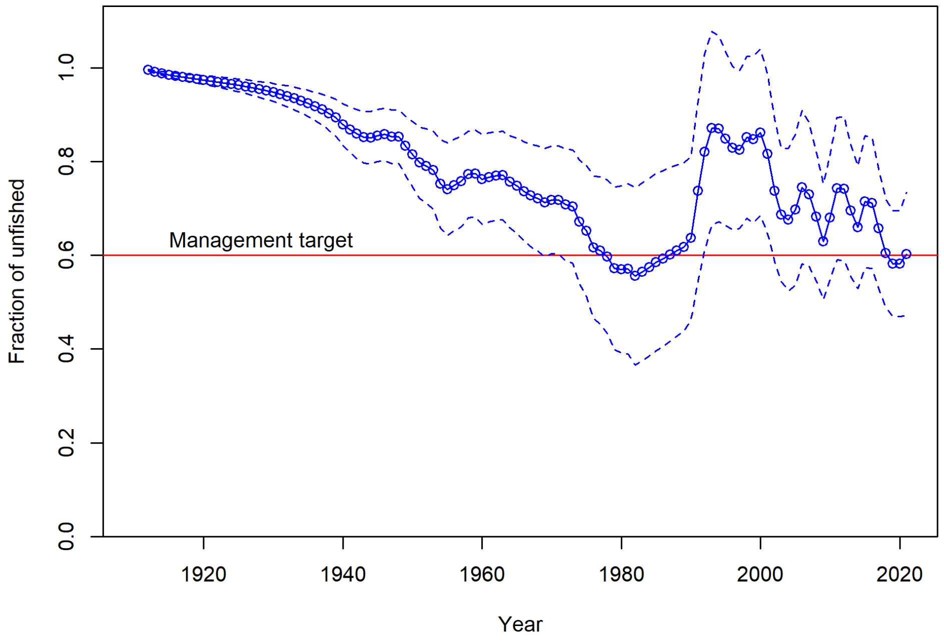

Figure 1: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2020, for scenario A

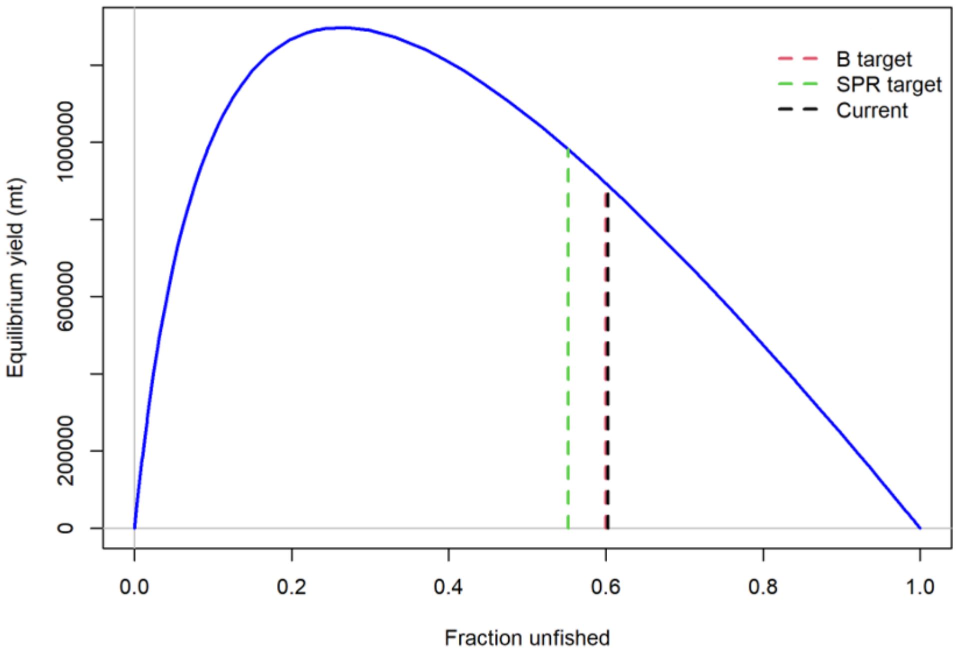

Figure 2: Equilibrium yield curve for Spanish mackerel for scenario A

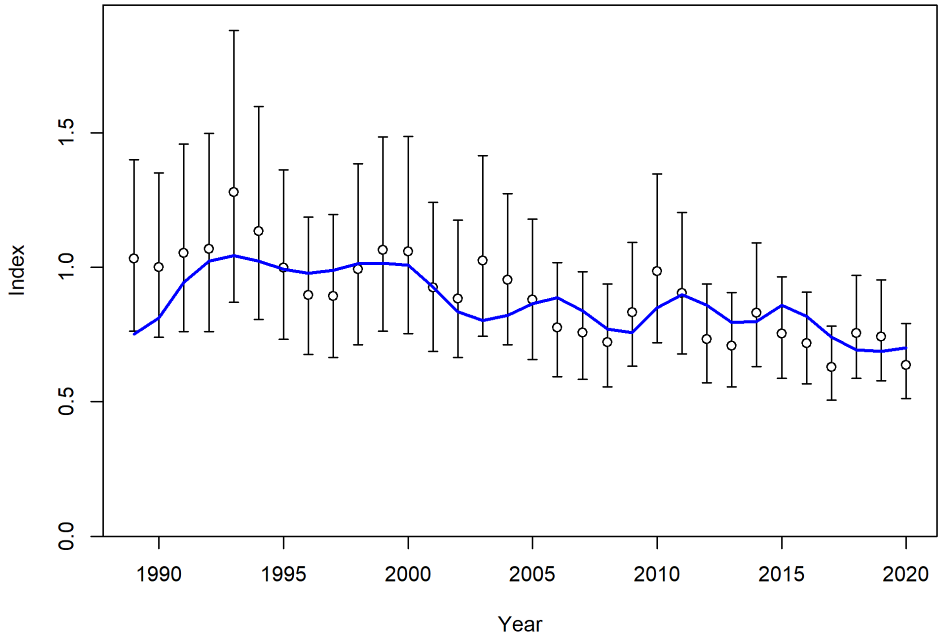

Figure 3: Model predictions (blue line) to commercial catch rates for Spanish mackerel for scenario A

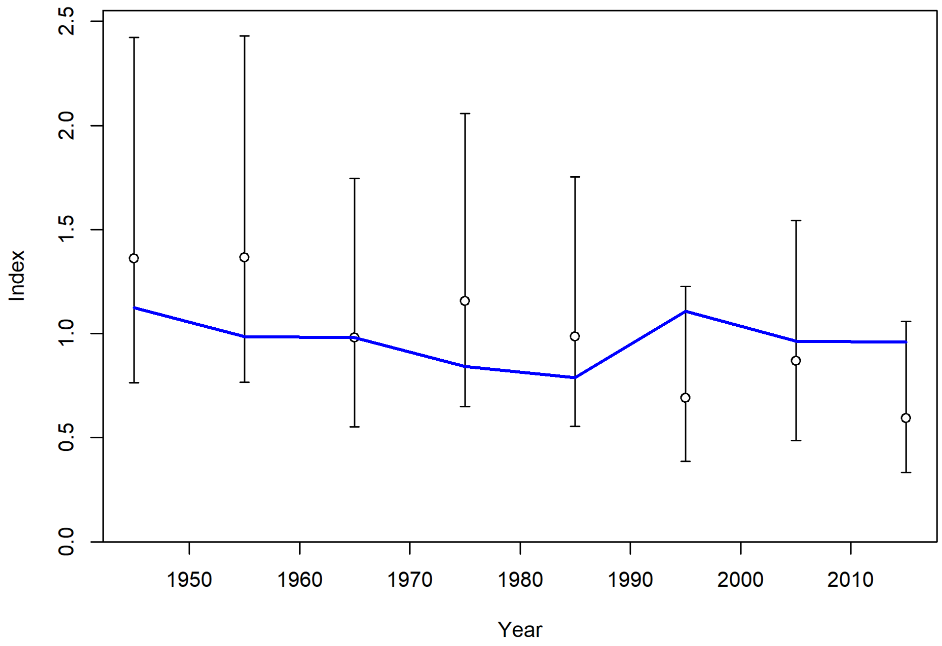

Figure 4: Model predictions (blue line) to historical decadal catch rates for Spanish mackerel for scenario A

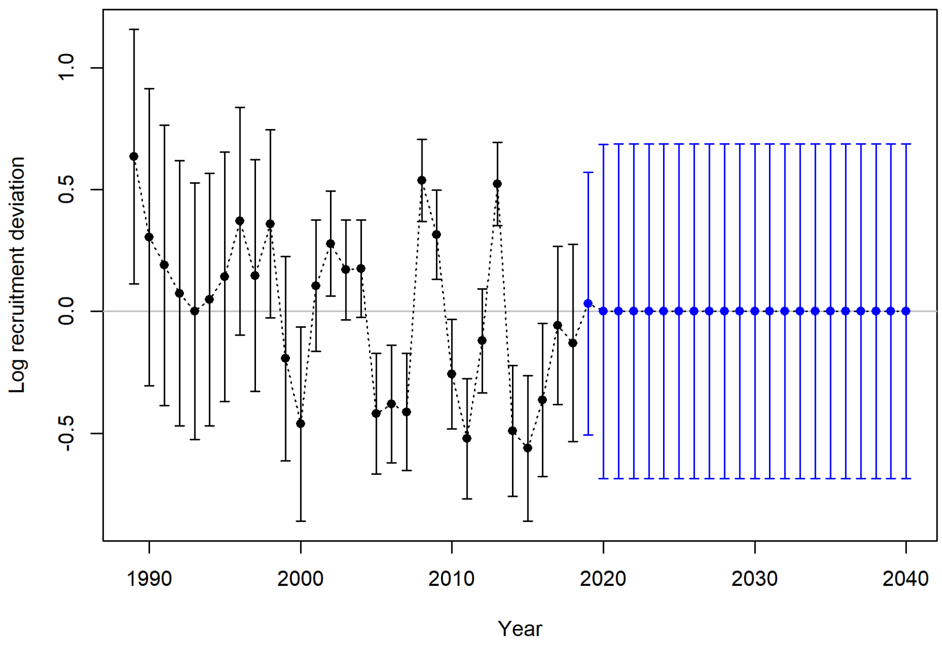

Figure 5 Recruitment deviations with 95% confidence intervals for Spanish mackerel for scenario A

Scenario B - Result warning: issue with model convergence (unable to find solution).

Scenario B was identical to the base case except steepness, *h,* was fixed at 0.70 instead of 0.45 with upper bound of natural mortality was set as 0.4. Note that this scenario had final gradient (0.00166) greater than threshold value of 0.0001, indicating the model had trouble finding solution.

Table 4: Stock Synthesis parameter estimates for the scenario B population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Natural mortality	0.18	2	0.01	0.4	0.25	0.01
Length at age 1 (*FL1*) female	67.60	1	30	90	72	1.33
Length at maximum age (*FLinf*) female	131.27	1	100	180	140	2.50
von Bertalanffy growth parameter (κ) female	0.28	1	0.1	0.4	0.22	0.02
Coefficient of variation in length at age 1 female	0.07	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (*FL1*) male	66.02	1	30	85	70	1.25
Length at maximum age (*FLinf*) male	114.03	1	100	200	120	1.26
von Bertalanffy growth parameter (κ) male	0.35	1	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	4	0.01	0.2	0.13	0.00
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	12.55	1	10	15	12.00	0.04
Commercial selectivity inflection (cm)	81.07	3	30	120	81	0.85
Commercial selectivity width (cm)	11.49	3	0	20	11	1.35

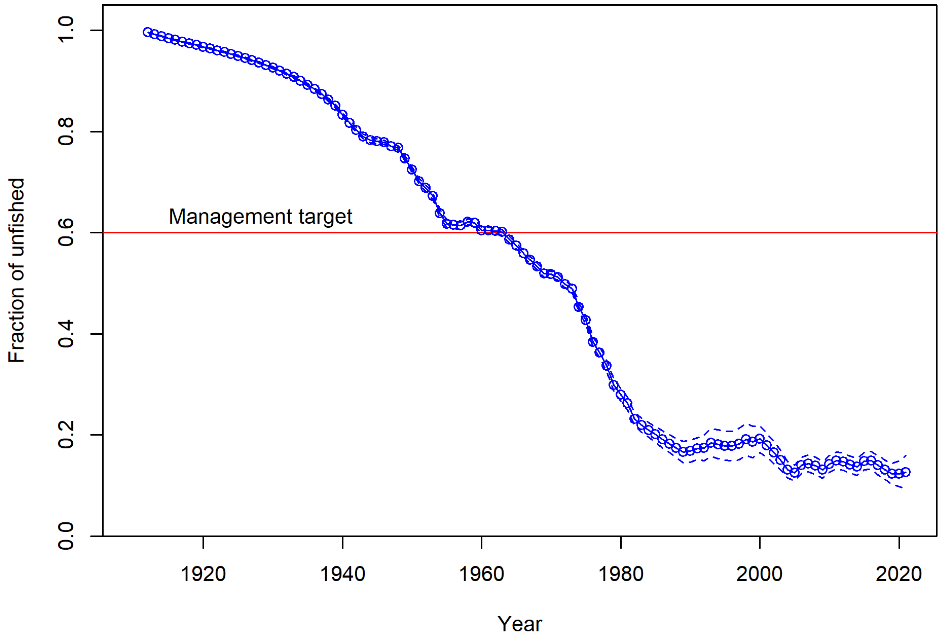

Figure 6: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2020, for scenario B

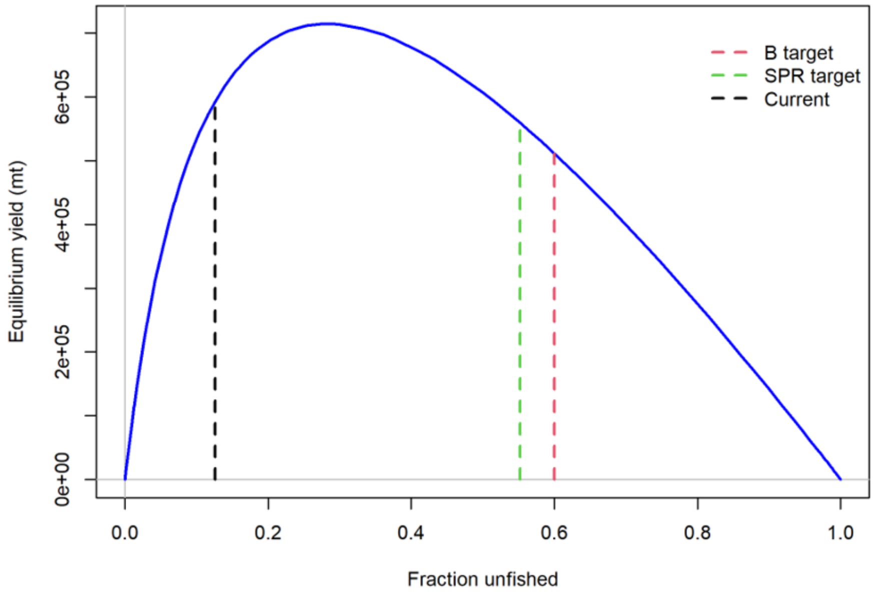

Figure 7: Equilibrium yield curve for Spanish mackerel for scenario B

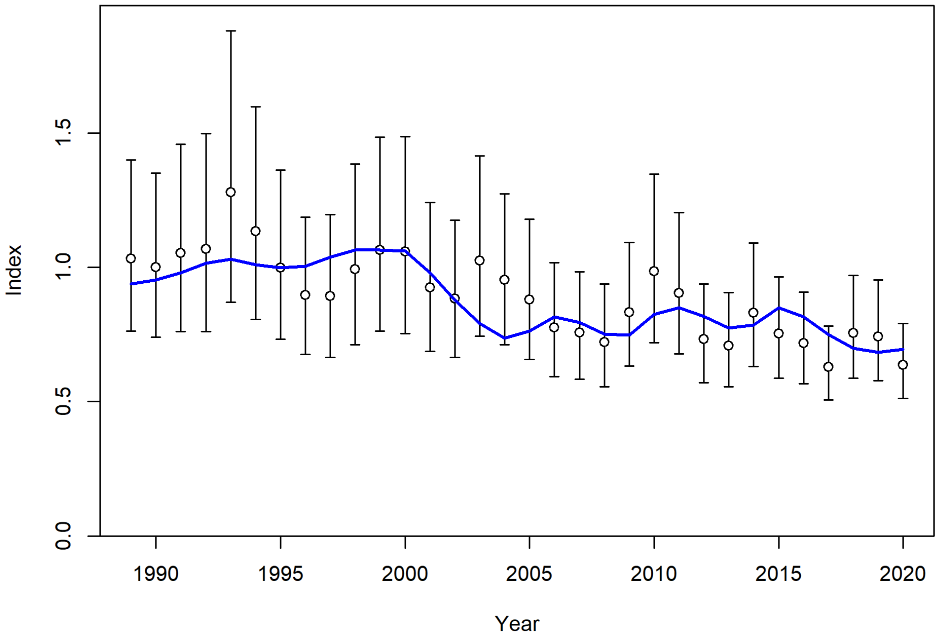

Figure 8: Model predictions (blue line) to commercial catch rates for Spanish mackerel for scenario B

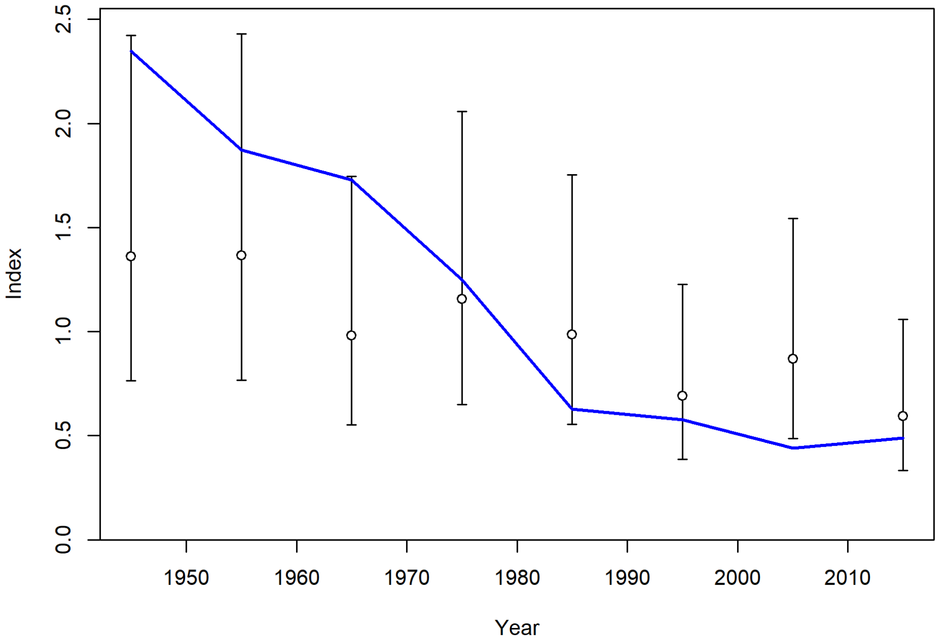

Figure 9: Model predictions (blue line) to historical decadal catch rates for Spanish mackerel for scenario B

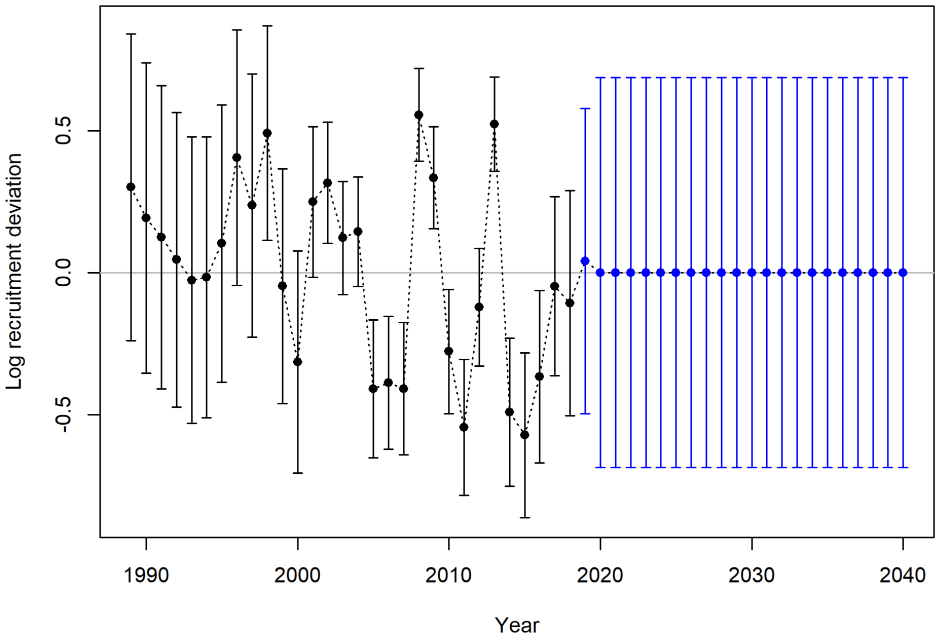

Figure 10 Recruitment deviations with 95% confidence intervals for Spanish mackerel for scenario B

Scenario C - Result warning: no optimal solution, poor fit to the index data, and the large early-year recruitment deviations were unlikely.

Scenario C used base case standardised catch rate and steepness (*h*) *and* natural mortality (*M*) were fixed at 0.7 and 0.25, respectively. This scenario had poor weighting to age and length composition data. Stock synthesis suggested further adjusting Francis weighting for length and age data by applying multiplier of 0.6691 and 0.7293, respectively. However, the model was unable to converge when these multipliers were applied to the model, indicating the model struggled to fit input data with current parameter settings.

Table 5: Stock Synthesis parameter estimates for the scenario C population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Length at age 1 (*FL1*) female	67.49	2	30	90	72	1.20
Length at maximum age (*FLinf*) female	131.51	2	100	180	140	2.24
von Bertalanffy growth parameter (κ) female	0.28	2	0.1	0.4	0.22	0.02
Coefficient of variation in length at age 1 female	0.07	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.00
Length at age 1 (*FL1*) male	65.91	2	30	85	70	1.09
Length at maximum age (*FLinf*) male	114.29	2	100	200	120	1.10
von Bertalanffy growth parameter (κ) male	0.35	2	0.1	0.45	0.21	0.02
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.05	4	0.01	0.2	0.13	0.00
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	12.85	1	10	15	13.3	0.02
Commercial selectivity inflection (cm)	80.59	3	30	120	60	0.75
Commercial selectivity width (cm)	11.19	3	0	20	0.5	1.10

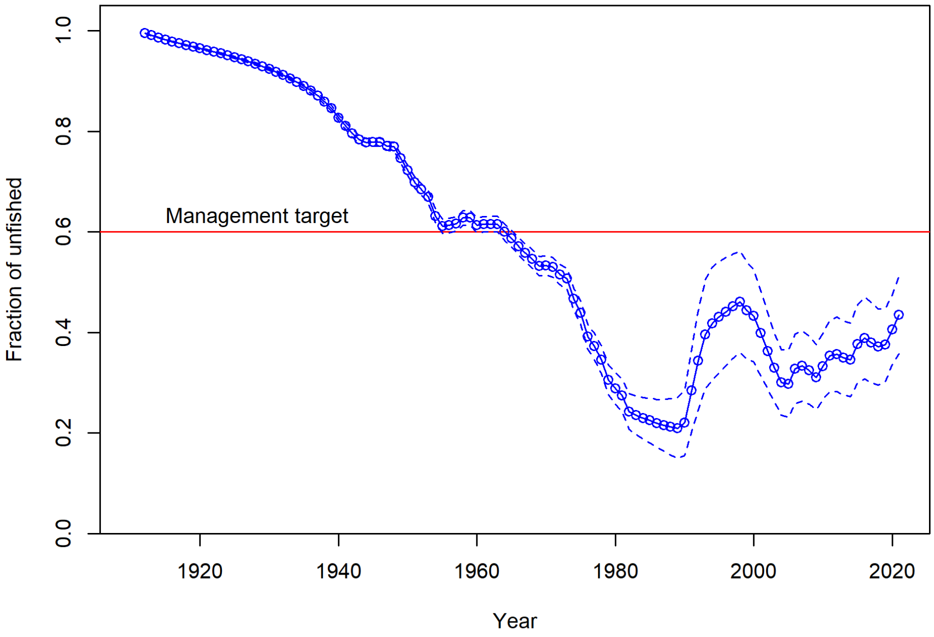

Figure 11: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2020, for scenario C

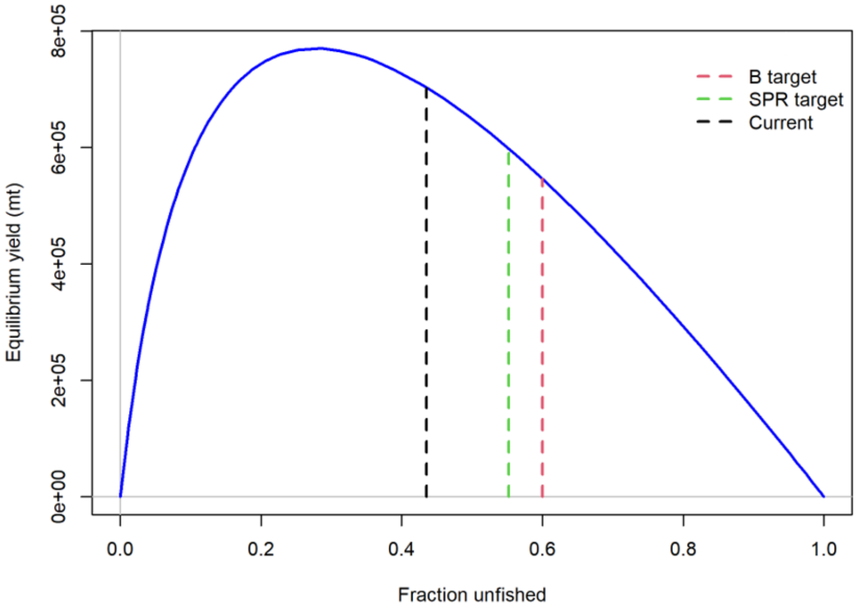

Figure 12: Equilibrium yield curve for Spanish mackerel for scenario C

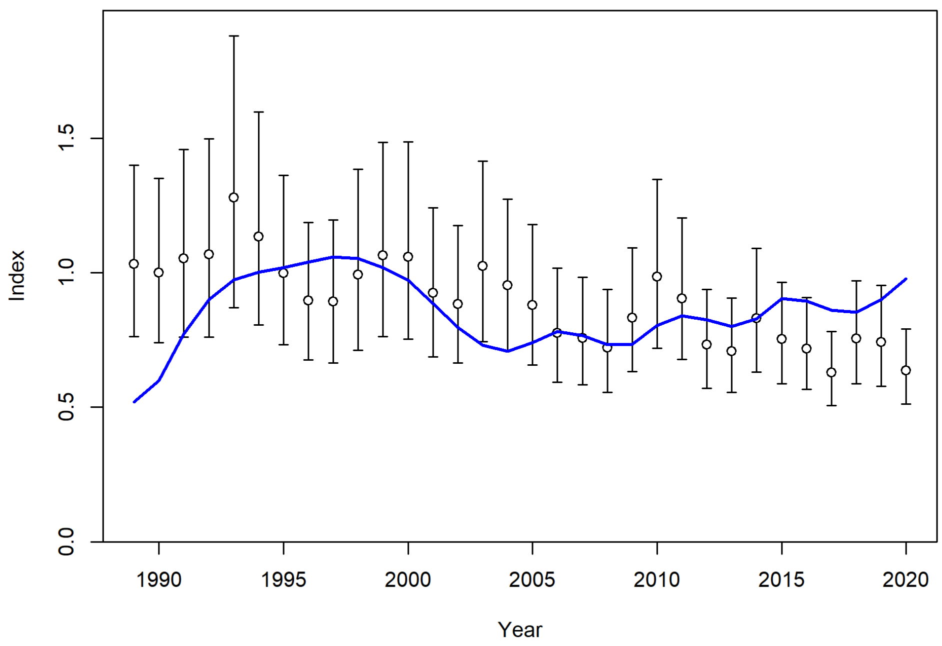

Figure 13: Model predictions (blue line) to commercial catch rates for Spanish mackerel for scenario C

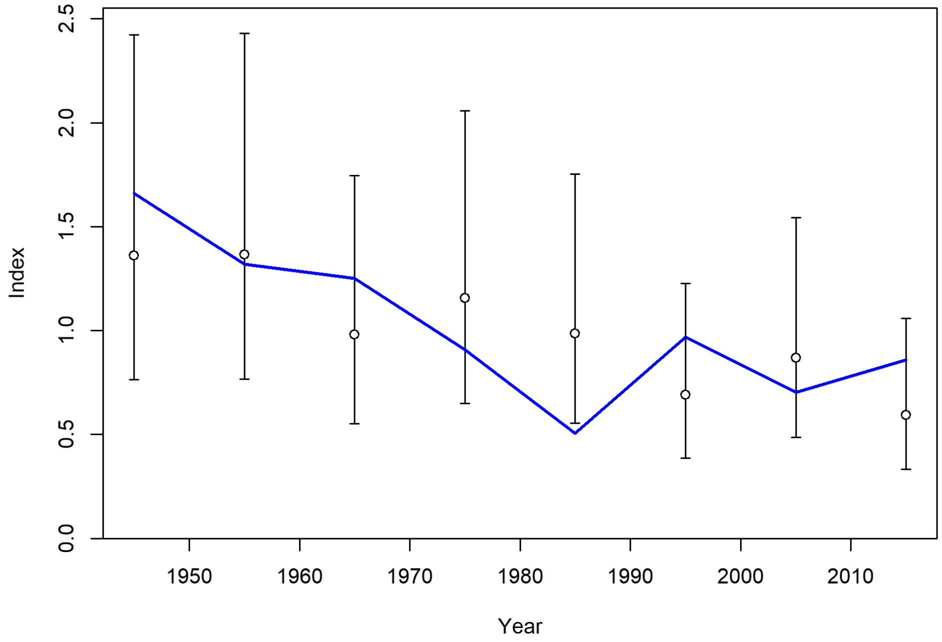

Figure 14: Model predictions (blue line) to historical decadal catch rates for Spanish mackerel for scenario C

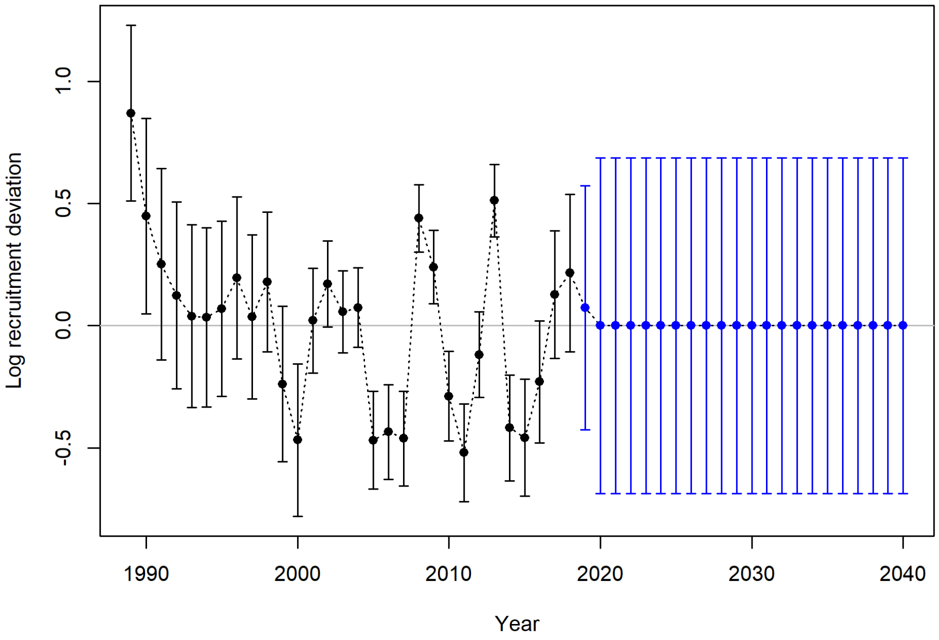

Figure 15 Recruitment deviations with 95% confidence intervals for Spanish mackerel for scenario C

Scenario D - Result warning: fixing two key parameters (h and M) was not ideal, poor fit to the index data, and the large early-year recruitment deviations were unlikely.

Scenario D used base case standardised catch rate and steepness (*h*) *and* natural mortality (*M*) were fixed at 0.7 and 0.33, respectively.

Table 6: Stock Synthesis parameter estimates for the scenario D population model for Spanish mackerel

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
Length at age 1 (*FL1*) female	66.84	1	30	90	72	1.42
Length at maximum age (*FLinf*) female	130.58	1	100	180	140	2.45
von Bertalanffy growth parameter (κ) female	0.29	1	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.07	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (*FL1*) male	65.72	1	30	85	70	1.29
Length at maximum age (*FLinf*) male	114.26	1	100	200	120	1.29
von Bertalanffy growth parameter (κ) male	0.35	1	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.05	4	0.01	0.2	0.13	0.00
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.39	1	10	15	13.3	0.06
Commercial selectivity inflection (cm)	80.55	2	30	120	81	0.82
Commercial selectivity width (cm)	10.94	2	0	20	11	1.26

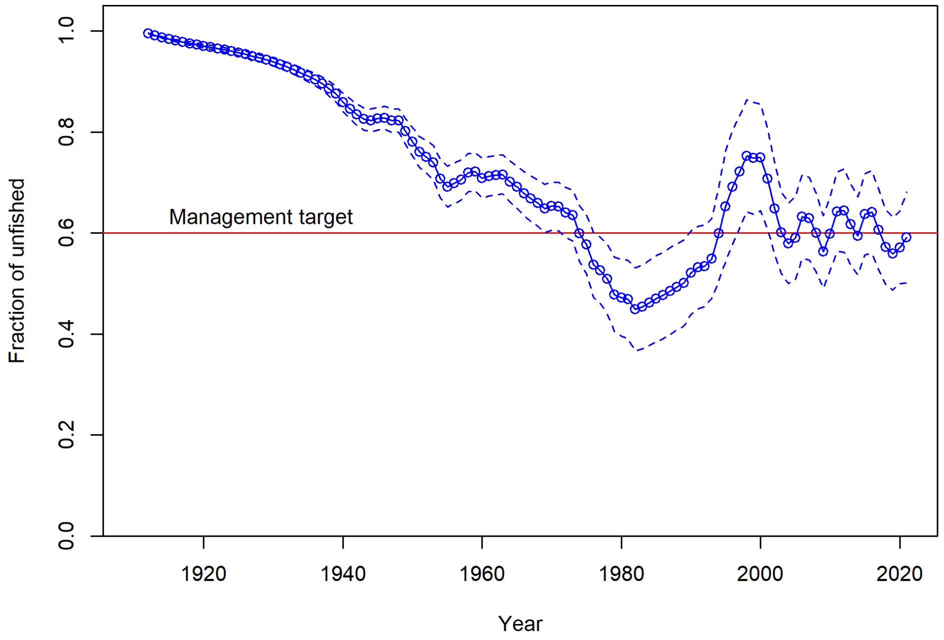

Figure 16: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2020, for scenario D

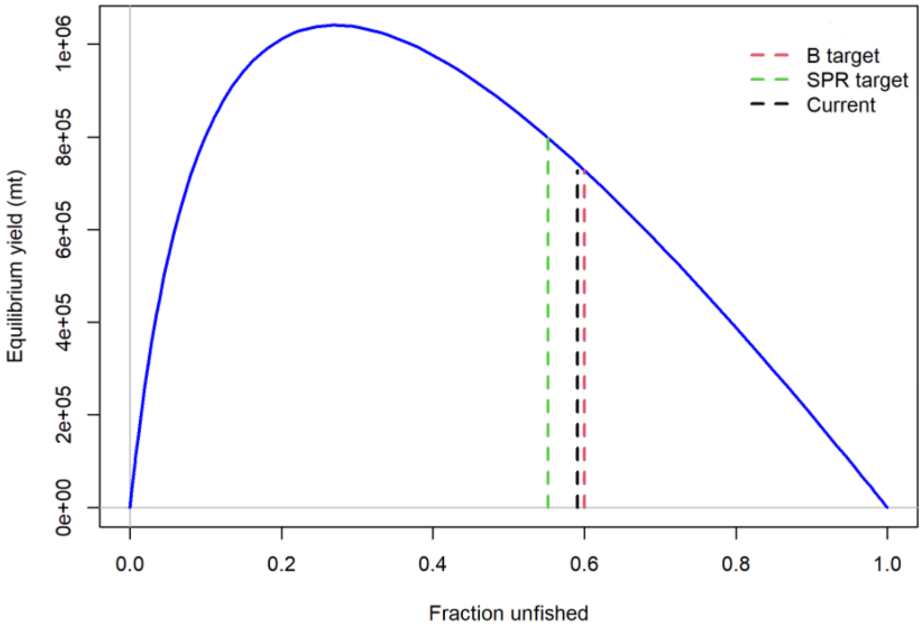

Figure 17: Equilibrium yield curve for Spanish mackerel for scenario D

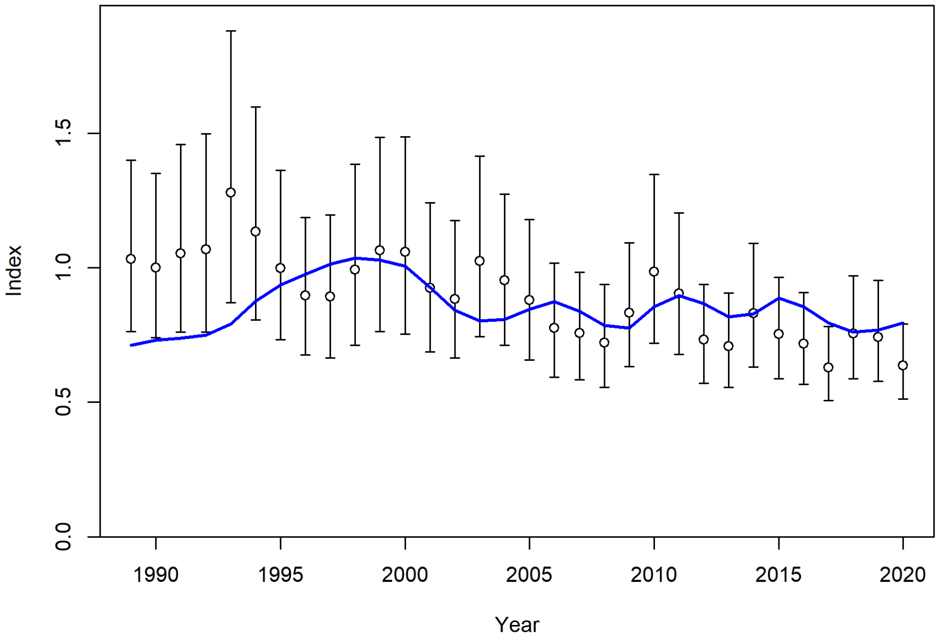

Figure 18: Model predictions (blue line) to commercial catch rates for Spanish mackerel for scenario D

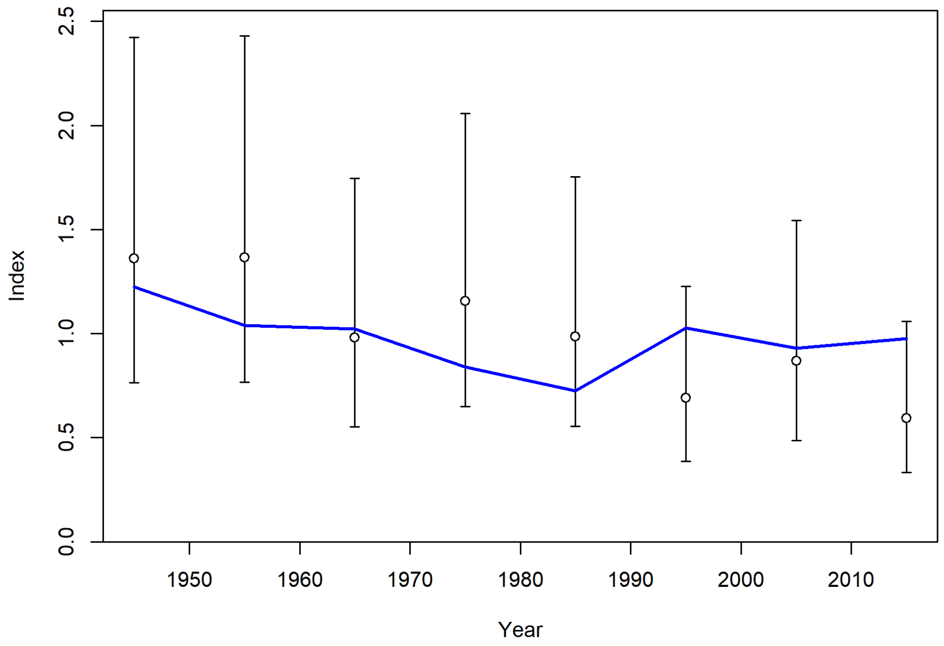

Figure 19: Model predictions (blue line) to historical decadal catch rates for Spanish mackerel for scenario D

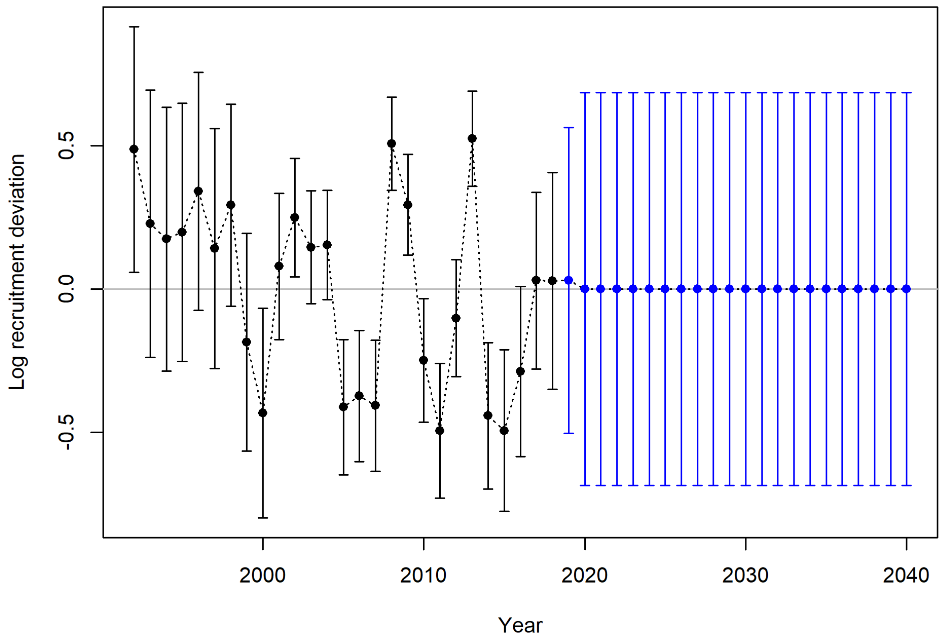

Figure 20 Recruitment deviations with 95% confidence intervals for Spanish mackerel for scenario D

Scenario E - No result warning: generally reasonable fits to the index data, the early-year recruitment deviations were not overly extreme, and model parameters appeared plausible.

Scenario E used standardised catch rate, natural mortality was fixed at 0.25 and steepness, *h,* was estimated in the model.

Table 7: Stock Synthesis parameter estimates for the scenario E population model for Spanish mackerel

Parameter	**Estimate**	**Phase**	**Min**	**Max**	**Initial value**	**Standard deviation**
Length at age 1 (*FL1*) female	66.90	1	30	90	72	1.40
Length at maximum age (*FLinf*) female	130.11	1	100	180	140	2.38
von Bertalanffy growth parameter (κ) female	0.29	1	0.1	0.4	0.22	0.03
Coefficient of variation in length at age 1 female	0.07	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age female	0.07	4	0.01	0.2	0.14	0.01
Length at age 1 (*FL1*) male	66.00	1	30	85	70	1.29
Length at maximum age (*FLinf*) male	114.17	1	100	200	120	1.31
von Bertalanffy growth parameter (κ) male	0.35	1	0.1	0.45	0.21	0.03
Coefficient of variation in length at age 1 male	0.08	4	0.01	0.3	0.13	0.01
Coefficient of variation in length at maximum age male	0.04	4	0.01	0.2	0.13	0.00
Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1911)	13.14	1	10	16	13.5	0.05
Beverton-Holt steepness (*h*)	0.49	3	0.2	1	0.7	0.02
Commercial selectivity inflection (cm)	81.10	2	30	120	60	0.87
Commercial selectivity width (cm)	11.38	2	0	20	0.5	1.34

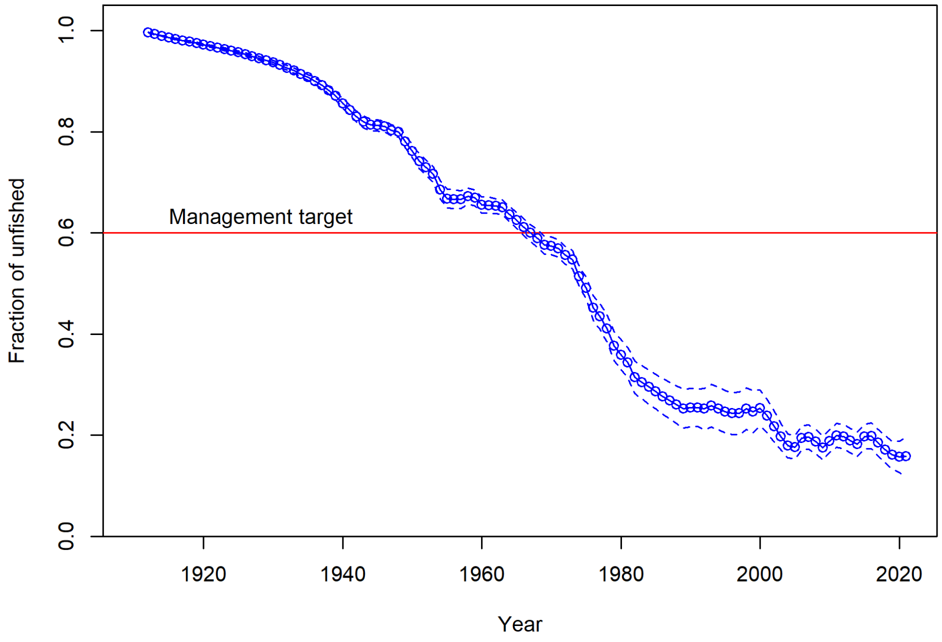

Figure 21: Predicted spawning biomass trajectory relative to virgin for Spanish mackerel, from 1911 to 2020, for scenario E

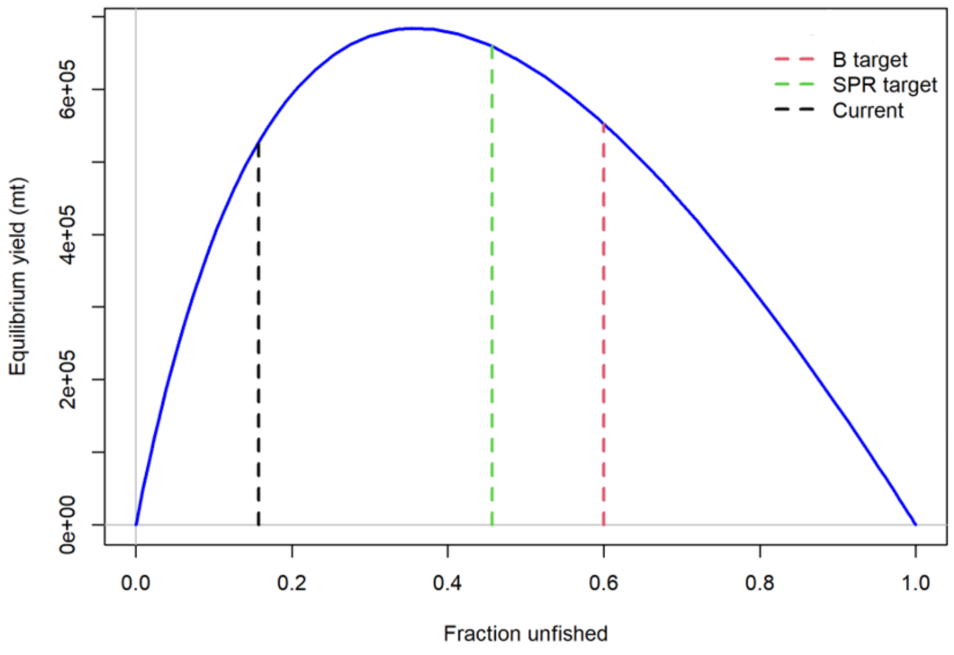

Figure 22: Equilibrium yield curve for Spanish mackerel for scenario E

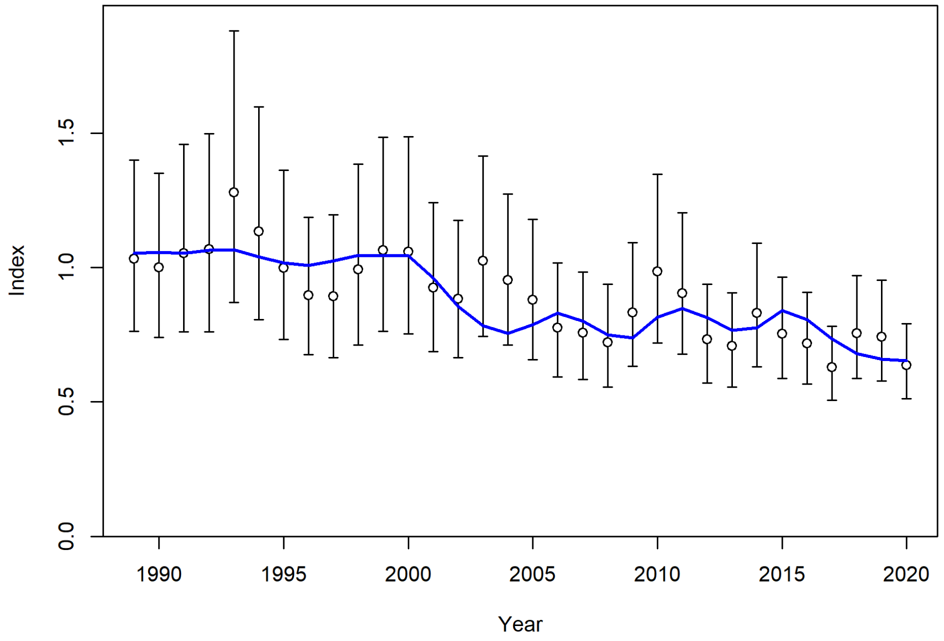

Figure 23: Model predictions (blue line) to commercial catch rates for Spanish mackerel for scenario E

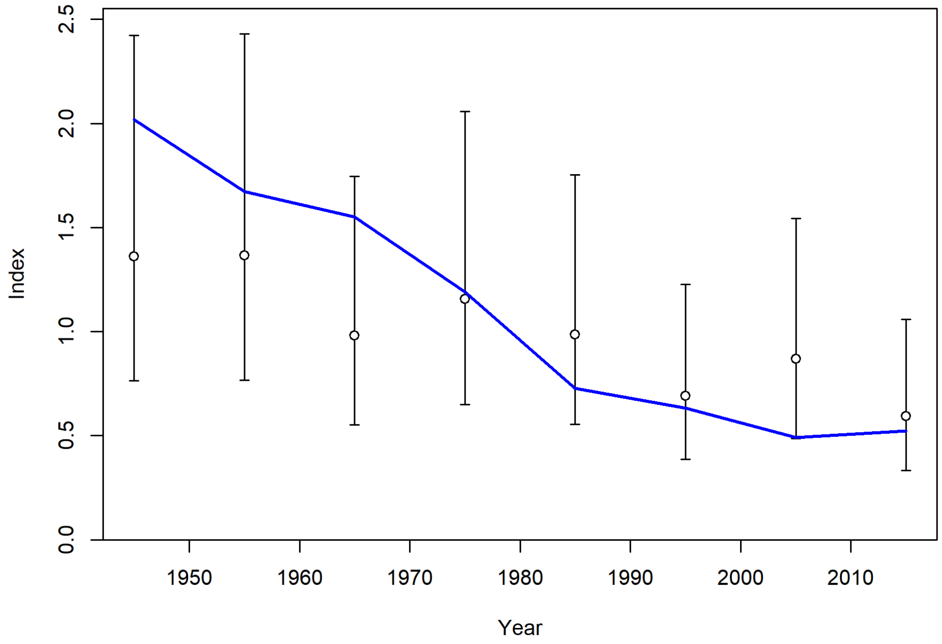

Figure 24: Model predictions (blue line) to historical decadal catch rates for Spanish mackerel for scenario E

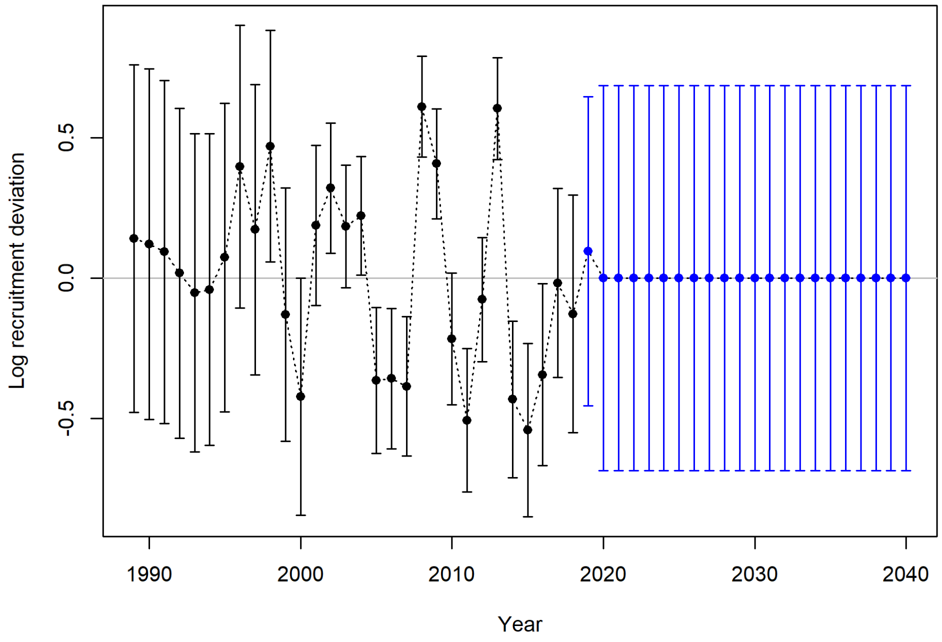

Figure 25 Recruitment deviations with 95% confidence intervals for Spanish mackerel for scenario E