Independent review of the stock assessment of east coast Spanish mackerel (*Scomberomorus commerson*) in Queensland, Australia.

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Prepared for

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Desk-top review
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Executive Summary

This is a desktop review of the 2021 Australian east coast Spanish mackerel (*Scomberomorus commerson*) fishery stock assessment by the Department of Agriculture and Fisheries (DAF) Queensland carried out during the period June 15 to 6 July 2021.

Major uncertainties for the stock assessment relate to total catch (including discards), catchability change and hyperstability in fishery CPUE and the assumed level of stock-recruitment resilience or steepness for the stock. I examined stock assessment settings and diagnostics in detail and agree that the assessment has been competently constructed and is adequate given the available data. The assessment uses a base-case and sensitivity scenario approach which is adequate for management purposes but lacks detail for scientific examination of the stock assessment model. I have provided advice on further consideration of model uncertainty and improvements to model documentation for scientific purposes.

It has long been recognised that steepness is a highly influential but uncertain parameter for fisheries stock assessments. Spanish mackerel do not fit the profile of a species likely to allow robust steepness estimation. This assessment chose a Beverton-Holt stock recruitment steepness fixed at a value of 0.45 for the base-case, based on a new meta-analysis (Thorson 2020). That low central value for steepness for Spanish mackerel is, in my experience with many assessments, inconsistent with previous accepted fisheries stock assessment practice for most schooling pelagic bony fish species and comparable existing DAF Spanish mackerel assessments that seem to centre near a value of 0.6. It therefore requires a much-expanded justification within the current assessment document. It is difficult to recommend use of such a value for a stock assessment base-case without having an improved understanding of why the meta-analysis produced this low value for the genus Scomberomorus.

The assessment report included a fairly comprehensive section on recommendations separated as they apply to data, monitoring and research, management and the stock assessment. I agree with those recommendations and particularly encourage any efforts to make use of earlier composition data that may enable extension of recruitment deviation estimation to earlier years, and exploration of the development of fishery-independent abundance indices such as from close-kin genetic analysis.

I am unable to support the conclusions regarding future harvest levels for the east coast Spanish mackerel stock until reservations regarding the most appropriate central value for steepness for the base-case are resolved.

1 Review Activities

This is a desktop review of the 2021 Australian east coast Spanish mackerel (*Scomberomorus commerson*) fishery stock assessment by the Department of Agriculture and Fisheries (DAF) Queensland (Tanimoto et al. 2021). The review process was sent out by DAF for competitive tender, and I was contracted to do the review. Formal terms of reference for the review were included in the contract. I received the Spanish mackerel stock assessment report and associated model input files on 9 June in preparation for commencement of the review on 15 June. During the review, I requested some additional documents listed in the Annex. Having access to the model files greatly assisted the review as I could examine more detailed diagnostics not provided by the assessment report and run my own diagnostic code on the models. It was discovered that I had not received the correct model SS executable file or input files used by scenario 8 due to problems transferring executable files via email, and this was corrected on 25 June. It seems that this problem may be avoided in future through transfer of assessment files using a file-sharing system such as OneDrive rather than by email. I provided my thoughts (largely as they appear in this review) regarding the use of a steepness value for the base-case assessment from the Thorson (2020) study to the assessment authors on 28 June. I completed the review on 6 July and sent my draft report to Mai Tanimoto, Alise Fox and Sue Helmke. Comments were received on 14 July and my report was adjusted according to those, without modification to overall findings. I thank all who I have had contact with for this review which progressed efficiently and professionally.

2 Review of stock assessment of Spanish mackerel

2.1 Scope of works for the review

The Department of Agriculture and Fisheries (DAF) is seeking an independent review of the “Stock assessment of Australian East Coast Spanish Mackerel fishery”. The review is not limited to, but should address the following points:

1. Provide comment model inputs and outputs and adequacy of these data to achieve the objectives of the assessment, including:
    a. Providing biomass ratio estimates in relation to the fishery reference points
    b. Assumptions used in the analysis of catch rates
    c. Assumptions used in the estimation of harvest sizes
    d. Confidence in model inputs and outputs
    e. Assumptions used in the stock synthesis models
    f. The adequacy of the population dynamic model used in the assessment
    g. Appropriate recommended biological catch / Total Allowable Catch.
2. Provide comment on the accuracy of key statements in the report summary and conclusion. How well are they supported by available data, analysis and literature?
3. Provide comment on recommendations for management and monitoring and inclusion of additional data in future assessments.
4. Any other outputs or graphical figures that the report could have provided.

2.2 Findings according to terms of reference

2.2.1 Provide comment model inputs and outputs and adequacy of these data in order to achieve the objectives of the assessment

2.2.1 a. Providing biomass ratio estimates in relation to the fishery reference points

For assessment purposes the east coast Spanish mackerel population is assumed to be a single reproductively isolated stock from Newcastle on the NSW coast to Cape York Peninsula in QLD. Predictable winter and spring feeding and spawning aggregations in northern tropical areas, movement of some fish to feed in southern waters during summer and autumn, and genetic studies support this assumption.

A time series of total spawning biomass (spawning output) is estimated for the stock as input to QDAF (2020) harvest control rules to reach future catch recommendations. The ratio of $B_{current}/B_0$ can be determined with more accuracy than absolute spawning biomass, and current management is based on a target for that ratio of 0.6 and a limit of 0.2 (QDAF 2020). Management currently relies on central values of these estimates from a selected base-case, and do not specifically take account of stock assessment uncertainty, except indirectly through selection of the target ratio and an uncertainty buffer. Uncertainty in stock assessment results is provided as asymptotic distributional ranges for the base-case, and via results from several sensitivity model scenarios.

2.2.1 b. Assumptions used in the analysis of catch rates

Queensland commercial line logbook data per fishing-operation day were used as input for catch rate standardisation for the commercial fishing fleet. O'Neill et al. (2018) describes issues that cause difficulty in interpreting catch rates from this fishery-dependent source that include: no consistent daily recording of each fishing operation's target species, vessels/skippers, gear, travel time, search time and efficiency, locations fished, active fishing time and zero catches. 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. A two-stage standardisation model was used. The first stage was a binomial GLM that predicted the probability of catching Spanish mackerel. The second stage was a LMM that predicted the annual catch magnitude for operations that had positive catches. Effects accounted for were year, latitude, season, wind, lunar phase, number of fishing operations and fishing power offset. This general form of standardisation is commonly applied in fisheries and seems appropriate. The assessment document did include a good summary of the standardisation procedure and main diagnostics produced.

The historical decadal catch rate from Thurstan et al. (2016) was not described in detail in the assessment document. However, it was stated that sample size and verification testing was done previously e.g. by O'Neill et al. (2018). This index (and associated fishing power estimates) does provide key input as the long-term abundance index for the assessment, beginning in 1941 and ending in 2013.

Accounting for change in fishing power is not commonly done with fishery-dependent abundance indices, but it is widely recognised as an important source of possible bias.

The work previously done to collect relevant information and to account for uncertainty in this assessment through application of differing fishing power scenarios seems to be a good approach to this difficult, important, and often ignored issue. In the absence of fishery-independent abundance indices, these efforts are particularly appropriate.

2.2.1 c. Assumptions used in the estimation of harvest sizes

The assessment document included an excellent figure (Figure 2.2) that summarises assumptions made to estimate harvest sizes from the various sources from 1911 to 2020. I recommend that such a figure be included in any assessment document where complicated catch history reconstruction has been carried out.

There are many assumptions that combine to enable the construction of a complete catch history. Major uncertainties include the mortality rate and size assumed for discarded fish for the recreational fishery, the relationship of recreational boat registrations to fishing effort for Spanish mackerel, the relative catch of commercial and recreational fishing effort, and hindcast or interpolated years of unknown catches for various fishery components.

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.

I agree that the current constructed catch history makes reasonable assumptions and is acceptable.

2.2.1 d. Confidence in model inputs and outputs

Confidence in model outputs derives from the correct use of an appropriate assessment model, while making full use of input data and estimating properties specific to the stock to allow total population estimation for management.

The current assessment has been developed using Stock Synthesis (SS) (Methot and Wetzel 2013) that has many advantages including use of input data of most types even if incomplete, verification via simulation of the basic dynamics and many assessment options, fitting of growth within the assessment, appropriate procedures for estimation of parameter uncertainty, wide use throughout the world with many previous applications, and automated methods for production and display of model diagnostics. There are also disadvantages of SS including a steep learning curve and potential risk of inappropriately using it and its many options, but I believe that the stock assessment team have undertaken appropriate formal SS training. I agree with the choice and appropriateness of the stock assessment framework and also acknowledge that there are perhaps equally capable alternatives available such as CASAL.

It has long been recognised that steepness is a highly influential but uncertain parameter for fisheries stock assessments. It has been generalised in the past that estimation of steepness within a stock assessment requires input data to support estimation of individual stock and recruitment points (informed by abundance or size/age composition data) that cover a wide range of stock size and potentially multiple fish-down and recovery periods (e.g. see Lee et al. 2012). Appropriate fixed values or prior distributions for steepness for most fish taxonomic groups have not been studied in detail, perhaps except for US Pacific coast rockfish. 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 schooling pelagic bony fish 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).

Spanish mackerel do not fit the profile of a species likely to allow robust steepness estimation. It does not provide long contrasting periods at different stock sizes that are informed by sufficient data to estimate recruitment deviations during those periods. Even so, the previous east coast Spanish mackerel stock assessment (O'Neill et al. 2018) estimated steepness within an ensemble approach that used 227 different models to attempt to encompass stock assessment uncertainty. This resulted in a clustering of 177 plausible scenarios with average steepness values of 0.31, 0.46, 0.61, 0.65 and 0.83. It is difficult to determine from the assessment documentation what aggregated average steepness value applies to all of the 11 stocks chosen for MCMC analysis. They did say that "stock status results and harvest reference points were sensitive to the reproductive rate r. MCMC analyses explored this uncertainty, with estimates of r < 4 [i.e. steepness < 0.5] considered conservative."

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.

The Thorson (2020) meta-analysis (as the title states) provides a new way of predicting recruitment density dependence and intrinsic growth rate for all fishes worldwide. This is accomplished via an integration of two previous meta-analytic models:

1. An evolutionary model of life-history parameters (Thorson et al., 2017) fitted to field measurements of size, growth, mortality and maturity for thousands of species worldwide as compiled by FishBase (Froese, 1990);

2. A hierarchical model for stock-recruit parameters (Thorson et al., 2014) fitted to stock and recruitment measurements from the original RAM database (Myers, Bridson, & Barrowman, 1995).

This seems to be a fine approach, possibly alleviating our previous difficulty in choosing appropriate steepness values for many species. It also potentially displaces previous accepted practice for fisheries stock assessment scientists. I was curious whether this new approach had gained acceptance by groups that recommend best or good practice for fisheries stock assessment, but this method is so new that information on that is not yet available. From that viewpoint, I recommend a degree of caution at this stage. It is possible to seek values of steepness from this new study at whatever taxonomic level seems most appropriate, and there is no guidance yet available for that either. The authors noted that the resultant steepness value for family Scombridae was 0.69. However, it was also noted that a wide range of steepness values existed when results were examined by genus. The value for genus Scomberomorus was chosen for this assessment, with a value of 0.45. 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.

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. I investigated how many Scomberomorus species assessments were in the RAM database and found six (4 US National Marine Fisheries Service king and Spanish mackerel, 2 Fisheries Agency of Japan Spanish mackerel), three of which may relate to those mentioned. I believe that follow-up work continuing from this is required to understand why the Thorson (2020) study produces a low steepness value for the genus Scomberomorus. It is difficult to recommend use of such a value for a stock assessment base-case without having that understanding.

2.2.1 e. Assumptions used in the stock synthesis models

The Spanish mackerel SS model is simply structured. It is annual, 1 spawning season, 1 fishing fleet, 1 survey, 1 area, 2 gender, 2 CPUE, with length/age/age-length compositions associated with the fishing fleet via simple length-based asymptotic selectivity and no modelling of discards (treated as additional catch). Model tuning included recruitment deviation bias adjustment and application of recommended multipliers for length and age composition data to adjust sample sizes. These general model features should all have been described in the assessment document under model assumptions. I examined model settings in comparison with others I have reference to and found none that were unusual except use of maturity option 6 which is less common, but simply allows maturity to be input by length as a vector.

R4SS output for the base-case revealed some notable aspects, but none of particular concern when compared to output of other accepted SS assessments. Fit to historical decadal catch rate shows a systematic pattern that would fail a runs test – 3 points fitted above observations 1945 to 1965, 4 points fitted below observations 1985 to 2015. This suggests some conflict in the model between early CPUE (the period of major stock biomass decline) and other model settings. Overall aggregated fits to composition data are relatively poor and residual plots show exceptionally large values at the tails of the distribution of the available data. However, it is recognised that the input data are relatively “noisy”.

2.2.1 f. Adequacy of the population dynamic model used in the assessment

For an assessment that used a base-case and uncertainty scenario approach, adequacy could be defined as whether the base-case provides a representative mid value among potential alternative models that adequately explore known major uncertainties. In addressing this, it would be useful if assessment documents provided a table that summarises those uncertainties and how the assessment has addressed them.

In Table 1 I present my own interpretation of a list of uncertainties for the current Spanish mackerel assessment and their associated questions. Most commonly for assessment documentation, such questions are converted to alternative scenarios that are examined more thoroughly via sensitivity analyses. The relative importance of uncertainties is often judged according to their influence on the stock assessment results.

Table 1 Dimensions of uncertainty and level potentially addressed via alternative model scenarios

Uncertainty	**Degree addressed**	**Comments/questions**
Total catch	No	A single best estimate for historical catches was used.
Fishery CPUE	No	Sensitivity to weighting applied in the assessment to recent and historical commercial CPUE series was not examined.
Fishing power change	Yes	Scenarios were constructed that gave different emphasis to fishing power change through time.
CPUE hyperstability	Partly	Scenarios were constructed that accounted for CPUE hyperstability or not, as a component of the commercial fishery CPUE standardisation.
Steepness	Yes	Sensitivity to different fixed steepness values around the base-case value was examined. Note reservations about the central base-case value chosen.
Natural mortality	Yes	Natural mortality was estimated for most scenarios.
Discards	Partly	Discarding was not modelled as part of the assessment, and data are probably insufficient to allow that. Assumptions about discards and discard mortality affect total catch for the recreational fishery and potentially catch and CPUE for the commercial fishery via effects such as shark depredation. Shark depredation was acknowledged and examined by additional sensitivity analyses.

Uncertainties in model implementation in this report are examined through the presentation of a base-case and 7 sensitivity model scenarios that examine alternative plausible values for steepness, natural mortality (fixed in one scenario), how CPUE interpretation included hyperstability and fishing power effects. Dimensions of uncertainty presented do cover apparent major ones, but a more comprehensive list can potentially be constructed. 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.

Hyperstability is a difficult problem to address for this fishery, and I think it has been recognised that the probability of zero catch approach used is perhaps the best approximate way to address it given the available data. Recommendations to collect additional data in future on aspects such as search effort and travel time may allow the problem to be further resolved via catch rate modelling, perhaps allowing extension of those results into the available historical data.

I agree with the authors that the sensitivity scenarios span a range of alternative model structures that are useful in conveying model uncertainty to fishery managers. My suggestions here apply to a wider range of sensitivity and other tests that could be examined and presented to allow improved scientific judgement of the behaviour and uncertainty of the assessment models.

Likelihood profiles provide useful insight to model behaviour, and it was good to see those included for R0 for the base-case and scenario 4. These indicate that those models achieved minimum values for the range of R0 examined, but that a probable implausible minimum also exists for extremely high R0 values. They also show that the different scenarios are greatly different in which model components (compositions, priors, indices) have the greatest influence on the minimum overall likelihood value.

I agree that sensible decisions have been made to choose among alternatives for the base-case, except my reservations regarding the central value for steepness already discussed. There is some potential interaction in accounting for hyperstability and fishing power, and I agree with the author’s decision to account for hyperstability and use the square root version of fishing power for the base-case.

The population dynamics model used for this assessment is adequate.

2.2.1 g. Appropriate recommended biological catch

Policy for the estimation of catch levels to achieve a target spawning biomass is outlined by QDAF (2020). Model results were projected forward following the 20:60:60 harvest control rule. Results show that this was done to 2040. This harvest control rule is consistent with the DAF Sustainable Fisheries Strategy. 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. I agree that the form of the harvest control rule and therefore projections follow from the policy and are appropriate. Methods used are therefore acceptable, but reservations remain regarding the base-case value for steepness used to make those projections.

2.2.2 Provide comment on the accuracy of key statements in the report summary and conclusion. How well are they supported by available data, analysis and literature?

For management purposes, the report adequately describes important aspects of the species biology, current assessment input data, model construction, and model results. I have discussed above some potential improvements in that regard, but mostly for scientific rather than management purposes. Uncertainty in the spawning biomass trajectory within the current base-case is presented, as well as the spawning biomass series for various sensitivity scenarios. Future harvest levels according to the harvest control rule for the base model as well as sensitivity scenarios were also provided. These are adequate to describe central values for future harvest recommendations and the uncertainty of those to some extent.

I am unable to support the conclusions regarding future harvest levels for the east coast Spanish mackerel stock until reservations regarding the most appropriate central value for steepness for the base-case are resolved.

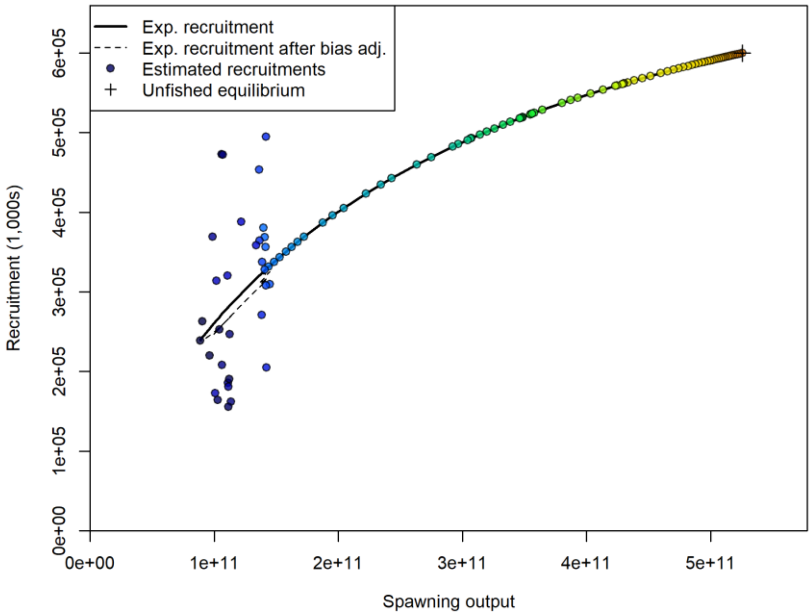
2.2.3 Provide comment on recommendations for management and monitoring and inclusion of additional data in future assessments

The assessment report included a fairly comprehensive section on recommendations separated as they apply to data, monitoring and research, management and the stock assessment. I agree with those recommendations. 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. I have included recommendations for additional exploration of model uncertainty in this report. It is a standard research recommendation to develop fishery-independent abundance indices for fisheries that do not have them. Whether this is possible is normally determined by the value and importance of the fishery. How this might be cost-effectively achieved for Spanish mackerel should be considered – e.g., close-kin genetic analysis as ready recommended by the authors. This is a significant problem for this fishery as it is reasonable to expect that catchability change and hyperstability of fishery-dependent abundance indices will be an on-going problem for future stock assessments.

2.2.4 Any other outputs or graphical figures that the report could have provided to aid fishery management processes

Outputs and graphical figures provided in the report were sufficient for fishery management purposes. However, they were not sufficient to allow scientific review of the stock assessment. As I was provided with model input files I was able to run my own diagnostics to support this review. I believe that it has become necessary to provide such files to scientific reviewers to allow a thorough examination of the assessment implementation.

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. For east coast Spanish mackerel this makes it noticeably clear that recruitment deviations are only estimated for a narrow range of spawning output values. While this is appropriate given available data, this plot emphasises that much of the stock history is minimally informed by data other than catches and potentially assumptions about life history such as steepness.



Where assessments are regularly made for the same species using the same modelling framework, an opportunity arises to provide an audit trail that comprehensively and transparently shows model changes since the last assessment – commonly called a bridging analysis. Such a bridging analysis involves examination of absolute spawning biomass and recruitment trends over time after the application of sequential changes to model source code version revision, structural assumptions, changes to fixed parameter values or priors, and the inclusion of recent data (source by source where possible – catch, index, age and length composition by fleet). This provides a continuum from the previous assessment to the current base-case. Such a process (or an improvement on it) could be considered in the future for any regular SS assessments by DAF. It is understood that a detailed bridging analysis may not be required if the absolute biomass and recruitment series have changed little from one assessment to the next, but experience says that this is rarely the case.

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. Provision of such a bridging analysis gives confidence to interested groups (e.g. managers or industry) that there is consistency among stock assessments. It also highlights where differences have arisen from – either via changes in modelling approach, or new data.

The ensemble approach to stock assessment is one that has been increasingly recommended (e.g. see Thorson 2020). A common current approach as in the assessment here uses a base-case and additional scenarios that represent axes of uncertainty as in the current assessment. 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.

Inclusion of the overall likelihood values in the summary table of sensitivity analysis results (Table 3.4) is useful, although differences in model structure and tuning sometimes make those statistically incomparable. 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.

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.

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. Such a document, if comprehensive, could be examined independently by statisticians for sign-off as procedures that can simply be updated for assessment purposes in the future, potentially without detailed re-examination as part of stock assessment reviews.

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Supplementary data files

SS starter, .ctl, .dat, and forecast files for the base-case model and 9 additional scenarios.