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Southern Bluefin Tuna
Inter-sessional Science 2016-17

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Cover photo: Russ Bradford, CSIRO. Fishing, tagging and releasing SBT for the CCSBT gene-tagging program, Great Australian Bight, March 2017.

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Southern Bluefin Tuna Inter-sessional Science 2016-17

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The CSIRO and Department of Agriculture and Water Resources funded a related project on Transition to a new Management Procedure for SBT 2016-17. Papers from this project are in Appendix A5-A7.

The team of CSIRO scientists involved included:

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Campbell Davies

Rich Hillary

Jessica Farley

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Non-technical Summary

CSIRO provides scientific support and advice to AFMA, ABARES, Department of Agriculture and Water Resources, and Australian Industry on southern bluefin tuna inter-sessional science, and participates in the Australian delegation to the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) Extended Scientific Committee (ESC). The inter-sessional science project in 2016/17 included:

- Preparation and running the Management Procedure (MP) in 2016 to recommend the 2018-2020 global Total Allowable Catch (TAC) for the associated national allocations.
- The regular scientific data exchange, evaluation of indicators and potential for exceptional circumstances, review of progress of the CCSBT Scientific Research Program.
- Participation and attendance at the September 2016 ESC and 2 day technical Operating Model and Management Procedure (OMMP) meetings.
- Approaches for inclusion of Unaccounted Mortality in TAC from 2021 onwards.
- Preparation for the 2017 stock assessment.
- Otolith reading (ageing) and estimates of age-frequency for the Australian surface fishery.

CSIRO prepared and presented a series of papers for the OMMP and ESC meetings which were funded through specific contracts with AFMA, Department of Agriculture and CCSBT. Ann Preece, Campbell Davies and Rich Hillary, from CSIRO, attended the OMMP and ESC meetings, presented papers, participated in discussions, completed technical operating models runs and analyses of results and were rapporteurs for meeting reports.

Key agreements reached by the OMMP and ESC in 2016 included:

- Advice for recommended global TAC in 2017 (14,647t) and 2018-2020 (17,647t) to the Commission.
- Use of the “MP approach” for incorporating uncertainty in total catches in future management strategy evaluation and new management procedure currently under development.
- The 2017 workplan for the development of a new MP to focus on reconditioning of operating models for the 2017 SBT stock assessment, which can then be used for testing candidate MPs in 2018.
- The methods for incorporating new data into the OM in preparation for the 2017 stock assessment and for future management strategy evaluation.
- The need for a maturity workshop and age-validation workshop in 2017.

These outcomes and recommendations from this project, the OMMP and ESC were supported by the Commission.

This SBT Inter-sessional Science 2016-17 project covered the planned priority items in the 2016 CCSBT work program, the AFMA SBT strategic plan, and the work up to June 2017 on the CSIRO

components of the CCSBT 2016 data exchange, and preparation for the 2017 stock assessment. All the objectives of the project have been met.

Keywords

Southern bluefin tuna, Commission for the Conservation of Southern Bluefin Tuna, stock assessment, operating models, management procedure, exceptional circumstances, management strategy evaluation.

1 Background

Through the SBT Inter-sessional Science Project, CSIRO provides scientific support and advice to AFMA, ABARES and Australian Industry, and contributes to the objectives of the Australian delegation at the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) Extended Scientific Committee (ESC) and its working groups.

The CCSBT has adopted a management procedure (MP) with a prescribed schedule of activities, the main component of which was to run the CCSBT MP in 2016 to set the 2018-2020 TAC. Preliminary reconditioning of the SBT operating models with updated data, scheduled for June 2017, is in preparation for the 2017 full stock assessment and Management Strategy Evaluation of SBT MPs. The CCSBT also requested advice on methods for including unaccounted mortalities in TAC advice.

The SBT inter-sessional science project incorporates archiving and reading (ageing) otoliths collected in the Australian fisheries, which had previously been covered in a separate project. These data are requested from each member's fisheries by the CCSBT.

The implementation schedule for the CCSBT MP was altered in 2015 with the CCSBT decision to cease the aerial survey and transition to a new MP by 2019. This will involve a significant amount of technical work and extensive, iterative consultation with ABARES, AFMA and Industry to ensure a successful outcome (i.e. a new CCSBT MP that is consistent with Australia's objectives in the Commission). The preliminary stages of the new MP work plan (2016-17) are covered in a separate project with the Department of Agriculture and Water Resources. The MP development work plan has essential links with this AFMA SBT Inter-sessional science 2016-17 project.

2 Need

The CCSBT ESC and inter-sessional science work plan in 2016/17 included the regular activities covered in each inter-sessional science contract, the work planned in the original MP implementation schedule, and additional work for the Australian delegation related to the requests from the CCSBT Commission.

The regular inter-sessional science work includes the scientific data exchange, evaluation of indicators and potential for exceptional circumstances, review of progress in the CCSBT Scientific Research Program, attendance at ESC and Operating Model and Management Procedure (OMMP) technical meetings, consultation and planning discussions.

The implementation schedule for the CCSBT MP involved running the Management Procedure in 2016 to set 2018-2020 TACs, and preparing for the 2017 full stock assessment, which will involve preliminary reconditioning of the operating models including incorporation of Close-Kin Mark Recapture data. The reconditioned operating models will also be used for management strategy evaluation of new candidate MPs. The CCSBT also requested advice from members on approaches for including unaccounted mortality for the 2021 TAC block onwards.

This SBT inter-sessional science project also includes the work on routine otolith archiving, ageing and developing age-length keys for the Australian SBT surface fishery. These data are required to be provided to the CCSBT by each member. This work is usually undertaken under a separate project with AFMA, but has been included in this project to reduce administration.

New CCSBT activities include the first stages of development of new candidate MPs to use a new recruitment index from gene-tagging data and, potentially, close-kin data. The development of a new MP and the intensive domestic consultation is an intensive piece of work, similar to the work undertaken in the years leading up to the 2011 adoption of the current MP. The initial preparatory work in 2016-17 will be covered in a separate project with the Department of Agriculture and Water Resources.

This project provides scientific advice and stock assessment advice to the SBTMAC and AFMA and covers the preparation and attendance at domestic and international meetings associated with Australia’s participation in the CCSBT.

3 Objectives

1. Participate in planning, consultation ESC and Operating Model and Management Procedure (OMMP) meetings, inter-sessional webinars, review of exceptional circumstances and 2017 CCSBT data exchange, and provide scientific advice to AFMA, ABARES, Industry and the CCSBT.
2. Prepare and run the MP to provide advice on the 2018-2020 TAC.
3. Provide advice on approaches for including unaccounted mortality for the 2021 TAC block and beyond.
4. Prepare for the 2017 stock assessment by preliminary reconditioning the Operating Models (OM) after data exchange in 2017.
5. Undertake the routine archiving and ageing of 100 SBT otoliths from the Australian surface fishery, and provide data to CCSBT. Construct age-length keys and estimate the age distribution of the Australian catch.

4 Results and Discussion

The project results are discussed for each objective below:

4.1 Objective 1: 2016 ESC and OMMP preparation

Participate in planning, consultation, ESC and Operating Model and Management Procedure (OMMP) meetings, inter-sessional webinars, review of exceptional circumstances and 2017 CCSBT data exchange, and provide scientific advice to AFMA, ABARES, Industry and the CCSBT.

CSIRO prepared and presented a set of papers (Appendix A.1-A.7) for the 2016 ESC and two day technical OMMP meeting, provided advice on the agendas and planning for the 2016 OMMP and ESC meetings, attended planning meetings in Canberra, participated in phone hook-up meetings with ABARES and Inter-Departmental Committee meetings and contributed to the CCSBT CPUE inter-sessional webinar held in late June 2016. The 2016 Extended Scientific Committee (ESC) was held on 5-10th September 2016, in Kaohsiung, Taiwan, and was preceded by a technical meeting of the OMMP working group (3 and 4th September, 2016). Campbell Davies, Rich Hillary and Ann Preece (CSIRO) participated as part of the Australian delegation, presented these papers, led and participated in discussions and rapporteured meeting reports.

The review of exceptional circumstances and meta-rules paper (Preece et al 2016a) provided the guiding structure for discussion of exceptional circumstances and the actions that they ESC should consider for both the TAC in 2017 (recommended in 2013) and the new TAC recommendation for the 2018-2020 TAC block. There were 3 exceptional circumstances to consider: the high 2016 aerial survey data point, the potential change in selectivity in the Indonesian Fishery and the potential for catches to be greater than the agreed TAC. No new exceptional circumstances were considered around the CPUE longline data, however we should note that there are unresolved uncertainties in the data used in the standardisation from the over-catch detected in the Japanese Market Review, which affects the whole time-series. The ESC concluded there was no reason to take action to modify the 2017 TAC recommendation (14,647t) or the 2018-2020 TAC recommendations (17,647t) in relation to its review of exceptional circumstances.

An update of inter-sessional science projects were provided to the ESC including details in Farley and Eveson (2016) on Australian otolith and ovary collection activities, direct ageing and length at age keys for the Australian surface fishery. The collection of ovaries to provide data for an independent estimate of age at maturity has been recognised as high priority research but is currently unfunded. Opportunistic sampling of 158 SBT ovaries by CSIRO has been undertaken with the co-operation of industry members. Two CCSBT workshops on maturity and ageing were scheduled for 2017.

The 2017 CCSBT data exchange items covered in this project have been completed on time. The delivery of nominal CPUE time series will be delivered before the due date of 15th June. This occurs after the CPUE input data file has been created by the CCSBT Secretariat.

CSIRO has had further consultation with AFMA, ABARES, the Department of Agriculture and Water Resources, Industry and SBTMAC on outcomes of the Commission meeting, future work plans, research priorities, development of a new management procedure and the role of operating models for stock assessment and management strategy evaluation.

4.2 Objective 2. Management Procedure TAC advice 2018-2020

Prepare and run the MP to provide advice on the 2018-2020 TAC.

CSIRO updated the code and data files used to run the stand-alone version of the MP, to calculate the recommended TAC for the 2018-2020 block (Hillary et al 2016a). The recommended increase to the TAC was 3,000t. The new recommended TAC is 17,647t per annum (2018-2020). The MP model performance and data inputs were examined in detail and agreed diagnostics presented. Detailed information on how the MP uses the two input data series in the calculation of TAC was provided, highlighting that the trend in CPUE, and not the high aerial survey data points, had the major influence on the recommended TAC increase. There has been a positive trend in the CPUE data, since 2007, and higher average aerial survey indices for the past 5 years relative to the average of the aerial survey series. The MP has been designed to be conservative, with respect to changes in recruitment, by reacting slowly to recruitment levels higher than the historical average (which is the current situation), and reacting strongly to signals of low recruitment. The combination of the CPUE and aerial survey data in this way led to better performance outcomes than other candidate MPs during testing in 2011, and also in 2015 when the value of a fishery independent recruitment index in the MP was assessed relative to CPUE only MP models (Anon 2016).

The ESC agreed that the MP should be used to calculate the recommended global TAC for the 2018-2020 block. The recommended global TAC advice was adopted by the Commission in October 2016.

4.3 Objective 3. Approaches for inclusion of Unaccounted Mortality

Provide advice on approaches for including unaccounted mortality for the 2021 TAC block and beyond.

The Commission had proposed two approaches for including unaccounted mortality in future TAC recommendations, following the sensitivity tests completed in 2014 indicated that potential catches over the TAC could undermined the CCSBT rebuilding plan. CSIRO provided scientific advice on the methods (Preece et al 2016b), and recommended that the “MP approach” be used in future, because it ensures that advice on the TAC has taken into account these additional catches, maintains the CCSBT’s commitment to science-based management and the work required to provide this form of advice has been built into the ESC work plan to develop a new MP.

The technical methods for incorporating uncertainties in the total catches taken by members and non-members will be included in updated and reconditioned operating models to test and select a new MP. Preece et al (2016b) also noted that data on historical member and non-member catches, as well as potential future catches, will be needed for reconditioning operating models for MP testing. Following presentation of this paper, the ESC recommended that the MP approach should be used in future TAC recommendations and that all sources of mortality should be included in testing the MP to ensure that the global TAC decisions will be robust to these uncertainties in total catches. In addition, the ESC agreed that the new MP, tested using MSE, will relate to the global TAC for Members and CNMs, only. This option avoids the need for accurate and precise estimates of unaccounted mortality, and the related uncertainties in these estimates, to deduct from the MP recommended TAC at each TAC setting interval. Rather, plausible ranges and sources of unaccounted mortality are incorporated in the MSE testing of candidate MPs to ensure, to the extent possible, that the MP implemented will be robust to these levels and sources of unaccounted mortality, should they be occurring. The Commission adopted the ESC advice to use the “MP approach” for the 2021 TAC block and beyond. The Commission agreed in 2015 to deduct an estimate of unaccounted mortality from the 2018-2020 TAC as an interim measure until the new MP is developed and tested.

4.4 Objective 4. 2017 stock assessment preparation

Prepare for the 2017 stock assessment by preliminary reconditioning the Operating Models (OM) after data exchange in 2017.

The scheduled 2017 stock assessment includes an update of the 2014 stock assessment models with recent monitoring data from the regular CCSBT scientific data exchange as well as incorporation of new data from the close-kin mark recapture research project (Bravington et al 2015; Davies et al 2016; Anon 2016). The data exchange and update of data files for running the SBT operating models will be completed in mid-June 2017. The preliminary re-conditioning of the operating models will be discussed at the 8th OMMP technical meeting in Seattle 19-23rd June, 2017. The OMMP meeting will review fits to data and the reference set of operating models for the “assessment of stock status” and sensitivity tests. The full stock assessment will be completed as part of the next Inter-sessional Science project (Preece, 2017) for the 2017 CCSBT Extended Scientific Committee meeting.

A CSIRO-FRDC (Davies 2016) project to genotype existing and new tissue samples to detect parent-offspring pairs and half-sibling pairs, commenced in October 2016, to provide additional data for the SBT operating models on adult abundance and an updated independent close-kin assessment. A new SNPs-based genotyping method, statistical analyses and additional tissue samples collected since the completion of the original close-kin project have provided data on adult abundance that covers a longer time period (previously 2002-2007, now 2002-2012) and an additional, independent source of source of kin-relationship: half-sibling pairs among cohorts. The POPs data can be integrated into the SBT OM using the same methods developed in 2012-13 (Hillary et al, 2012, 2013). The Half-Sibling Pairs data also provide information on adult abundance and mortality (Bravington et al 2015, 2016). The 2016 OMMP meeting agreed on the technical specifications (Hillary et al, 2016b) for how to incorporate the new data in conditioning the operating models. Code has been written to incorporate changes required for including the new Close-Kin Mark-Recapture data and this will be reviewed at the 8th OMMP meeting.

4.5 Objective 5. Otolith ageing for the Australian surface fishery

Undertake the routine archiving and ageing of 100 SBT otoliths from the Australian surface fishery, and provide data to CCSBT. Construct age-length keys and estimate the age distribution of the Australian catch.

The report for the 2015-16 ageing project was presented at the 2016 CCSBT ESC (Farley and Eveson, 2016). Over 100 otoliths have been collected and archived from the Australian surface fishery in 2017. Age (from otolith reading) and length data for the Australian surface fishery in the 2016 season have been provided to the CCSBT as part of the scientific data exchange. Proportions-at-age were estimated using standard age-length-keys and by applying the method developed by Morton and Bravington (2003) to the combined age-length data and length frequency data obtained from the Surface Fishery catch sampling program.

4.6 Transition to a new MP

Project with the Department of Agriculture and Water Resources.

Three papers were prepared and presented to the OMMP and ESC under this separate, but related project, on development of a new MP (Davies et al, 2016), methods for including new data in reconditioning operating models (Hillary et al, 2016b), and methods for generating data in projections for MP testing (Hillary et al, 2016c). The OMMP agreed and ESC recommended that the new data sources described in Hillary et al (2016b, c) and Davies et al (2016) should be considered in candidate management procedures, and agreed that it would be useful to explore a broad range of forms of candidate MPs and their performance under MSE testing. The meetings also agreed on the technical specifications for how to incorporate the new data in conditioning the OM, as outlined in Hillary et al (2016b). These recommendations form part of the work program for reconditioning the operating models for the 2017 stock assessment and subsequent MSE testing of candidate MPs.

Given the substantial workload associated with an updated stock assessment in 2017, which may identify new issues to be resolved in the conditioning the OMs, the timetable for development of a new MP 2017-2019 was revised to separate the stock assessment delivery from development and testing of new MPs. The main focus of the OMMP meeting in June 2017 will be on the reconditioning of operating models for the stock assessment, with the MP development work becoming the focus of the work program following completion of the stock assessment at the Sept 2017 ESC.

5 Benefits / Management Outcomes

Stakeholders in the Southern Bluefin Tuna Fishery benefit from the implementation of a scientifically designed and tested management procedure (Hillary et al, 2016a). The CCSBT MP is used to recommend the global TAC, and encompasses meta-rules that provide a regular schedule and agreed process for review of data, methods, and MP performance. The MP has provided stability, increased certainty and increases in the Australian TAC, over the past 6 years. These benefits have been attested to by Industry, fisheries managers and E-NGOs. An additional benefit has been the time and strategic focus this orderly science and management process has provided to concentrate on planning and prioritising and securing the necessary funding for future inter-sessional science work plans as well as addressing strategic science needs.

In 2016, through this project, CSIRO provided substantial input to the 2016 OMMP and ESC meetings; presenting papers and leading discussions that informed decisions made at the ESC and Extended Commission, providing technical input to meetings, summarising technical model changes and runs, and rapporteured meeting reports.

The adopted management Procedure was run in 2016 to set the global TAC for the 2018-2020 block, following review of data inputs and consideration of meta-rules and evidence for exceptional circumstances. The MP TAC increase of 3000t was recommended by the ESC and adopted by the Commission. The structured nature of this review and consideration of exceptional circumstances was central to the ESC and Commission being prepared to agree the full 3000t recommended increase in the global TAC from the MP. The three potential sources of exceptional circumstances identified by the ESC generated substantial debate and consideration around this TAC recommendation. In the absence of the agreed process for MP implementation and review, it is likely, given history, that this situation could have developed into contested scientific views and an *ad hoc* negotiation at the Commission which, had it occurred, would weaken the operation of the Commission and it’s good standing among tuna RFMOs. It will be important to retain and refine this implementation framework as part of the development of the new MP.

Accounting for all sources of mortality remains an issue for scientific evaluation and performance of the MP in rebuilding the SBT stock, in addition to providing robust scientific advice on stock status. An amount to account for non-cooperating non-member catches was agreed by the Commission to be deducted from the 2018-2020 TAC, as an interim measure, before a new MP is developed and implemented that is robust to these uncertainties in total catches. The 2016 ESC recommended an “MP approach” which incorporates uncertainty in total catch in the Management Strategy Evaluation of the new MPs which would be used to set TAC from 2021 onwards. The future MP TAC recommendations (from 2021 onwards) will be for members and cooperating non-members only, with no need to estimate the amount of non-member catch to be deducted.

The work plan for the transition to a new management procedure was reviewed at the ESC to focus the 2017 OMMP and ESC on the scheduled stock assessment. The existing schedule of events related to the implementation framework for the MP remains in place, with a stock assessment in 2017 and MP-based recommendations for the 2021-2023 TAC block in 2019.

The preparatory work for the 2017 stock assessment has included code changes for incorporation of substantial informative new data from the close-kin mark-recapture project. These data provide direct information on adult abundance, and will be included in the 2017 assessment of stock status at the ESC in September.

The ESC has reviewed future monitoring and research priorities. The new CCSBT Scientific Research Program has made substantial investment in projects providing monitoring data for recruitment (gene-tagging) and adult abundance (close-kin mark recapture). CSIRO's development of cost-effective methods for monitoring the stock have been incorporated into the CCSBT Scientific Research Program and included in the Commission's budget in 2017. These research programs often have flow on effects for other Australian and International fisheries, potentially leading to improved monitoring, assessment and management of other global stocks.

The direct benefits of this project include: government, industry and community confidence that the SBT rebuilding strategy and MP implementation program is based on the best scientific advice; that previous TAC reductions and current TAC settings have been effective in reducing fishing mortality on the stock and are providing for rebuilding consistent with the Commission's rebuilding plan; and increases in the TAC, with associated economic returns to the Australian Industry and wider community.

6 Conclusion

This SBT Inter-sessional Science 2016-17 project covered the identified priority items of SBTMAC for the 2016 CCSBT work program, and the work up to June 2017 on the CSIRO components of the CCSBT 2017 data exchange. All the objectives of the project have been met.

CSIRO has delivered thorough, rigorous scientific advice on the key agenda items at the 2016 OMMP technical meeting and ESC meeting, and provided briefings, consultation and advice to AFMA, ABARES, Industry and SBTMAC.

The CCSBT MP has been used three times, as scheduled, to recommend the TAC. Each time the Commission has agreed the recommended TAC. In 2016 the TAC increased by 3000t for the 2018-2020 block.

The Extended Commission has requested that the ESC transition to a new Management Procedure that will use gene-tagging data as the recruitment index. This brings forward and alters the previously agreed MP implementation and review process (Anon 2013, Attachment 10). Development and MSE testing of new MPs will involve a substantial amount of work for the inter-sessional science over the next several years, given the ambitious schedule agreed by the CCSBT and the scope for wider range of MP behaviour relative to the 2009-2011 MP development process. The updated MP schedule of events involves a full stock assessment in 2017, MP development 2016-2019 and TAC setting using a new MP in 2019, assuming an MP has been agreed for implementation by this schedule.

Outputs from this inter-sessional science project have been considered in depth by OMMP and ESC and are reflected in recommendations and advice of the ESC to the Commission, and by the Extended Commission in the 2016 TAC decision and their funding decisions and approach to the future work program.

7 References

Anon. 2015. Report of the sixth operating model and management procedure technical meeting. Commission for the Conservation of Southern Bluefin Tuna, 30-31 August, Incheon, South Korea.

Anon. 2016. Report of the twenty first meeting of the Scientific Committee. Commission for the Conservation of Southern Bluefin Tuna, 10 September, Kaohsiung, Taiwan.

Bravington M, Eveson P, Grewe P, Davies C. 2015. SBT Close-Kin Mark-Recapture: options for the medium term. Report CCSBT-ESC/1509/19 prepared for the twentieth meeting of the CCSBT Extended Scientific Committee, 1-5 September, Incheon, South Korea.

Bravington MV, Skaug HJ and Anderson EC. 2016. Close-Kin Mark-Recapture. Statistical Science 2016, Vol. 31, No. 2, 259–274 DOI: 10.1214/16-STS552

Davies CR. 2016a. Next-generation Close-kin Mark Recapture: using SNPs to identify half- sibling pairs in Southern Bluefin Tuna and estimate abundance, mortality and selectivity. FRDC-CSIRO Project 2016-044.

Davies, C.R., Preece A., Hillary R. 2016b. Initial considerations on forms of candidate management procedures for SBT. CCSBT-OMMP/1609/6, CCSBT- ESC/1609/BGD-5.

Farley J, Eveson P. 2016. An update on Australian otolith and ovary collection activities, direct ageing and length at age keys for the Australian surface fishery. CCSBT-ESC/1609/15.

Hillary R, Preece A, Davies C, Bravington M, Eveson P, Basson M. 2012. Initial exploration of options for inclusion of the close-kin data into the SBT operating model. Report CSBTESC/1208/21 prepared for the seventeenth meeting of the CCSBT Extended Scientific Committee, 27-31 August, Tokyo, Japan.

Hillary R, Preece A, Davies C. 2013. Updates to the CCSBT Operating Model including new data sources, data weighting and re-sampling of the grid. CCSBT-ESC/1309/15.

Hillary RM, Preece AL, Davies CR, Kurota H, Sakai O, Itoh T, Parma AM, Butterworth DS, Ianelli J, Branch TA. 2015. A scientific alternative to moratoria for rebuilding depleted international tuna stocks. Fish and Fisheries 17(2): 469-482.

Hillary R, Preece A, Davies C. 2016a. MP results and estimation performance relative to current input CPUE and aerial survey data. CCSBT-ESC/1609/18.

Hillary R, Preece A, Davies CR. 2016b. Reconsideration of OM structure and new data sources for 2017 reconditioning. CCSBT-OMMP/1609/4, CCSBT- ESC/1609/BGD-4.

Hillary R., Preece A., Davies C.R. 2016c. Methods for data generation in projections. CCSBT-OMMP/1609/7, CCSBT- ESC/1609/BGD-6.

Morton, R. and Bravington, M. 2003. Estimation of age profiles of southern bluefin tuna. CCSBT Scientific Meeting; 1-4 September 2003, Christchurch, New Zealand. CCSBT-ESC/0309/32.

Preece A, Davies C. R., Hillary R. 2016a. Meta-rules and exceptional circumstances considerations. CCSBT-ESC/1609/17.

Preece, A., Davies, C.R. and Hillary, R. 2016b. Advice on incorporating Un-Accounted Mortalities in stock assessment and Management Procedure evaluation and implementation. CCSBT-OMMP/1609/05, CCSBT- ESC/1609/BGD-3.

Preece AL. 2017. AFMA ARC Application: SBT Inter-sessional Science 2017-18 project.

8 Appendices

A1. Farley J, Eveson P. 2016. An update on Australian otolith and ovary collection activities, direct ageing and length at age keys for the Australian surface fishery. CCSBT-ESC/1609/15,

A2. Hillary R, Preece A, Davies C. 2016a. MP results and estimation performance relative to current input CPUE and aerial survey data. CCSBT-ESC/1609/18

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A7. Hillary R., Preece A., Davies C.R. 2016c*. Methods for data generation in projections. CCSBT-OMMP/1609/7, CCSBT-ESC/1609/BGD-6.

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An update on Australian otolith and ovary collection activities, direct ageing and length at age keys for the Australian surface fishery.

Jessica Farley and Paige Eveson
CCSBT-ESC/1609/15

Prepared for the Extended Scientific Committee for the Twenty First Meeting of the Scientific Committee, Kaohsiung, Taiwan, 5 – 10 September, 2016

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1 Abstract

This report provides an update on (i) the southern bluefin tuna (SBT) otolith and ovary collection activities in Australia over the past year (2015/16 fishing season) and (ii) estimates of proportion-at-age of the Australian surface (purse seine) fishery to include the 2014/15 fishing season.

Otoliths from 171 SBT (60-122 cm fork length) caught in the Great Australian Bight were received and archived into the CSIRO hard-parts collection during the 2015/16 season. In addition, samples of ovaries from 158 SBT (105 to 195 cm FL) caught off southeast Australia were collected and archived.

Age was estimated for 100 SBT from 2014/15 and the proportions-at-age were estimated using standard age-length-keys and by applying the method developed by Morton and Bravington (2003) (M&B method) to the combined age-length data and length frequency data obtained from the catch sampling program. Provided that the length frequency data are representative of fish caught in the surface fishery, and given our goal of estimating proportions at age in the catches (not in the population), the M&B estimator with "unknown growth" (see Methods) should be most accurate. For the 2014/15 season, the proportion at age estimates from the M&B method with unknown growth are 73% age 2 and 20% age 3. These estimates are very similar to the 2013/14 season, but suggest a larger proportion of age 2 and smaller proportion of age 3 fish in the catches than in any of the previous seasons.

2 Introduction

2.1 Age estimation & proportion-at-age

Most stock assessments, including those for southern bluefin tuna (SBT), use age-based models to estimate stock abundance. These models require estimates of the annual catch in numbers at age (catch-at-age) for each fishery as an input. For many fisheries, however, the only direct information available is the size distribution of the catch (catch-at-length) and total number caught. Although length provides some information on the age structure of the catch, since age and length are related, there is a need to convert catch-at-length into catch-at-age. Many simulation studies have shown that using direct age data, as opposed to size data, in age-structured assessment models is more likely to give unbiased estimates of stock status. Direct ageing from hard parts (otoliths) identifies different age groups among similarly sized fish and is generally considered a fundamental requirement of fisheries monitoring, particularly for long-lived species such as SBT.

The most common way of using direct age data in assessments has been the construction of age-length-keys from which proportions at age in the catch can be estimated. Morton and Bravington (2003) developed more efficient parametric methods to estimate proportions-at-age for SBT and recommended between 100-200 otoliths from the Australian surface fishery would be sufficient to provide acceptable levels of precision (CVs under 20%). Since 2002, we have been archiving between 100-400 otoliths annually, but only ageing (reading) 100. The additional otoliths provide a reserve which can be aged if we find that the CVs of the proportion-at-age estimates based on 100 samples are too high (i.e., greater than 20%).

Since the 2002 fishing season, Australia has been obliged to provide annual length-at-age estimates for the surface (purse seine) fishery in the Great Australian Bight (GAB) to CCSBT. The 2011 CCSBT-ESC listed as a priority item consideration of new data sources in the operating model with particular reference to direct ageing data (Anon, 2011). In 2012, as part of the review of the Scientific Research Program, the CCSBT ESC reiterated the central role and importance of these direct age data and the need to improve the representative nature of samples from all fisheries (Anon, 2012). Support was also noted for a second inter-laboratory comparison of direct ageing methods and a costed proposal was presented to the ESC in 2014 (Anon, 2014).

2.2 Maturity

There remains uncertainty about the size and age that SBT mature and the functional form of the maturity schedule. Up until 2013, the SBT operating model (OM) used a “knife-edge” maturity relationship, which specified that 0-9 yr olds made no contribution to the spawning biomass or reproductive output of the population and 10+ yr olds all contribute in proportion to their weight. In 2013, the method was updated to use the currently available estimates of maturity and additional information provided by the close-kin estimate to give a spawning potential by age (Anon 2013a). It was acknowledged, however, that there was no independent estimate of a maturity schedule for SBT (Anon 2013b). In 2014, a costed proposal for developing one (Farley et al., 2014) was supported by the ESC, and sample collection for maturity was listed as a high priority in the work plan for 2015 and ongoing. A sample size of 220 was proposed to be collected from statistical area 4 by Australia and Japan.

3 Methods

3.1 Otolith sampling 2015/16

Developing an otolith sampling scheme from the surface fishery sector is challenging because of the farming (aquaculture) component in Port Lincoln. The challenge is that fish can grow between their time of capture in the wild and the time when they are harvested after having been retained in farms during the grow-out phase. It is also important to note that the period when fish for farming are captured corresponds to a season when juvenile SBT are growing rapidly. Thus, otoliths collected from fish at the time of harvest, at the completion of the grow-out phase, will not provide the best length-at-age data for developing age-length keys for the fishery. In response to these issues, Australia has developed a sampling program based on fish that die either during towing operations or during the first two weeks after fish are transferred from towing cage into farm cages.

The current protocol requires that all farm operators provide a sample of 10 fish that have died either in towing operations or within the first weeks after fish have been transferred to stationary farm cages. A company contracted to the Australian Fisheries Management Authority (AFMA), Protec Marine Pty Ltd, measures the length of each fish and extracts the otoliths from these mortalities. In the past there have been between ~25 and 40 tow cages a year, giving a total of 250-400 otoliths collected from this sector each season. In recent years, however, the number of fish available for otolith sampling has declined primarily because of low mortalities in the cages during the towing operations (Farley et al., 2013).

SBT were also sampled during CCSBT gene-tagging fieldwork operations in the Great Australian Bight in February 2016 (Bradford and Preece, 2016). As the tagging program was targeting two year-old fish, it provided an opportunity to collect otoliths from fish smaller than those generally sampled from the surface fishery. Otoliths were only collected from mortalities, which were recorded against CSIROs research mortality allowance approved by the CCSBT.

3.2 Ovary sampling 2016

Ovaries were collected opportunistically from SBT caught by commercial longline operations off southeast Australia in 2016. The fish were measured to the nearest cm (FL) and the ovaries (or part of one lobe) were removed and sent to the laboratory fresh. A core subsample was taken from each ovary and fixed in 10% formalin for future histological analysis.

3.3 Direct ageing for 2014/15

Of the 133 otoliths collected from the Australian surface fishery in the 2014/15 season (see Farley et al., 2015), 100 were selected for age determination. The number of otoliths selected was based on the work by Morton and Bravington (2003) who estimated that between 100-200 otoliths from the surface fishery would be sufficient to provide acceptable precision (CVs under 20%). Otoliths were selected based on size of fish (length stratified sampling strategy rather than random sampling) to obtain as many age estimates from length classes where sample sizes were small. The fish selected for age estimation ranged in size from 80-130 cm fork length (FL).

One otolith from each fish was selected, weighed to the nearest 0.01 mg and sent to Fish Ageing Services Pty Ltd (FAS) in Victoria for sectioning and reading. FAS is a fee-for-service ageing laboratory established in early 2009. The SBT otolith reader at the FAS was previously associated with the Central Ageing Facility (CAF), and has read SBT otoliths since 1999. The technique to read SBT otoliths developed by CSIRO was transferred to the CAF prior to and during the CCSBT's Age Estimation Workshop in 2002 (Anon., 2002). The sister otolith, if present, remained in the hardparts collection.

Four serial transverse sections were cut from each otolith with one section including the primordium. The preparation of multiple sections for most otoliths had the advantage of increasing the likelihood of at least one section being clear enough to interpret. All sections were mounted on glass slides with resin and polished to 400 µm following the protocols given in Anon. (2002).

Opaque (dark) and translucent (light) zones were visible along the ventral 'long' arm of each otolith section, and the number of opaque zones was counted. An ageing reference set (n=50 sectioned otoliths) was read by FAS prior to reading each season's otoliths for calibration purposes.

The selected otoliths were then read at least two times by FAS without reference to the previous reading, size of fish, otolith weight or capture date. An otolith reading confidence score was assigned to each otolith reading:

0. No pattern obvious
1. Pattern present – no meaning
2. Pattern present – unsure with age estimate
3. Good pattern present – slightly unsure in some areas
4. Good pattern – confident with age estimate
5. No doubt

The precision of readings was calculated using Average Percent Error (Beamish and Fournier, 1981).

A potential problem in assigning age for SBT is that the theoretical birth date is January 1 (middle of the spawning season; see CCSBT-ESC-0509-Info) and opaque increments are formed during winter (May and October) (Gunn et al., 2008). Using the number of increments as an estimate of age can be misleading if SBT are caught during the winter. However, SBT in the GAB are caught during summer (November to April), so there is less confusion about assigning an age from increment counts. For example, SBT with 2 increments in their otoliths were classed as 2 year-olds. Thus, SBT of the same age, caught in the same fishing season, were spawned in the same spawning season.

3.4 Age distribution of the surface fishery

The most common way of estimating proportions at age in a given year, using age-at-length samples and a length distribution sample in the same year, is via an age-length key (ALK). The length frequency data are multiplied by the proportion of fish in each age class at a given length to give numbers (or proportions) at age. In mathematical terms, the proportion of fish of age *a*, p_a, is estimated as follows:

$$\hat{p}_a = \sum_l \frac{N_l}{N} \frac{n_{al}}{n_l}$$

where N_l is the number of fish in the length sample of length *l*, n_{al} is the number of fish in the age-length sample of age *a* and length *l*, $N = \sum_l N_l$ and $n_l = \sum_a n_{al}$.

A drawback of the ALK method is that it makes no use of the information about likely age contained in the length frequency data alone—thus it is inefficient, with variance up to 50% higher than necessary (see Morton & Bravington, 2003, Table 2). This is especially true for fisheries that catch young fast-growing fish, such as the Australian SBT surface fishery, where length is quite informative about age. As an alternative to the ALK, Morton and Bravington (2003) developed a parametric method which makes more efficient use of the information in both the length frequency and direct age data. The basis for the method is maximization of the following log-likelihood within each year:

$$\Lambda = \sum_l \left\{ N_l \log\left(\sum_a p_a p_{l|a} \right) + \sum_a n_{al} \log\left(p_a p_{l|a} \right) \right\}$$

where N_l, n_{al} and p_a are defined as above for the ALK, and $p_{l|a}$ is the probability that a fish of age *a* will have length l. Recall that the proportions at age (p_a) are what we are interested in estimating.

Here we assume $p_{l|a}$ follows a normal distribution with mean and variance that are either (a) known *a priori*, or (b) unknown and needing to be estimated together with the proportions at age. The former “known growth” approach is slightly more efficient if accurate estimates are available and if growth is consistent across cohorts; the latter “unknown growth” approach is robust to changes in growth and almost as efficient, so it is generally to be preferred. Variances for the proportion at age estimates can be obtained from the Hessian using standard likelihood theory.

Previously we applied the standard ALK method and the method of Morton and Bravington (hereafter referred to as the M&B method) to the age-length and length-frequency data from the Australian surface fishery in seasons 2001/02 through 2013/14 (see Farley et al., 2015). Here we update the analysis to include data from the 2014/15 season. For the M&B method, we applied both the known and unknown growth approaches for comparison. In the known growth case, mean and standard deviation (SD) in length at age were assumed equal to the values in Table 1. These values were derived using the growth curve for the 2000s reported in Table 3 of Eveson (2011) and assuming the mid-point of the surface catches to be 1 February. The SDs include individual variation in growth, measurement error, and growth within the fishing season, taken as 1 December to 1 April (see Polacheck et al. 2002, p.44-48, for more information on calculating variance in expected length at age). In the unknown growth case, we found it was necessary to set lower and upper bounds on the mean length at age parameters, or else unrealistic estimates could be obtained for data-limited age classes (discussed in greater detail later). We chose fairly generous bounds equal to the mean length at age ±2 standard deviations (SDs), as calculated from the otolith age-length data.

Table 1. Mean and standard deviation (SD) in length at age derived from the growth model for the 2000s.

AGE	MEAN LENGTH (CM)	SD
1	55.0	5.7
2	81.9	6.3
3	102.6	6.8
4	114.7	7.3
5	124.8	7.8
6	133.4	8.2
7	140.7	8.5
8	146.8	8.8

Length samples are taken from the tow cages each year (previously 40 fish were sampled per cage but this was increased to 100 fish per cage in the 2012/13 season and for subsequent seasons), and the data scaled up by the number of fish in each tow cage to estimate the length frequency distribution of the entire catch. For the M&B method, it is important to estimate the "effective sample size"[1] of the length data in order to correctly weight the relative information of direct age data versus length data in the likelihood, and also to estimate variances correctly. This entails a re-scaling of the length frequencies derived from the scaled-up tow cage samples, as described in Basson et al. (2005). Specifically, if T is the number of tow cages in a particular season, c_i is the number of fish in tow cage i, m_i is the total number of fish sampled from tow cage i, and m_{il} is the number of fish of length l in the sample from tow cage i, then we estimate π_l, the frequency of fish of length l over all tow cages, to be

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[1] The length samples taken from the tow cages do not constitute independent random draws from the entire catch (since the lengths of fish within a tow cage are not representative of the entire catch). The effective sample size refers to the sample size that leads to the equivalent variance as the tow cage samples had in fact been independent random draws.

$$\hat{\pi}_l = \sum_i c_i^* \frac{m_{il}}{m_i}$$

where

$$m_i = \sum_l m_{il}$$

and

$$c_i^* = \frac{c_i}{\sum_{j=1}^{T} c_j}.$$

The variance of $\hat{\pi}_l$ is estimated by

$$\mathrm{V}[\hat{\pi}_l] = \sum_i \frac{c_i^{*2}}{m_i}$$

Finally, we estimate the effective sample size of fish of length *l* to be

$$\tilde{N}_l = \frac{\hat{\pi}_l}{\mathrm{V}[\hat{\pi}_l]}.$$

These are the numbers we used as the N_l's for both the ALK and M&B methods.[2]

For the ALK method, the age-at-length and length frequency data were binned into 5-cm length classes. Generally, enough otoliths are available so that there are very few "missing rows" in the ALK for any year when 5-cm length bins are used; i.e., there are very few length bins for which the proportions-at-age cannot be calculated. However, this is not always the case; e.g., for the 2010/11 season there were no fish belonging to length bin 85-90 cm in the age-length data despite ~7% of the observations from the length-frequency data being in this range. The consequences of this were discussed in Farley et al. (2012).

For the M&B method (with known or unknown growth), the age-at-length and length frequency data were binned into 1-cm length classes.

4 Results and Discussion

4.1 Otolith sampling 2015/16

A total of 137 sets of otolith were collected from the Australia surface fishery in the 2015/16 season (Table 2). The sampled fish were 78 to 122 cm in length, with modes around 90-95 cm and 102-108 cm (Fig. 1).

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[2] For the ALK method, which only makes use of the proportion of fish of a given length class and not the absolute numbers, it should not matter whether we use the scaled-up tow cage numbers or the re-scaled effective sample sizes, but for consistency we use the same numbers for all methods.

As noted in previous reports to the Scientific Committee, it is clear that the current sampling protocol does not provide either a fixed number of otoliths from each length class nor has it provided representative samples of otoliths from all length classes in proportion to their abundance in the catch from the surface fishery. In previous seasons, this has often resulted in an apparent disproportionate number of large fish sampled compared to the size distribution of SBT from the surface fishery (based on CCSBT CatchAtLength data). The exact reason for the disparity is unclear, but could be the result of selection biases in the choice of dead fish to retain for otolith sampling or due to size related differences in towing and early farming related mortality rates. It could also be due to biases in the estimated size distributions of fish in the tow cages. The resulting age-length keys have "missing rows" where there are no or very few age estimates for the smaller length classes. The missing rows could lead to highly uncertain (less robust) age-length-keys and highlights the issue of representative otolith sampling for the fishery. It is unknown if sufficient fish were sampled within each length class to estimate the age distribution of the surface fishery catch in the 2015/16 fishing season. Reliable estimates of catch-at-age are also dependent on measuring a representative sample of the catch.

An additional 34 sets of otoliths were collected during the gene-tagging fieldwork operations in the Great Australian Bight (Table 2). The sampled fish were 60 to 95 cm in length, the majority from a mode between 76 and 80 cm (Fig. 1). Some of these otoliths may be required for developing the age-length key for the 2015/16 season.

Table 2. Number of SBT with otoliths collected from the Australian surface fishery and during gene-tagging operations in the 2015/16 fishing season.

SOURCE	NO. OTOLITHS	LENGTH RANGE (CM)	MEAN FL (CM)
Australia surface fishery	137	78-122	100.95
Gene-tagging operations	34	60-95	79.0

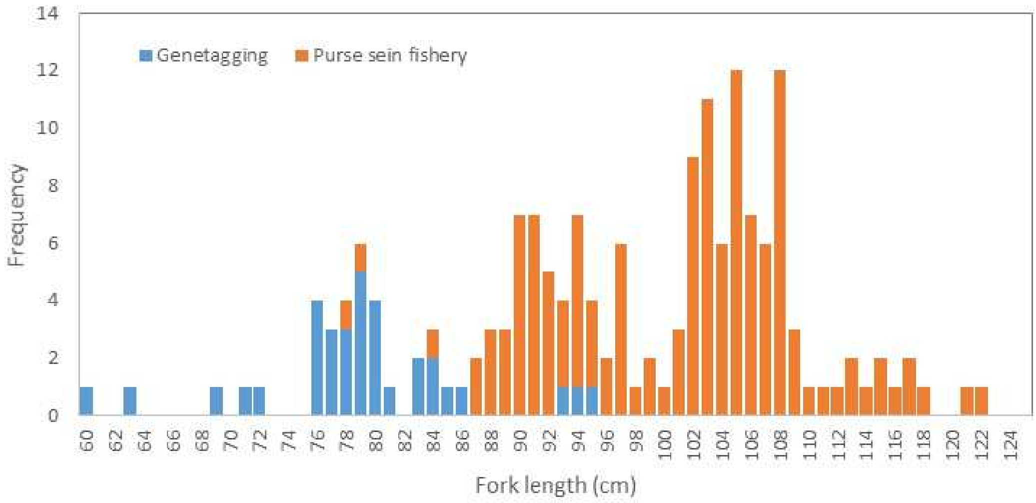

Figure 1. Length frequency of SBT with otoliths sampled from the Australian surface fishery and during gene-tagging operations in the 2015/16 fishing season.

4.2 Ovary sampling 2016

In 2016, 157 ovaries were sampled from SBT caught by the Australia longline fishery off southeast Australia (Table 3). One additional ovary was sampled from an SBT caught in the Australian recreational fishery off Tasmania. In 2014 and 2015, 20 ovary samples were collected in total (Table 3). The sampled fish were between 101 and 190 cm FL in length, with the majority in the 120 to 155 cm length classes (Fig. 2).

In 2014, the ESC work plan listed a 3-day workshop to discuss and finalise maturity criteria for SBT as a priority for 2016. In 2015, the ESC noted that the maturity workshop was a higher priority than an ageing workshop, and that it could be considered for 2016 or early 2017. Farley et al. (2015) proposed that this workshop be held at Indonesia’s Research Institute for Tuna Fisheries to reduce costs by some participants.

Table 3. Number of SBT with ovaries sampled by Australia in 2014 - 2016.

YEAR	NO. OVARIES	LENGTH RANGE (CM)	MEAN FL (CM)
2014	19	134-190	151.1
2015	1	101	101.0
2016	158	105-185	138.5
Total	178		

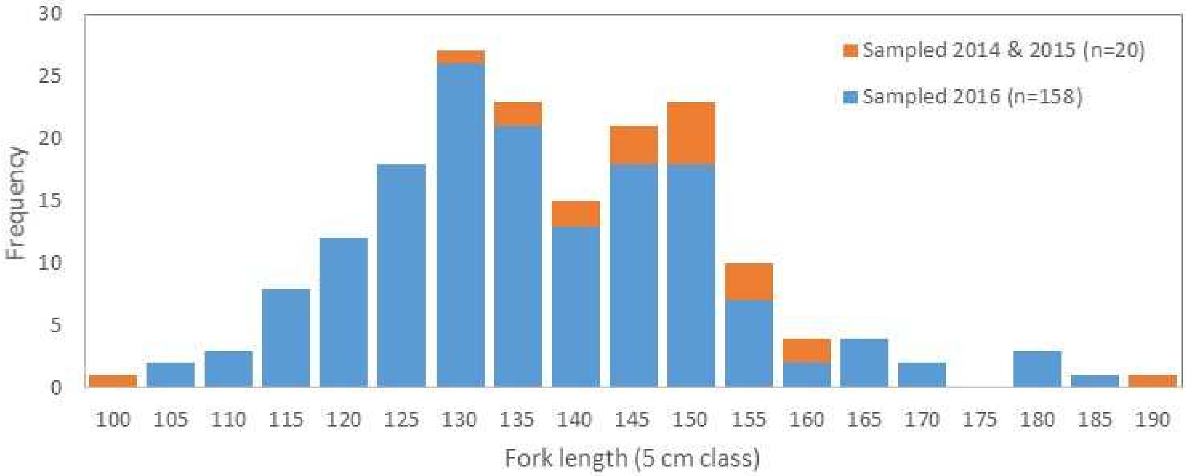

Figure 2. Length frequency of Australian caught SBT with ovaries sampled.

Of the 220 samples proposed to be collected a total of 178 has been collected by Australia since 2014. Other members have also been collecting ovaries. The next steps in preparation for the workshop on maturity are (i) preparation and reading ovary histology by member countries, and (ii) an inter-laboratory histology interpretation exchange exercise to allow all laboratories to examine and classify the ovaries prior to discussion at the workshop. At the workshop, standardised histology classification criteria for ovaries can be agreed before the maturity classification of each SBT is finalised. Analysis of the results to estimate the maturity schedule of SBT can then be initiated.

4.3 Direct ageing for 2014/15

A final age estimate was given all 100 SBT selected for ageing from the Australian surface fishery. Ages ranged from 1-6 years and the length to age relationship is given in Fig. 3. The average percent error between readings was 4.18% and the percent agreement was 74.0%. When successive readings differed, they were only by ±1 indicating a good level of precision. When readings differed, a final age was obtained by re-examining the otolith with the knowledge of the previous two age estimates as recommended by Anon. (2002).

Table 3 shows the numbers of fish by age in each 5-cm length class for the fishing seasons. These data are used in both the standard ALK and M&B methods of estimating the proportions of fish at age in the surface fishery, noting that for the M&B method the data are broken down by 1-cm, as opposed to 5-cm, length classes.

4.4 Age distribution of the surface fishery 2001/02 to 2014/15

The proportions at age estimated from the standard ALK method, the M&B method with known growth, and the M&B method with unknown growth are compared in Figure 4. The actual values are provided in Appendix A (Tables A1-A3). For many seasons there is reasonably good agreement between the various methods, but for others the estimated proportions at ages 2-4 are considerably different. For example, in the two most recent seasons (2013/14 and 2014/15), the proportion of fish estimated to be age 2 is much greater using the standard ALK and the M&B method with unknown growth than the M&B method with known growth. Likewise, the proportion of age 3 fish is estimated to be much smaller with the ALK and M&B method with unknown growth than the M&B method with known growth.

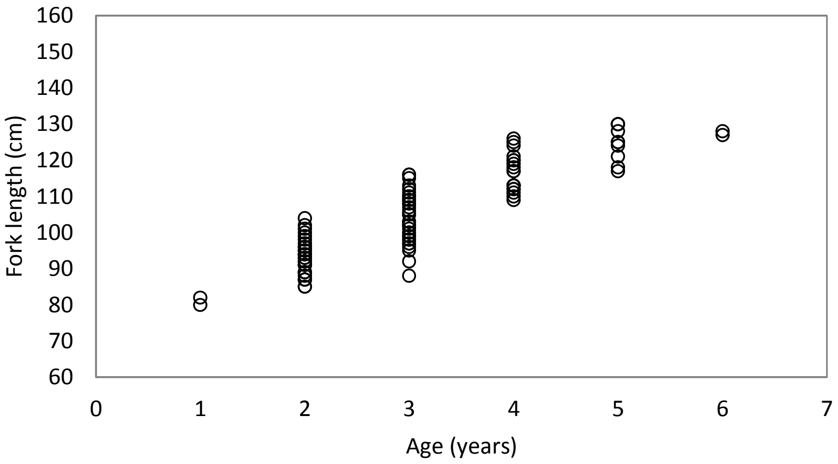

Figure 3. Length at age for SBT caught in the Australian surface fishery in the 2014/15 fishing season (n=100).

Table 3. Age-length-key for the 2014/15 fishing seasons for the Australian surface fishery. The lower length of each 5cm length bin is given in the first column and ages are shown across the top.

	AGE						
LENGTH (CM)	1	2	3	4	5	6	TOTAL
80	2						2
85		9	1				10
90		10	1				11
95		7	8				15
100		4	9				13
105			9	1			10
110			6	8			14
115			3	4	2		9
120				4	2		6
125				2	3	2	7
130					3		3
Total	2	30	37	19	10	2	100

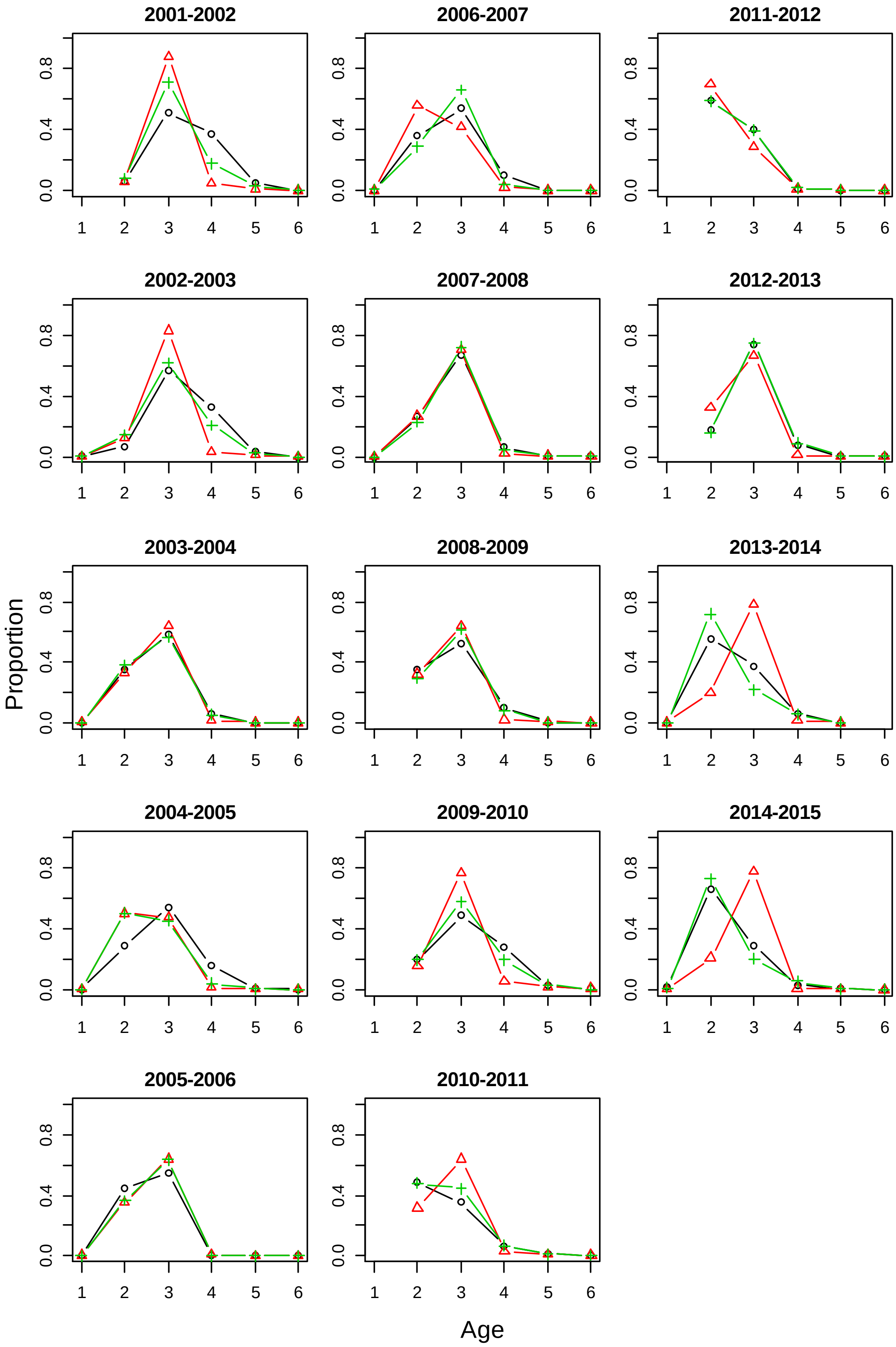

Figure 4. Estimated proportions of fish at age in each fishing season using i) the ALK method (black, open circles); ii) the M&B method with known growth (red, open triangles); iii) the M&B method with unknown growth (green, plus symbols).

The M&B method with unknown growth produces estimates that fit the length data very closely for all seasons (Fig. 5), with the exception of the 2010/11 season (as discussed in Farley et al. 2012). In comparison, the M&B method with known growth does not fit the length data nearly so well (Fig. 6). This is to be expected since the unknown growth method estimates the mean and SD in length at age based on the data (Tables A4 and A5 in Appendix A), and these estimates can be quite different than those derived from the growth model (Table 1). In particular, the mean length estimates from the M&B method for age 2 are larger in all seasons than the estimate from the growth model, and the age 3 and 4 estimates smaller (with one exception for age 3 in 2013/14) (Fig. 7).

The growth model was estimated based on age-length data and tag-recapture data for fish born in the 2000s. It does not include the length-frequency data due to concerns about size-selective fishing (Polacheck et al. 2002, Appendix 3), and is not specific to fish in the Great Australian Bight (GAB) nor to seasons. Provided that the length-frequency data are representative of fish caught in the surface fishery, and given our goal of estimating proportions at age in the catches (not in the population), the M&B estimator with unknown growth should be most accurate. Using this method, the proportion at age estimates for the 2014/15 season are 73% age 2 and 20% age 3. These estimates are very similar to the 2013/14 season, but suggest a larger proportion of age 2 and smaller proportion of age 3 fish in the catches than in any of the previous seasons. The mean length at age estimates for the 2014/15 season for ages 2, 3 and 4 are 93, 99 and 109 cm respectively.

The relatively small numbers of otoliths for fish of age 1 and age 5+, as well as the low proportion of fish corresponding to these age classes in the length-frequency data, can lead to difficulties in estimating mean length for these ages. Since the proportion at age estimates are so close to 0 for these age classes, the consequences of incorrectly estimating their mean length should be small. Of some concern, however, are the mean length estimates for age 4 fish, which are sometimes estimated to be very close to the mean length for age 3 (Fig. 5; Fig. 7). It is possible to impose tighter bounds on the mean length at age parameters, but doing so simply results in the age 4 estimates falling on the lower bound, so it is not a very satisfactory solution. A possibility for future consideration is to incorporate *a prior* distributions on the mean length at age parameters—this would provide an intermediate approach to the known and unknown growth methods currently available.

CVs of the estimated proportions at age using the M&B method with unknown growth were calculated by dividing the square root of the Hessian-based variance estimates by the estimates (Table A6 in Appendix A). Where the estimated proportion at age was less than 0.01 (i.e., for age 1 and most of ages 5 and above), we have opted not to show the CV because dividing by such a small number can lead to a very large and misleading CV. For the 2014/15 season, the CV of the estimates for ages 2-4 are 3%, 13% and 24% respectively. In general, the proportion at age estimates are quite precise for ages 2 and 3 (CVs < ~10%), but less so for age 4 and 5 (ranging from 14% to 39%) since these older age classes have less data available. As discussed in Farley et al. (2012), the 2010/11 season was an exception with much higher CVs for the age 2 and 3 estimates than in previous seasons due to a contrast between the direct age data and length-frequency data for fish of ages 2 and 3 in this season.

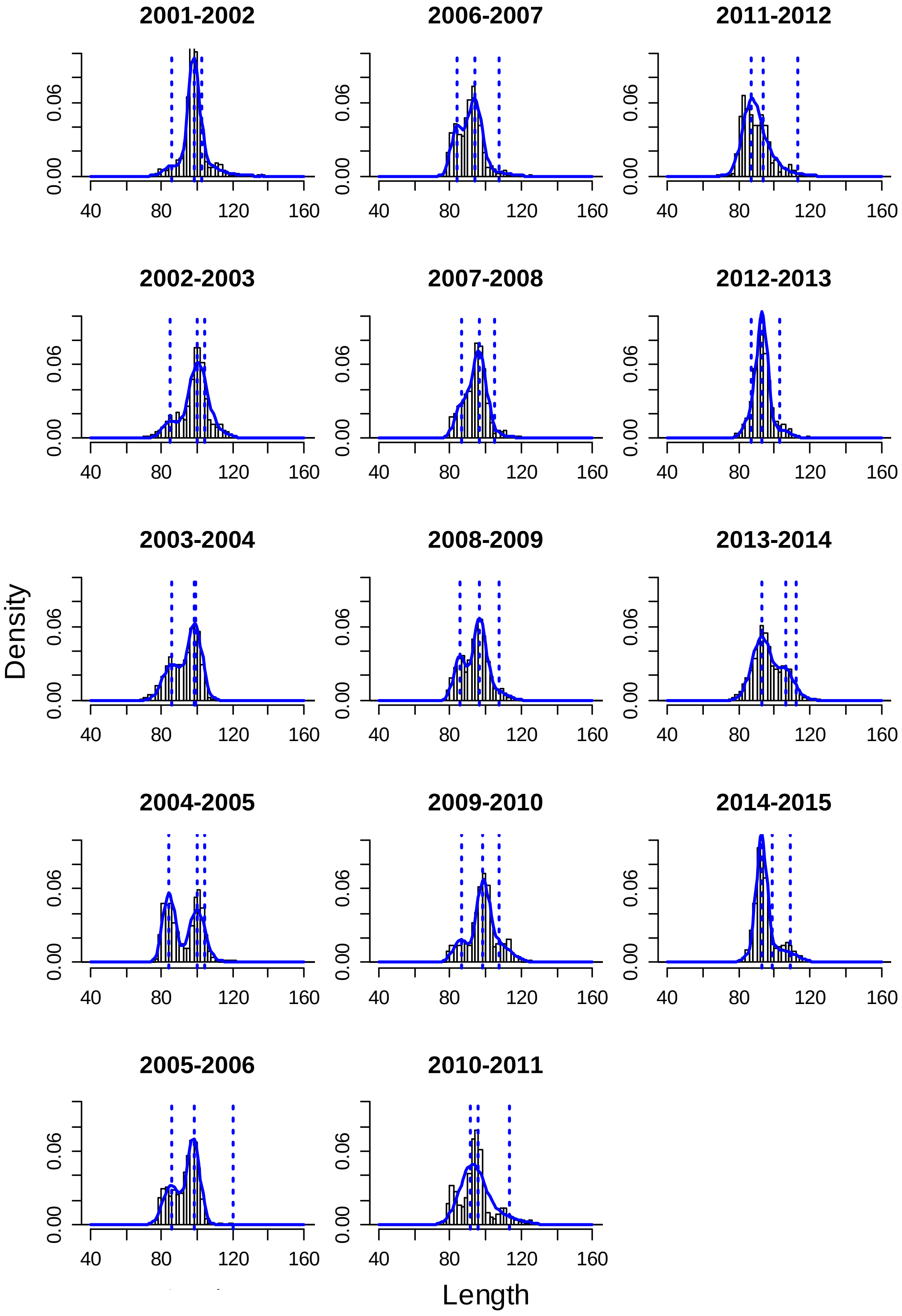

Figure 5. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and estimated mean lengths at age for ages 2-4 from the M&B method with unknown growth (solid blue curve and dashed blue vertical lines).

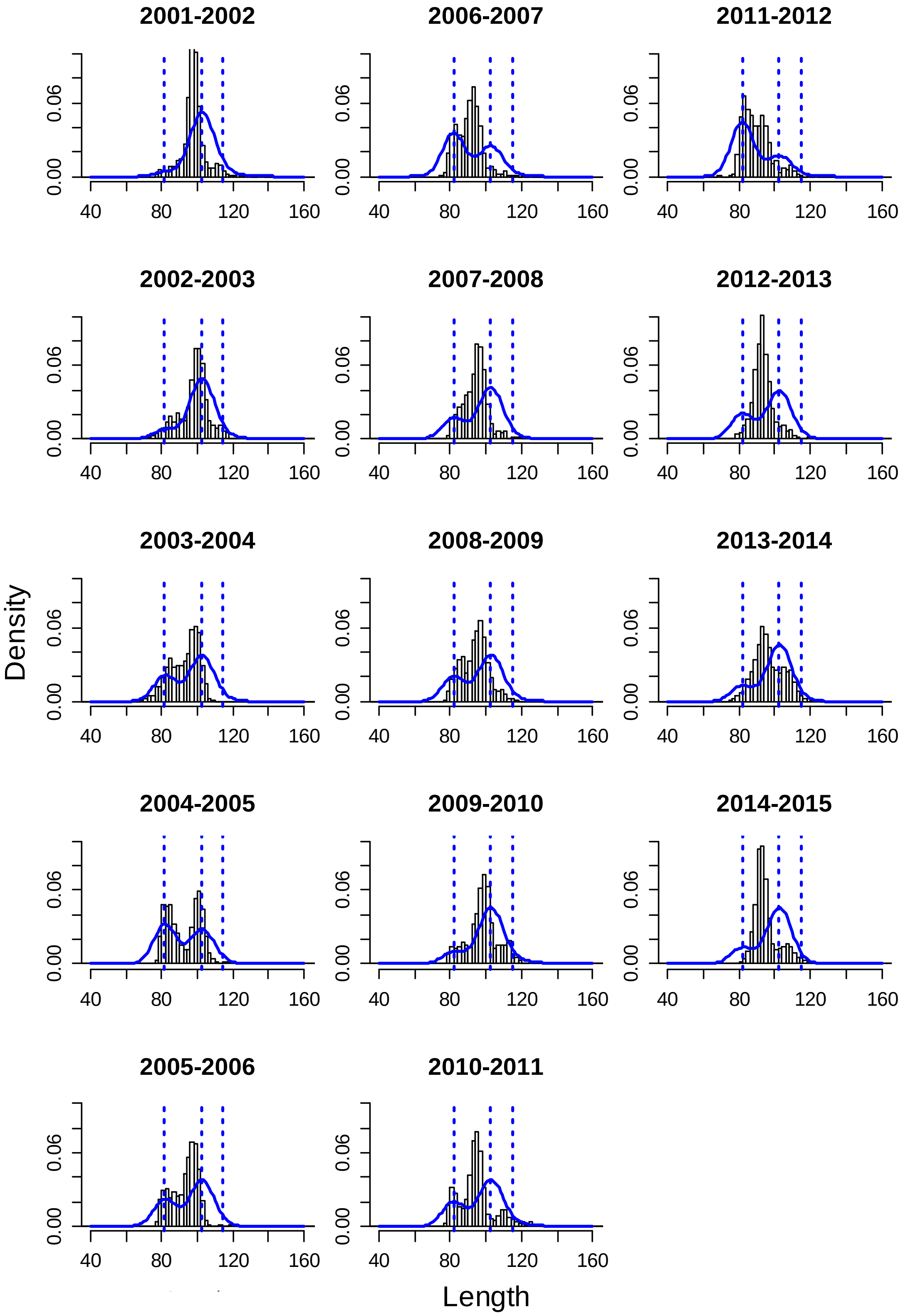

Figure 6. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and "known" mean lengths at age for ages 2-4 from the M&B method with known growth (solid blue curve and dashed blue vertical lines).

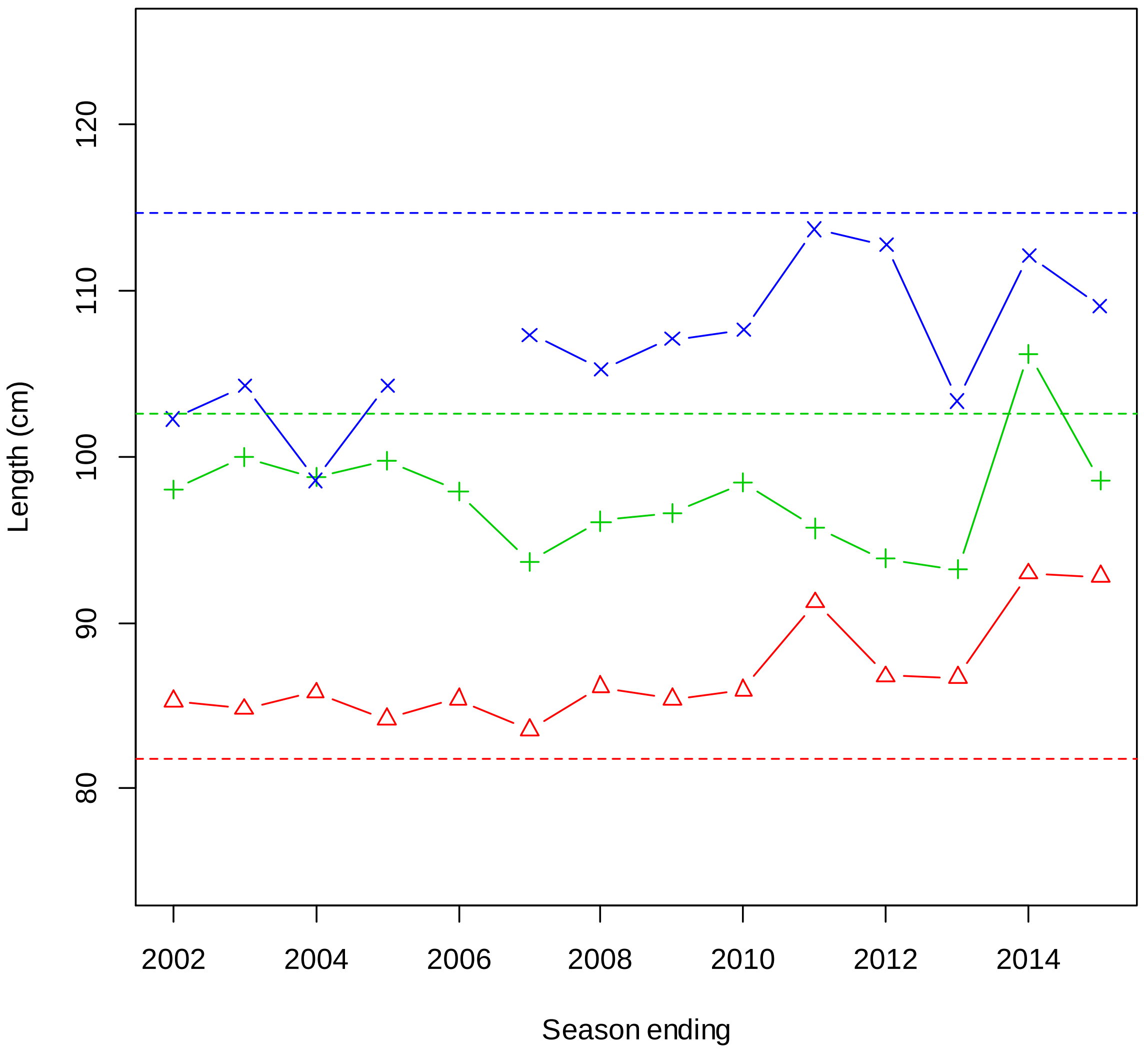

Figure 7. Mean length at age estimates using the M&B method with unknown growth (red triangle = age 2; green plus = age 3; blue cross = age 4). Note the age 4 estimate for 2006 is omitted because there were insufficient data to get a reliable estimate. For comparison, the horizontal dashed lines show the mean length at age estimates for ages 2-4 used in the M&B method with known growth (derived from the 2000s growth model in Eveson 2011).

As in previous reports, we again stress that the proportions at age derived here apply only to fish caught in the GAB surface fishery. They are unlikely to apply to the population of fish found in the GAB due to the size-selective nature of the surface fishery, and they are less likely to apply to the global population since data collected in the GAB are not representative of fish found in other regions (for example, age-1 fish found off Western Australia are smaller on average than age-1 fish found in the GAB at the same time, likely due to a later spawning event; Polacheck et al. 2002).

5 Summary

A total of 171 otoliths and 137 ovary samples were collected and archived in the 2015/16 fishing season. Direct age estimates were obtained for 100 SBT caught in the 2014/15 season in the GAB.

For the 2014/15 season, the proportion at age estimates from the M&B method with unknown growth are 73% age 2 and 20% age 3. These estimates are very similar to the 2013/14 season, but suggest a larger proportion of age 2 and smaller proportion of age 3 fish in the catches than in any of the previous seasons. The mean length at age estimates for ages 2, 3 and 4 are 93, 99 and 109 cm respectively.

When combined with length-frequency data, the otolith sample sizes for age estimation of the Australian surface fishery (100 otoliths per fishing season) appear to provide acceptably low CVs for ages 2 and 3. Whether the higher CVs for age classes 4 and 5 are adequate can only be evaluated once the direct age data are used in the SBT operating model. If it is important, then there will be a need to re-evaluate the sampling design for otoliths including (a) number sampled per length class and (b) the number of otoliths that need to be read. The estimated proportions at age will also only be representative of the catch if the size frequency distribution of the fish sampled is representative. This work highlights the need for continued discussion within the CCSBT regarding development of protocols for obtaining representative samples of length at age from all fisheries, and the technical details of how the direct age data will be incorporated into the operating model. The direct ageing data set is a significant resource, which can be improved as more otoliths are collected and read (fish age estimated) from subsequent years.

References

Anonymous. (2002). A manual for age determination of southern bluefin Thunnus maccoyii. Otolith sampling, preparation and interpretation. The direct age estimation workshop of the CCSBT, 11-14 June 2002, Queenscliff, Australia, 39 pp.

Anonymous. (2011). Report of the Seventeenth Meeting of the Scientific Committee, Commission for the Conservation of Southern Bluefin Tuna, 19 – 28 July, Bali, Indonesia.

Anonymous. (2012). Report of the Seventeenth Meeting of the Scientific Committee, Commission for the Conservation of Southern Bluefin Tuna, 27-31 August, Tokyo, Japan.

Anonymous. (2014). Report of the nineteenth meeting of the Scientific Committee. Commission for the Conservation of Southern Bluefin Tuna, 6 September, Auckland, New Zealand.

Basson, M., Bravington, M., Peel, S. and Farley, J. (2005). Estimates of proportions at age in the Australian surface fishery catch from otolith ageing and size frequency data. CCSBT-ESC/0509/19.

Beamish, R.J. and Fournier, D.A. (1981). A method for comparing the precision of a set of age determinations. Canadian Journal of Fisheries and Aquatic Sciences 38: 982-983.

Bradford, R and Preece, A. (2016). Progress report on the pilot gene-tagging implementation in 2016. CCSBT-ESC/1609/07.

Eveson, P. (2011). Updated growth estimates for the 1990s and 2000s, and new age-length cut-points for the operating model an management procedures. CCSBT-ESC/1309/11, 18th Meeting of the Scientific Committee, 2-7 September 2013, Canberra, Australia.

Farley, J., Eveson, P. and Clear, N. (2012). An update on Australian otolith collection activities, direct ageing and length at age in the Australian surface fishery. CCSBT ESC-1208-18, 17th Meeting of the Scientific Committee, 27-31 August 2012, Tokyo, Japan.

Farley, J., Eveson, P. and Clear, N. (2013). An update on Australian otolith collection activities, direct ageing and length at age in the Australian surface fishery. CCSBT ESC-1208-18.

Farley, J., Eveson, P. and Clear, N. (2015). An update on Australian otolith collection activities, direct ageing and length at age in the Australian surface fishery. CCSBT ESC-1509-13, 20th Meeting of the Scientific Committee, 1-5 September, Incheon, South Korea.

Gunn, J.S., Clear, N.P., Carter, T.I., Rees, A.J., Stanley, C., Farley, J.H., and Kalish, J.M. (2008). The direct estimation of age in southern bluefin tuna. Age and growth in southern bluefin tuna, Thunnus maccoyii (Castelnau): Direct estimation from otoliths, scales and vertebrae. Fisheries Research 92:207-220.

Morton, R. and Bravington, M. (2003). Estimation of age profiles of southern bluefin tuna. CCSBT Scientific Meeting; 1-4 September 2003, Christchurch, New Zealand. CCSBT-ESC/0309/32

Polacheck, T., Laslett, G.M., and Eveson, J.P. (2002). An integrated analysis of growth rates of southern bluefin tuna for use in estimating the catch at age matrix in the stock assessment. Final report. FRDC project no. 1999/104.

Appendix A

Results from fitting the standard ALK method and the Morton & Bravington (M&B) method with known and unknown growth to the Australian surface fishery age-length and length-frequency data.

Table A1: Proportions at age for each fishing season estimated using the standard ALK method. (Four decimal places are shown to retain the small but non-zero proportions for ages 1 and >4). NA = not applicable.

	AGE							
SEASON	1	2	3	4	5	6	7	8
2001-2002	NA	0.0626	0.5130	0.3742	0.0457	0.0039	0.0006	NA
2002-2003	0.0013	0.0652	0.5726	0.3256	0.0350	0.0002	0.0001	0.0000
2003-2004	0.0000	0.3515	0.5817	0.0665	0.0003	0.0000	0.0000	NA
2004-2005	0.0000	0.2853	0.5448	0.1572	0.0122	0.0003	0.0001	0.0000
2005-2006	0.0000	0.4505	0.5448	0.0044	0.0002	0.0001	NA	NA
2006-2007	0.0023	0.3571	0.5405	0.0996	0.0004	0.0001	0.0000	NA
2007-2008	0.0000	0.2637	0.6698	0.0624	0.0036	0.0005	NA	NA
2008-2009	NA	0.3531	0.5273	0.1065	0.0052	0.0000	NA	NA
2009-2010	NA	0.1961	0.4871	0.2798	0.0253	0.0024	NA	NA
2010-2011	NA	0.4864	0.3519	0.0667	0.0124	0.0029	0.0000	NA
2011-2012	NA	0.5886	0.3970	0.0118	0.0022	0.0000	0.0000	NA
2012-2013	NA	0.1749	0.7441	0.0786	0.0020	0.0004	0.0000	0.0000
2013-2014	0.0000	0.5559	0.3748	0.0659	0.0022	NA	NA	NA
2014-2015	0.0156	0.6605	0.2888	0.2971	0.0043	0.0001	NA	NA

Table A2: Proportions at age for each fishing seasons estimated using the M&B method with known mean and variance in length at age. NA = not applicable.

	AGE							
SEASON	1	2	3	4	5	6	7	8
2001-2002	NA	0.0575	0.8812	0.0470	0.0108	0.0023	0.0012	NA
2002-2003	0.0013	0.1212	0.8333	0.0318	0.0091	0.0021	0.0005	0.0007
2003-2004	0.0048	0.3336	0.6394	0.0176	0.0036	0.0010	0.0001	NA
2004-2005	0.0016	0.5028	0.4759	0.0129	0.0042	0.0009	0.0012	0.0006
2005-2006	0.0014	0.3502	0.6379	0.0096	0.0008	0.0002	NA	NA
2006-2007	0.0022	0.5585	0.4179	0.0181	0.0026	0.0005	0.0002	NA
2007-2008	0.0006	0.2681	0.7065	0.0197	0.0040	0.0011	NA	NA
2008-2009	NA	0.3247	0.6413	0.0235	0.0086	0.0018	NA	NA
2009-2010	NA	0.1556	0.7692	0.0513	0.0165	0.0074	NA	NA
2010-2011	NA	0.3148	0.6384	0.0313	0.0094	0.0059	0.0003	NA
2011-2012	NA	0.6988	0.2857	0.0114	0.0029	0.0009	0.0003	NA
2012-2013	NA	0.3241	0.6632	0.0088	0.0018	0.0018	0.0002	0.0002
2013-2014	0.0003	0.1984	0.7799	0.0184	0.0030	NA	NA	NA
2014-2015	0.0012	0.2067	0.7792	0.0091	0.0032	0.0006	NA	NA

Table A3: Proportions at age for each fishing seasons estimated using the M&B method with unknown mean and variance in length at age. NA = not applicable.

	AGE							
SEASON	1	2	3	4	5	6	7	8
2001-2002	NA	0.0803	0.7093	0.1780	0.0279	0.0040	0.0006	NA
2002-2003	0.0016	0.1465	0.6200	0.2061	0.0256	0.0002	0.0001	0.0000
2003-2004	0.0004	0.3783	0.5647	0.0565	0.0001	0.0000	0.0000	NA
2004-2005	0.0000	0.5025	0.4526	0.0393	0.0053	0.0003	0.0000	0.0000
2005-2006	0.0000	0.3664	0.6322	0.0010	0.0002	0.0001	NA	NA
2006-2007	0.0078	0.2876	0.6621	0.0422	0.0003	0.0001	0.0000	NA
2007-2008	0.0000	0.2287	0.7228	0.0438	0.0042	0.0005	NA	NA
2008-2009	NA	0.2930	0.6170	0.0864	0.0035	0.0000	NA	NA
2009-2010	NA	0.1969	0.5783	0.1939	0.0290	0.0019	NA	NA
2010-2011	NA	0.4775	0.4438	0.0659	0.0100	0.0028	0.0000	NA
2011-2012	NA	0.5885	0.3943	0.0151	0.0022	0.0000	0.0000	NA
2012-2013	NA	0.1568	0.7500	0.0902	0.0022	0.0008	0.0000	0.0000
2013-2014	0.0004	0.7200	0.2187	0.0580	0.0029	NA	NA	NA
2014-2015	0.0120	0.7292	0.2024	0.0525	0.0035	0.0004	NA	NA

Table A4: The estimated mean length at age (in cm) for each fishing season using the M&B method with unknown mean and variance in length at age. NA = not applicable.

	AGE							
SEASON	1	2	3	4	5	6	7	8
2001-2002	NA	85.3	98.0	102.3	113.8	119.7	136.3	NA
2002-2003	72.2	84.8	100.0	104.3	113.1	129.7	132.6	141.6
2003-2004	66.2	85.8	98.8	98.6	113.1#	128.3#	122.7	NA
2004-2005	44.5#	84.2	99.8	104.3	111.5	120.0#	137.7	137.5
2005-2006	69.2*	85.4	97.9	120.4	130.7	132.8	NA	NA
2006-2007	82.2	83.5	93.7	107.4	129.2	129.8	141.7	NA
2007-2008	57.3	86.2	96.1	105.3	111.4	133.0	NA	NA
2008-2009	NA	85.4	96.6	107.1	117.2	125.4	NA	NA
2009-2010	NA	86.0	98.5	107.6	116.9	126.1	NA	NA
2010-2011	NA	91.2	95.7	113.7	124.6	125.7	143.5	NA
2011-2012	NA	86.8	93.8	112.8	115.3	137.8	126.2	NA
2012-2013	NA	86.7	93.2	103.4	118.0	119.4	140.8	143.4
2013-2014	68.3	93.0	106.2	112.1	125.5	NA	NA	NA
2014-2015	83.8*	92.8	98.6	109.1	121.1	127.5	NA	NA

Estimate hit lower bound.

* Estimate hit upper bound.

Table A5: The estimated standard deviation in length at age (in cm) for each fishing season using the M&B method with unknown mean and variance in length at age. NA = not applicable.

	AGE							
SEASON	1	2	3	4	5	6	7	8
2001-2002	NA	4.2	3.2	7.3	7.4	7.6	0.2	NA
2002-2003	2.9	4.4	4.8	6.9	6.6	4.6	2.2	2.1
2003-2004	3.5	5.2	3.9	6.4	5.1	4.4	5.6	NA
2004-2005	4.0	3.5	4.3	6.8	7.9	8.8	6.4	7.9
2005-2006	3.1	4.6	3.6	7.6	4.1	2.8	NA	NA
2006-2007	3.2	3.1	4.2	5.9	2.7	3.0	0.0	NA
2007-2008	0.6	3.6	4.2	7.1	8.9	1.7	NA	NA
2008-2009	NA	3.3	3.8	4.9	3.6	2.3	NA	NA
2009-2010	NA	4.3	3.6	5.3	4.3	3.6	NA	NA
2010-2011	NA	6.4	8.0	5.3	3.5	4.7	0.0	NA
2011-2012	NA	4.8	7.5	4.7	6.3	1.9	6.8	NA
2012-2013	NA	3.8	3.0	5.4	3.5	3.9	0.1	0.0
2013-2014	1.8	5.5	4.1	4.9	10.0	NA	NA	NA
2014-2015	2.2	3.0	8.6	5.6	5.3	0.2	NA	NA

Table A6: Coefficients of variation (CVs) of the estimated proportions at age for each fishing season using the M&B method with unknown mean and variance in length at age. A dash (--) indicates where the estimated proportion at age was less than 0.01. NA = not applicable.

	AGE							
SEASON	1	2	3	4	5	6	7	8
2001-2002	NA	0.13	0.03	0.14	0.25	--	--	NA
2002-2003	--	0.10	0.06	0.18	0.39	--	--	--
2003-2004	--	0.05	0.04	0.31	--	--	--	NA
2004-2005	--	0.03	0.04	0.36	--	--	--	--
2005-2006	--	0.06	0.03	--	--	--	NA	NA
2006-2007	--	0.07	0.03	0.18	--	--	--	NA
2007-2008	--	0.10	0.04	0.31	--	--	NA	NA
2008-2009	NA	0.07	0.04	0.19	--	--	NA	NA
2009-2010	NA	0.09	0.05	0.14	0.37	--	NA	NA
2010-2011	NA	0.22	0.23	0.18	0.32	--	--	NA
2011-2012	NA	0.12	0.17	0.34	--	--	--	NA
2012-2013	NA	0.19	0.04	0.08	--	--	--	--
2013-2014	--	0.02	0.09	0.23	--	NA	NA	NA
2014-2015	0.61	0.03	0.13	0.24	--	--	NA	NA

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MP results and estimation performance relative to current input CPUE and aerial survey data

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CCSBT-ESC/1609/18

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Abstract

As in previous years, the performance of the estimation part of the CCSBT MP is explored prior to the TAC calculations. We also include the updated MP data inputs and the resultant preliminary TAC recommendation that arises from running the MP, which will be used to set the TAC for 2018–2020. The population model within the MP is fitted to the most recent CPUE (up to 2015) and scientific aerial survey (up to 2016) data. The model performs more than adequately with the majority of the data well explained and the key parameters well estimated. The very high survey estimates of 2014 and, in particular 2016, still fall within the 95% predictive interval. In summary, given the MP estimation procedure performs well, there are no model-specific impediments to running the MP to set the next three-year TAC block. The preliminary TAC recommendation for 2018–2020 is 17,647t (i.e. the maxmimum 3,000t increase permitted).

1 Background

The CCSBT MP is model-based, in that there is a relative abundance population model that is statistically fitted to the scientific aerial survey and standardised Japanese long-line CPUE data and the harvest control rule acts on the model-derived quantities, not the raw indices. While not a formal stock assessment, the use of an estimation model means it is necessary to check that the underlying probability model (population dynamics and likelihood combined) is performing adequately.

This paper assesses the predictive performance of the MP estimation model given the updated MP input data. The MP model uses the maximum posterior density (MPD) estimate to calculate the TAC but we use Markov chain Monte Carlo (MCMC) methods to fully explore the information content of the data for the MP model, and use the posterior samples to assess the predictive performance of the model itself given the observed data. An additional section we included here, that was not included in previous such papers, are the actual data inputs to the Bali procedure and the preliminary result (in terms of the recommended TAC) of running the MP for the 2018–2020 TAC block.

2 Material & Methods

2.1 Data sets

Two key abundance data sets are used in the CCSBT MP:

1. Standardised Japanese long-line CPUE [1] used in the MP (1994-2015)
2. Scientific aerial survey [2] (1993-2000,2005-2014,2016)

2.2 MP data files

In order to run the standalone version of the MP code in 2016, data files and the code needed to be updated. All changes were uploaded to github. The code used to run the MP (`BaliProc.tpl`) was updated to include code changes developed in 2015 to allow for missing 2015 aerial survey data.

The MP input data file (BaliProc.dat) was updated with new aerial survey and CPUE time series. The CPUE time series used in the MP is the average of 2 base CPUE series multiplied by the over catch correction factors in the historical parts of the timeseries (see Att 10 of 2013 ESC report). The main data file for running the Bali procedure is called BaliProc.dat and can be found in the Appendix.

To account for overall changes in the scale of the aerial survey index, given it is an area-weighted sum, an adjustment is made to the survey-to-CPUE catchability (referred to as the qratio: q_R/q_B) in the MP. A Bayesian bootstrap procedure is used to ensure that the ratio is robust to potential outliers (see the `qratio.tpl` source file for details). Given one can get slightly different answers from different computers, traditionally we have run the procedure on one machine and everyone then uses that value. The data file is qratio.dat (see Appendix). The agreed value of the qratio parameter is 885.593.

2.3 MP population & estimation model

First, it makes sense to revisit the specifics of the MP population model: recruitment (R_y) and adult (B_y) biomass are related as follows:

$$B_{y+1} = R_y + g_y B_y, \tag{2.1}$$

where g_y is the adult biomass net growth effect (encompassing natural mortality, growth and exploitation effects). For recruitment to the fully exploited stock the following model is assumed:

$$R_y = \exp\left(\mu_R + \epsilon_y^R\right), \tag{2.2}$$

with $\epsilon_y^R \sim N\left(-\sigma_R^2/2, \sigma_R^2\right)$. For the g_y a conceptually similar model is assumed and

$$g_y = \exp\left(\mu_g + \epsilon_y^g\right), \tag{2.3}$$

with $\epsilon_y^g \sim N\left(-\sigma_g^2/2, \sigma_g^2\right)$. For the aerial survey data I_y^{AS} a lognormal relationship to the recruiting biomass is assumed but with a one-year delay: $I_y^{AS} \sim LN\left(q_R R_{y+1}, \sigma_{AS}^2\right)$. The reason for this delay is because we assume that the aerial survey covers ages 2 to 4 and that the CPUE covers ages 4 and above. To make sure that we are more likely to detect the movement of a signal in the aerial survey appearing in the CPUE data this delay is assumed as R_y represents the recruitment biomass contribution to the adult biomass (assumed covered by the CPUE). The situation is simpler for the CPUE likelihood and these data are assumed log-normally distributed about the adult biomass: $I_y^B \sim LN\left(q_B B_y, \sigma_B^2\right)$. The model is unidentifiable without additional information on the catchability ratio q_R/q_B and the details of how this is dealt with can be found in [3].

Fixed quantities in the MP model are as follows:

- Variance in recruitment biomass random effects: $\sigma_R = 0.38$
- Variance in biomass growth random effects: $\sigma_g = 0.25$
- Observation error for CPUE index: $\sigma_S = 0.2$
- Observation error for aerial survey index: $\sigma_{AS} = 0.15$
- Catchability for CPUE: $q_B = 1$
- Catchability for aerial survey: $q_R = 885.593$
- Initial adult relative biomass: $B_{1994} = q_B^{-1} I_{1994}^B$

In terms of estimated parameters (and priors) we have:

- μ_R and μ_g with uniform priors
- ϵ_y^R and ϵ_y^g with (informative) normal priors and penalties to ensure that over years $\mathbb{E}\left(\epsilon_y^\bullet\right) = 0$

To efficiently obtain a representative sample from the joint posterior of the parameters a Metropolis-within-Gibbs MCMC routine was written in C++. A burn-in level of 1,000 iterations was used, with 1,000 being retained with a thinning factor of 100 employed to reduce auto-correlation in the Markov chains. Non-convergence of the chains was explored using regular diagnostic methods [4].

3 Results

3.1 Parameter estimates

Table 3.1 details the posterior estimates of the mean recruitment biomass, μ_R, and adult biomass growth, μ_g, parameters. Given the assumption of uniform priors and the posterior CVs of 0.04 and 0.1 for the recruitment and growth means, respectively, the data are clearly informative.

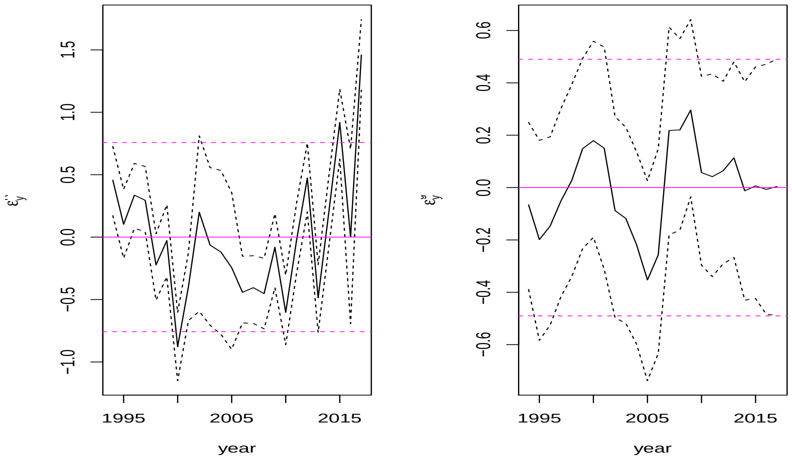

Figure 3.1: **Median (full) and 95% credible interval (dashed) for the recruitment (left) and adult growth (right) random effects. Posterior estimates are coloured in black with the prior coloured magenta.**

Parameter	*Summary*
μ_R	-1.51 (-1.62; -1.41)
μ_g	-0.36 (-0.44; -0.29)

Table 3.1: **Summaries of time-independent parameters in terms of posterior median and, in brackets, the lower and upper limits of the 95% credible interval.**

Figure 3.1 summarises the recruitment biomass and adult biomass growth random effects, in terms of posterior *vs.* prior estimates. In terms of the recruitment random effects, the data are clearly informative across all years - even when the aerial survey data are missing. That is because the three lowest years of CPUE (2006-2008) cannot be explained by low biomass growth alone and are partially attributed to low recruitment from the incoming juveniles. This links with the observed low age 0 recruitments from 1999-2002 in the OM and in other data sources. When interpreting how the recruitment terms in the MP model relate to the aerial survey remember always to subtract one year from the model terms to link them to the survey (the model terms represent the biomass *recruiting* into the long-line fleets and are linked to the cohorts seen in the aerial survey the year before). We see that the posterior estimates for the recruitment random effects fall outside the prior 95%ile for both 2015 and 2017 (with the missing year in 2016 shrunk towards the mean as one would expect). Adult biomass growth random effects are also well informed by the data, except for the last three years (2014-2016) where they basically line up with the prior. This is because 2015 is the last year of CPUE so 2014 would be the last data-informed estimate of these effects. That is not to say that we have no data on the adult biomass in these years, as the aerial survey in year y influences the adult biomass dynamics in year $y+1$ - given these data are up to and including 2016 we clearly have information on B_{2017}. The recruitment biomass, adult biomass and adult biomass growth dynamics can be seen in Figure 3.2.

3.2 Data fits and predictive performance

Figure 3.3 summarises the estimation performance summary of the model, in terms of fits to the data and posterior predictive performance. In short, how well does the probability model predict the data post-estimation. For posterior predictive analyses the Bayesian p-value is the probability with which the predicted discrepancy statistic (”closeness” of the simulated data to the deterministic prediction) is greater than the observed one (”closeness” of the actual data to the deterministic prediction). In this work, as in

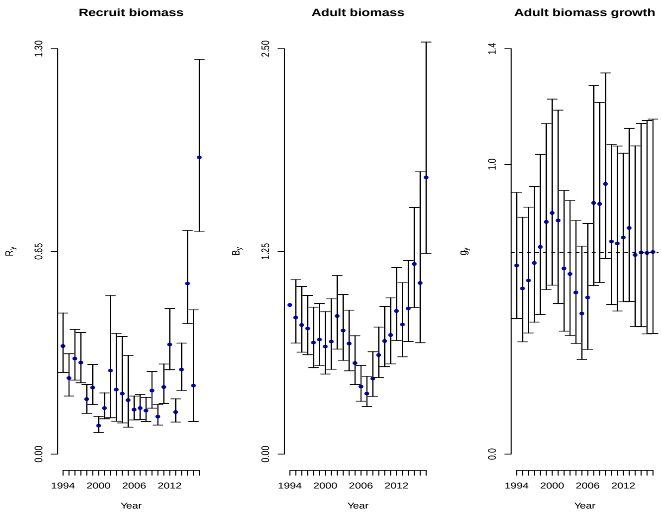

Figure 3.2: **Median (blue circles) and 95% credible interval for the recruitment biomass (left), adult biomass (middle) and biomass net growth (right).**

previous analyses [3], a non-parametric approach is taken with the median absolute deviation used as the discrepancy statistic. Ideally, one would like Bayesian p-values as close to 0.5 as possible, with values outside the range of 0.05-0.95 suggesting something systemically wrong with the model.

Figure 3.3 clearly demonstrates that both data sets are fitted well, with the fits to the CPUE data notably smoother than the raw data without missing the trends. The very high survey years in 2014 and 2016 are under-estimated by the model, but are still within the 95% predictive interval. In terms of posterior predictive performance the Bayesian p-values for the scientific aerial survey and CPUE data of 0.37 and 0.64, respectively, also indicate that the data are also being fairly well explained by the model.

3.3 Running the MP

The preliminary TAC calculated for the 2018–2020 block from running the `BaliProc` code in 2016 is 17,647t, a 3000t increase which is the maximum permitted. This recommendation is subject to consideration of exceptional circumstances and meta-rules by the 2016 ESC, with the final TAC decision to be made at the extended Commission.

4 Discussion

The performance of the estimation part of the CCSBT MP was explored, considering the information content of the data in relation to the key estimated parameters and the predictive abilities of the MP model. In general, all the parameters are well informed by the data, with the only clear prior forcing coming for the final years (2014-2016) of the adult biomass growth random effects for which there are no CPUE data to inform them. An interesting observation is how the CPUE data inform the recruitment biomass random effects in the missing years of the aerial survey. The CPUE data suggests lower recruitment in those years (as seen in other data and the OM) given the strong dip in the CPUE from 2006 to 2008. This further emphasises the point that by treating the key MP input data in such an integrated manner we can not only reduce the influence of observation error but also extract valuable (and consistent) information on recruitment and adult biomass dynamics from *both* data sources.

The model fits both data sources well, with no clear residual trends apart from an under-estimation of the high aerial survey points in 2014 and 2016. In terms of predictive performance - i.e. how much like the observed data do model-simulated data look - the model also does well in relation to both abundance

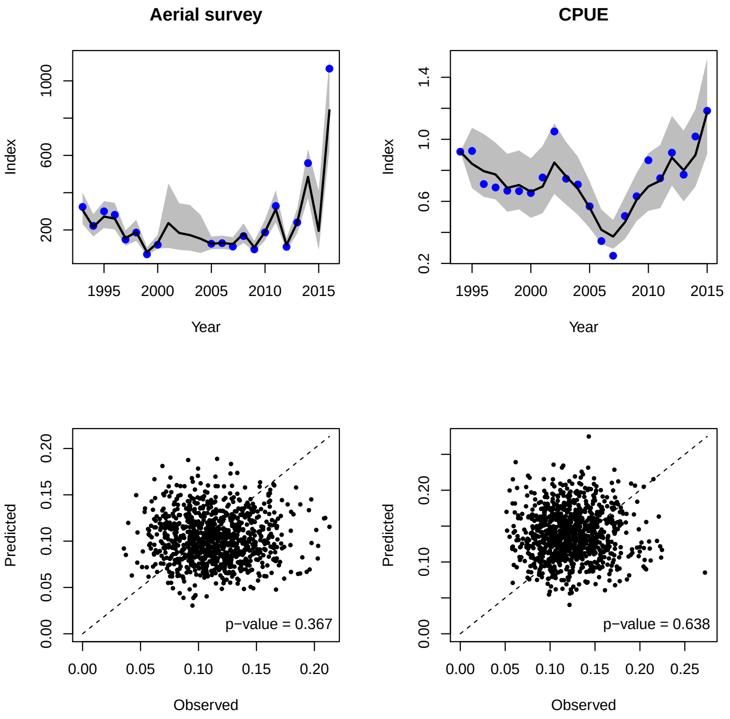

Figure 3.3: **Top row summarises fits to aerial survey (left) and CPUE (right) indices (observed, circles; predicted median (full) and 95% credible interval (dotted lines)). Bottom row summarises the posterior predictive performance of the model (including the p-values).**

indices. The very high 2014 and 2016 survey points, while under-estimated, are still within the 95% predictive interval. In conclusion, there are no issues that would suggest we cannot run the MP for calculating the next TAC block. The preliminary recommended TAC for 2018–2020 arising from running the MP was 17,647t, the maximum (3,000t) increase permitted.

5 Acknowledgements

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References

[1] Itoh, T., Sakai, O., and Takahashi, N. (2016) Update of the core vessel data and CPUE for southern bluefin tuna in 2016 *CCSBT-ESC/1609/21*.

[2] Eveson, J. P., Farley, J., and Bravington, M. V. (2016) The aerial survey index of abundance: updated analysis methods and results for the 2015/16 fishing season. *CCSBT-ESC/1609/9*.

[3] Hillary, R. M., and Preece. A. (2011) Updated technical specifications and performance analyses for MP1. *CCSBT-ESC/1107/12*.

[4] Brooks, S. P., and Roberts, G. O. (1997) Assessing Convergence of Markov Chain Monte Carlo Algorithms. *Stat. & Comput.* 8, 319–335.

Appendix

The BaliProc.dat file:

```
# Control file for SBT Bali Procedure - updated with data from the 2016
data exchange.
# Last year TAC already set
2017
# TAC in that year
14647
# catchability ratio AS vs CPUE -updated 20/6/2016
#849.843 = 2013 qratio value
885.593
# CPUE series for MP (1969-2015) -ave of BASE w0.8 w0.5 x overcatch multipliers
-updated 15/6/2016
2.3887
2.3219
2.1354
2.1971
1.8767
1.9349
1.4765
1.8997
1.6703
1.4060
1.2015
1.3857
1.3010
1.0253
1.0165
1.0432
0.8720
0.6506
0.6491
0.5405
0.5815
0.6417
0.5278
0.5792
0.8127
0.9203
0.9251
0.7117
0.6897
0.6687
0.6661
0.6538
0.7542
1.0506
0.7460
0.7087
```

```
0.5682
0.3443
0.2496
0.5056
0.6329
0.8652
0.7491
0.9141
0.7722
1.0182
1.1843
#historical aerial survey (1993-2016) (-11.0 = missing data) AS 16/6/2016
323.6244
221.814
299.876
281.26
148.5044
185.9542
69.2512
120.4431
-11.0
-11.0
-11.0
-11.0
125.8429
129.1713
110.7976
167.2365
95.7831
187.0467
328.5074
109.3264
240.4568
558.7715
-11.0
1065.5126
```

The qratio.dat file:

```
# number of bootstrap replicates
1000

#the existing "old" qratio value that needs to be updated
# 838.2094 = 2011 qratio
849.843
# number of data ponts in AS comparison (length of old series effectively)
17

# latest AS (minus missing years AND final years!)- 2016 data
323.6244
221.814
299.876
281.26
148.5044
185.9542
69.2512
120.4431
125.8429
129.1713
110.7976
167.2365
95.7831
187.0467
328.5074
109.3264
240.4568
#558.7715
#-11.0
#1065.5126

# previous AS (minus missing data!)  - 2013 data
348.2291
239.245
315.3104
292.9836
154.1827
184.9522
73.2641
130.8224
128.9778
130.5659
112.7744
174.1606
102.1017
200.3936
352.9442
101.2156
255.694
```

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Meta-rules and exceptional circumstances considerations

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CCSBT-ESC/1609/17

Prepared for the Extended Scientific Committee for the Twenty First Meeting of the Scientific Committee, Kaohsiung, Taiwan, 5 – 10 September, 2016

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Abstract

The meta-rules for the CCSBT Management Procedure (MP) include an annual review of the input monitoring series for the MP and fishery and stock indicators, which is intended to identify conditions and/or circumstances that may represent a substantial departure from which the MP was tested, termed “exceptional circumstances”, and where appropriate recommend the required action. In 2016, the ESC will review MP implementation in the context of both: i) the TAC set in 2013 for the 2017 quota year, and ii) the TAC for the 2018-2020 block, which is scheduled to be recommended at the 2016 meeting of the ESC.

Issues of potential concern in 2016 include: 1) the high 2016 data point in the aerial survey index monitoring-series; 2) the unresolved shift in selectivity in the Indonesian fishery since 2013; 3) evidence that total catches (members and non-members) are greater than the TAC (either annually or over the quota block). The 2016 aerial survey index, while outside the bounds of the reference and robustness tests conducted during MP testing, is outside the bounds in a positive direction and, in this respect, is not cause for immediate action with respect to current TACs. The second issue, is of continuing concern, but not for the operation of the MP; rather for the monitoring of the spawning stock, close-kin sample collection and the impact on OM conditioning and advice on stock status. Some progress has been made by the Extended Commission on the latter issue, and the ESC will need to advise on their potential impact on TAC setting and consideration for the 2017 stock assessment and MP testing.

1 Introduction

The meta-rules for the CCSBT Management Procedure (MP) includes a review of the input monitoring series for the MP and fishery and stock indicators (annual), periodic assessments of the status of the stock via reconditioned operating models (3 year intervals), and in depth review of the MP performance (6 years intervals), to determine whether there is evidence for exceptional circumstances and decide what, if any, action should be taken to deviate from the TAC recommended by the MP (Attachment 10 of the 2013 ESC report (Anon 2013)).

The annual review of the MP input series, stock and fishery indicators is intended to identify conditions and/or circumstances that may represent a substantial departure from which the MP was tested, termed “exceptional circumstances”, and where appropriate recommend the required action. In 2016, the ESC will review MP implementation in the context of both: i) the TAC set in 2013 for the 2017 quota year, and ii) the TAC for the 2018-2020 block, which is scheduled to be recommended at the 2016 meeting of the ESC.

Issues of potential concern in 2016 include: 1) the high 2016 index for the aerial survey monitoring-series; 2) the unresolved shift in selectivity in the Indonesian fishery since 2013; and 3) evidence that total catches (members and non-members) are greater than the TAC (either annually or over the quota block). These issues will need to be considered by the ESC and principles and process for action agreed, if required. Some actions are already underway to address the latter two issues by members and the Extended Commission, which will be reported to the ESC and/or the Extended Commission.

These same issues will also need to be considered in terms of the data required and the potential impact on re-conditioning operating models and associated work on the development of a new MP and the 2017 stock assessment. Additional exceptional circumstances may be identified at the ESC following review of stock and fisheries indicators.

As the ESC will be recommending a TAC in 2016 for the 2018-2020 TAC block, there is also concern regarding whether previously un-accounted catches will be adequately accounted for in members and non-member’s TACs, but these catch amounts have not yet been specified. These data will be also needed for the reconditioning of the OMs in 2017 (historical and future intended catch quantities).

2 Meta-rules and exceptional circumstances

As noted above, the meta-rules include a process for identifying exceptional circumstances. Exceptional circumstances are events, or observations, that are outside the range for which the CCSBT MP was tested and, therefore, indicate that application of the total allowable catch TAC generated by the management procedure MP may be highly risky, or highly inappropriate.

The exceptional circumstances process under the meta-rules involves the following three steps:

1. Determining whether exceptional circumstances exist,
2. A “process for action” that examines the severity (and implications) of the exceptional circumstances for the operation of the MP, and the types of actions that may be considered, and
3. “Principles for action” that determine how recommendations from the management procedure might be altered, if at all, based on the most recent reconditioning of the OM.

The Meta-rules process as adopted by CCSBT can be found at Attachment 10 of the 2013 ESC report (Anon 2013).

3 Progress on issues identified by the 2015 ESC

At the 2015 ESC annual review of the MP implementation, the lack of information on recent recruitment and implications for the MP were major issues for consideration (Anon 2015). These were resolved by the CCSBT by recommencing the scientific aerial survey (for at least 2016 and 2017) and undertaking the gene-tagging pilot study in 2016, as recommended by the ESC. The CCSBT plans to run the aerial survey in 2017 and start the on-going gene-tagging recruitment monitoring program. By 2019 the ESC aims to have developed a new MP that uses the gene-tagging juvenile absolute abundance estimates as a recruitment index.

The 2015 ESC also noted the cumulative effect of all potential catches above the TAC, i.e. member and non-member catches and unaccounted mortalities, and re-iterated its request to the Extended Commission to take steps to quantify all sources of unaccounted SBT mortality. A review of SBT in the China Market and an updated analysis on potential non-member catches (Edwards et al, 2016) will be provided to the 2016 ESC. Member catches were noted to be in excess of the TAC in 2013 and 2014 and the Extended Commission was urged all members to ensure adherence to its TACs. Preliminary reported catches for 2015 do not exceed the 2015 TAC (CCSBT, 2016).

Accounting for sources of additional mortalities from members in the TAC has also progressed, with the Extended Commission redefining member's "attributable catches". Members agreed to continue research on these attributable sources of mortality and report on their attributable catches to the ESC and CC, commencing in 2016.

The Commission also plans to account for non-member catches through a "direct approach" in 2016. This will involve setting aside from the MP recommended TAC an allowance to account for non-member catches before allocating the remainder of the TAC for the 2018-2020 block to members (CCSBT 2015). If implemented as described, this approach will be operating outside of the MP processes and, therefore will be untested. Two alternative approaches to account for additional mortality are being considered in 2016 for TAC recommendations under a new MP (i.e. the 2019 decision and beyond) (Preece et al, 2016).

4 Exceptional circumstances in 2016 and potential severity for MP

The following items may represent exceptional circumstances and will be reviewed by the ESC in 2016:

1) the historically high estimate of juvenile relative abundance for 2016 from the aerial survey,
2) the unresolved shift in selectivity in the Indonesian fishery since 2013,
3) continuing concern that total fishing mortality (from members and non-members) are greater than the TAC recommended by the MP.

Further exceptional circumstances may also be identified at the ESC as part of the annual review of stock and fishery indicators.

In considering the potential for exceptional circumstances arising from these issues, we have examined whether: 1) the inputs to the MP are affected, 2) the population dynamics are potentially significantly different from those for which the MP was tested (as defined by the Reference and Robustness sets of OMs), 3) the fishery or fishing operations have changed substantially, 4) total removals are greater than the MP recommended TACs, and 5) if there are likely to be impacts on the performance of the SBT rebuilding plan as a result.

The events are considered individually, however, the implications of the combination of events for the performance of the MP and the ability of the ESC to provide robust advice on the status and trends of the stock should also be considered.

4.1 Aerial Survey relative abundance estimate in 2016

The 2016 aerial survey estimate of juvenile relative abundance is the highest point in the time series (see Farley and Eveson, 2016). There is no information on the 2015 juvenile relative abundance, because the aerial survey was not run and the selectivity of the LL1 longline fleet has shifted back towards older age classes in recent years. The 2014 index was also high, relative to all other years. The 2016 data point is outside the range of values for which the MP was tested in 2011. It follows that this index value represents “exceptional circumstances”.

As the direction of the exceptional index value is positive and there was no evidence of unusual conditions for operation of the aerial survey, there is no apparent reason to review the 2017 TAC (set in 2013).

Hillary et al (2016) review the data and operation of the MP in 2016 for the 2018-2020 TAC block, and conclude that the MP operation is not affected by the high data point, and therefore can be used to calculate the recommended TAC. The MP has been designed with a “cap” which limits the change in TAC from one 3 year block to the next. This cap or TAC change limit is set to 3000t. The

3000t cap was reached in the preliminary calculation of the recommended TAC from the MP in 2016. An analysis of MP outputs for alternative values for the 2016 aerial survey data point, given that all other input data remain the same, indicates that the recommended TAC would remain the same (i.e. at the 3000t cap) unless the 2016 aerial survey data point was lower than the very low point recorded 5 years ago, in 2012 (see Appendix 1 for these results).

Hence, in considering the second stage of the meta-rules process for the 2018-2020 TAC block, we conclude that that there is no “exceptional impact” resulting from this high data point on the operation of the MP or the TAC advice arising from it. Therefore there is no need to engage step three of the process to alter the TAC recommendations in light of the high 2016 index from the aerial survey.

In the context of the 2017 reconditioning of operating models, however, these two recent high values of the index (2014 and 2016) are likely to be highly influential on projections in the short term, as was the case for most recent stock assessment (in the case of the 2014 index value). These will be supplemented by the 2017 aerial survey estimate which will be included in the reconditioning of operating models and in the 2017 stock assessment advice. The ESC will need to revaluate the implications of these recent aerial survey indices at that time.

4.2 Changes in the Indonesian fishery selectivity

Since 2013, unusually large numbers of small fish have been recorded in the Indonesian catch monitoring data from Benoa, Bali (see Farley et al, 2016). It is not known whether these fish were caught on or off the spawning ground, and/or whether these data indicate a substantial shift in the selectivity of the Indonesian fishery. Attempts have been made to match the catch monitoring data with additional fishery data provided by Indonesia, but linking the records has proved difficult. Further data analyses are planned, but at this stage the issue is unresolved.

The potential shift in selectivity does not affect the data inputs to the MP, but may indicate changes in the operation of the Indonesian fishery that were not included in the OM used at the time of testing the MP. The advice from 2015 regarding this issue remains the same for the 2017 TAC recommendation and the 2018-2020 TAC recommendation: the potential change in selectivity is of concern but the immediate implications for the operation of the MP are insufficient on their own to constitute to recommend modification to the MP recommendation. The previously recommended action should continue to be pursued so that the shift may be addressed in the next reconditioning of the operating models in 2017 (Davies et al, 2015).

4.3 Total fishing mortalities exceeding the TAC

As noted previously (Davies et al, 2015), the design and simulation testing of the MP assumed that all removals from the stock were accounted for, i.e. the implementation of the TAC was exact. In 2014, the ESC evaluated the impacts of potential un-accounted mortalities from a variety of sources on stock status and the rebuilding plan (Anon 2014). The results indicated that, for the scenarios examined, there was likely to be little impact on current stock status; but if the total mortalities were as large as those considered in the ‘added-catch scenario’ (Anon 2014), and they continued into the future, then the impacts on the performance of the MP rebuilding plan may be substantial. The ESC 2014 noted that the added catch scenario was potentially plausible given the available data, analysis and reports. The ESC could only use simple scenarios (i.e. the level and trajectory of potential un-accounted mortality) in these scenario analyses because there is very limited data or information on the specifics of the potential member and non-member unaccounted mortalities.

In 2014 the ESC agreed that the scenarios considered for potential unaccounted mortalities, if they were in fact occurring, triggered exceptional circumstances. The ESC did not recommend urgent management action on the level of the TAC at the time, but did request that the Commission make provision of more informative data on unaccounted mortalities a priority. The 2015 ESC re-iterated its request to the Extended Commission to take steps to quantify all sources of unaccounted SBT mortality. Little new data has become available since this request was made, however, some new data will be presented in 2016 (see below).

In addition to the uncertainties in member and non-member catches, total reported catches by members have been greater than the global TAC in recent years. The global TAC was reported to have been exceeded by 485 t in 2013 and 354 t in 2014 (Anon, 2015). Final figures for 2015 are not yet available, but preliminary figures indicate that members' reported catches didn't exceed the 2015 TAC (CCSBT, 2016).

We consider this issue in the context of the 2017 TAC (recommended in 2013), and note that it is probable that total fishing mortalities (from member reported catches, non-member unaccounted mortalities, additional member "attributable" catches, uncertainties in catches that may or may not be attributed) have exceeded the 2015 TAC, and this may impact the performance of the rebuilding plan. This is an on-going exceptional circumstance that the EC is addressing through two key actions: members have agreed to start accounting for "attributable catches" from 2016, although full accounting will not occur until 2018, and the EC has agreed to take account of non-member catch in the setting of future TACs (discussed in Preece et al, 2016).

For the 2016 recommendation for the 2018-2020 TAC block, the quantities of non-member catches and new components of member's attributable catches that will be accounted for in future TAC setting decisions by the EC have not yet been specified. If the catch quantities to be attributed to total catch by members and/or the allocation for non-member catches do not account for the total fishing mortality, then the potential for impact on the rebuilding plan for SBT will remain.

Actions have been taken to estimate some of these quantities. A market review of SBT in China has been commissioned by the secretariat and results will be presented at the 2016 ESC. Two papers in 2015 attempted to quantify potential levels of non-member UAM in the Pacific and Indian Oceans by indirect methods (Chambers and Hoyle, 2015; Hoyle and Chambers, 2016). These methods have been updated in 2017 and extended to the Atlantic Ocean (Edwards et al, 2016). There are substantial uncertainties and assumptions made in these analyses. Papers have been presented in 2015 on uncertainties in members catches (Jeffriess, 2015; Itoh and Takeda, 2015; Patterson and Hansen, 2014.) and may be updated for consideration in 2016. These issues have been discussed in the past but remain unresolved. For members' newly defined catches that will become "attributable", quantities for each catch component will need to be specified, even though there may be little information on the actual catch quantities. These catches will also need to be specified for the reconditioning of operating models in 2017 so that their potential impact on the most recent estimates of stock and fishery dynamics can be considered in light of the original MP testing conditions. The 2016 ESC will need to consider whether, or not, it will provide additional advice to the EC on this particular exceptional circumstance in the context of the 2018-2020 TAC MP recommendation, given the limited progress with resolving the substantial uncertainties associated with total mortalities for the SBT stock.

5 Conclusions

Through the meta-rules process we have examined the high aerial survey data point in 2016, the potential shift in selectivity in the Indonesian fishery, and the potential for fishing mortality to be greater than the TAC. The impacts of these issues have been considered for the 2017 TAC (recommended in 2013) and the 2016 recommendation for the 2018-2020 TAC block.

The high aerial survey data point does not affect running of the MP in 2016 but may affect future population dynamics estimates, which will be examined in the full stock assessment scheduled for 2017.

The Indonesian selectivity change remains unresolved. Similarly, this does not directly impact on the running of the MP in 2016, but will need to be addressed prior to the 2017 reconditioning of operating models.

The potential for fishing mortalities to continue to be greater than the TAC is of concern for the 2017 TAC recommendation. Action has been taken by the EC and members will account for their attributable catches from 2016 onwards, and an allowance for non-member catches will be made in the next TAC block (2018-2020).

For the 2016 recommendation for the 2018-2020 TAC block, the uncertainty in whether total fishing mortality will exceed the TAC remains a concern. At present, the new components of catches that will be attributed to the members have not been specified, and the adjustment to take account of non-member catches has not yet been specified. The ESC is not in a position to determine with confidence if total catches (all forms of member and non-member) will be greater than TAC.

References

Anon. 2013. Report of the Eighteenth Meeting of the Scientific Committee, 7 September 2013, Canberra, Australia.

Anon. 2014. Report of the Nineteenth Meeting of the Scientific Committee, 6 September, 2014, Auckland, New Zealand.

Anon. 2015. Report of the Twentieth Meeting of the Scientific Committee, 5 September 2015, Incheon, South Korea.

CCSBT. 2016. Secretariat review of catches. CCSBT-ESC/1609/04.

Chambers M, Hoyle S. 2015. Estimates of non-member catch of SBT in the Indian and Pacific Oceans. CCSBT-ESC/1509/10.

Davies C, Preece A, Hillary R. 2015. Meta-rules for implementation of CCSBT Management Procedure and consideration of exceptional circumstances and 2017 scheduled review of MP. CCSBT-ESC/1509/12.

Edwards C, Williams A, Hoyle S. 2016. Estimates of Southern Bluefin Tuna Catch by CCSBT Non-Member states. CCSBT-ESC/1609/BGD-02.

Farley and Eveson. 2016. The aerial survey index of abundance: 2016 updated results. CCSBT-ESC/1609/9.

Farley J, Nugraha B, Proctor C, Grewe P. 2016. Update on the length and age distribution of SBT in the Indonesian longline catch and close-kin tissue sampling and processing. CCSBT-ESC/1609/8.

Hillary R, Preece A, Davies C. 2016. MP results and estimation performance relative to current input CPUE and aerial survey data. CCSBT-ESC/1609/18.

Hoyle S, Chambers M. 2015. Estimating Southern Bluefin Tuna Catches by Non-Members of CCSBT. CCSBT-ESC/1509/21.

Itoh, T. and S. Takeda. 2015. Update of estimation for the unaccounted catch mortality in Australian SBT farming in 2015. CCSBT-ESC/1509/32(Rev)

Jeffriess B. 2015. An updated Review of Tuna Growth Performance in Ranching and Farming Operations. CCSBT-ESC/1509/35

Patterson H, Hansen S. 2014. Post-release survival of tuna and tuna-like species in longline fisheries. CCSBT-ESC/1409/14, CCSBT-ESC/1509/BGD 01.

Preece A, Davies C, Hillary R. 2016. Advice on incorporating UAM in stock assessment and MP evaluation and implementation. CCSBT-OMMP/1609/05, CCSBT- ESC/1609/BGD-3.

Appendix 1. Bali Procedure experimental runs with alternative aerial survey data points

The Bali Procedure was updated in July 2016 to incorporate the new data and update the qratio value. The preliminary run of the MP is documented in Hillary et al, 2016.

To test the impact of the high 2016 Aerial Survey data point, a range of alternative values were used in the Bali Procedure to examine whether the recommended TAC was sensitive to the value of this data point. All other data used in the Bali Procedure were unchanged, i.e. the full aerial survey time-series was not re-analysed, and the index was not re-standardised, and the qratio value was not updated to include this alternative aerial survey value.

Results:

2016 data point set to	AS value	TAC increase from 2013
Original 2016 estimate	1065.5126	3000t
Same as 2014 estimate	558.7715	3000t
Same as 2012 estimate	109.3264	3000t
lower	100.0	2850t

These test results show that for alternative values of the 2016 aerial survey data point, there is no change in the TAC recommendation (because there is a cap in place at 3000t) until the value becomes lower than the low value observed in 2012. Therefore this single high point in 2016, by itself, is not affecting the TAC recommendation.

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APPENDIX A4.

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Advice on incorporating Un-Accounted Mortalities in stock assessment and Management Procedure evaluation and implementation

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CCSBT-OMMP/1609/05, CCSBT- ESC/1609/BGD-3

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Citation

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Abstract

In light of the potential impacts of catches exceeding the recommended TAC, the CCSBT Extended Commission (EC) has indicated that in 2016 it will use a “direct approach” to account for catches by non-members in the 2018-2020 TAC block. This will involve setting aside an allowance from the TAC to account for non-cooperating, non-Member catches before allocating the remainder of the global TAC to Members and Cooperating-Non-Members (CNMs). The EC also agreed that members would account for any additional sources of mortality arising from their fisheries within their national TAC allocation (termed “attributable catches”). Sources of attributable catches were agreed and members are expected to commence reporting on aspects of attributable catches in 2016.

The Extended Commission has identified 2 approaches for accounting for non-cooperating, non-member (here after referred to as non-member) fishing mortalities in TAC recommendations beyond the current 2016 decisions. These are: 1) a “Direct approach”, as above, and 2) an “MP approach” which requires re-tuning the MP with unaccounted mortality scenarios, so that the TAC recommended by the MP takes into account the uncertainties in non-Member catches.

The EC has requested that the Extended Scientific Committee (ESC) provide advice on the relative merits of these approaches in the longer term (i.e. for the 2019 setting of the 2021-2023 quota block and beyond), and how this might be influenced by, for example, increasing trend in catches by non-Member fleets as the stock rebuilds, or for other reasons (Anon 2015 EC). The EC has also asked the ESC to develop a new MP by 2019 (for the setting of the 2021-2023 TAC block and beyond). The development of a new MP will involve reconditioning operating models with the catches (2018-2020) accounted for in the 2016 “direct approach” along with all other sources of additional mortality that the ESC considers justified. Incorporating all the sources of mortality in testing and tuning a new MP is equivalent to the “MP approach”, which is consistent with the CCSBT commitment to an MP approach for management of the stock (Anon, 2015). An additional consideration that may be of concern to the EC is how to account for a proportion of the historical non-member catches becoming member or CNM catch in the future. This can be accommodated, as part of the development and tuning of a new MP, if this were likely to occur.

The data available to the ESC to consider impacts of all sources of unaccounted mortalities remains quite limited. Very little new data has become available since the 2014 ESC consideration of this issue. We note that the time-series of catches (past and future) for these sources of fishing mortalities (member and non-member) will need to be resolved and specified prior to the reconditioning of operating models in 2017, for management strategy evaluation (MSE) of the new Management Procedure (MP) and stock assessments.

1 Introduction

The development and tuning of the CCSBT Management Procedure (MP) assumed that the TAC recommended by the MP would be caught perfectly. That is, there was no allowance for implementation error (catches being greater, or less, than the recommendation from the MP). At the time of adoption of the MP it was assumed that existing uncertainties in catches had been, or would be, resolved before implementation of the TAC advice in 2011. There was no provision for uncertainty in catches by members and CMNs (included with "members" in this paper), or additional catches by non-cooperating, non-members (here after referred to as non-members). As there continued to be evidence of total catches in excess of the TAC at the time of the second MP run and TAC recommendation in 2013, the Commission requested advice from the ESC on i) the sources and, ii) the likely impacts of unaccounted mortalities on MP performance.

The ESC reviewed the potential scale and impacts of member and non-member un-accounted mortalities on the performance of the MP and assessment of stock status in 2014 (Anon., 2014; Preece et al., 2014). The OMMP Technical meeting and ESC had difficulty defining the quantities of unaccounted mortalities associated with each of the potential sources due to the limited and indirect nature of the data available for this task (Anon 2014, para 21-30, 47-68). In the absence of more informative data, scenarios were developed for catch quantities, size-classes and temporal variability of potential unaccounted mortalities by the ESC (Anon 2014, para 28). Results from these scenarios indicated that there was limited impact on the stock status advice at that time, but the scenarios had the potential to undermine the rebuilding strategy for the stock and reduce the level of the TAC over the rebuilding period (Anon., 2014, Attachment 8).

In light of the potential impacts of catches exceeding the recommended TAC, the ESC requested that the EC and Compliance Committee urgently provide more detailed information to allow the impact of unaccounted mortalities to be properly assessed (Anon., 2014, para 95).The ESC Chair formally requested that members provide the ESC with access to the CDS data, which was considered a potentially useful source of information.

The ESC reviewed the request from the EC again at its 20th meeting in Korea (Anon., 2015, paras 72-85). However, there were no new data or information available to the ESC to assess the implications any further than those completed in 2014. It was noted at that time that a proposed review of SBT in the Chinese market may provide additional information on aspects of the unaccounted mortalities for the 2016 meeting of the ESC.

In preparing to set the 2018-2020 TAC in 2016, the EC has indicated that it will use a "direct approach" to account for catches by non-members, because there is insufficient time to re-tune the current MP to take account of the additional mortality. This will involve setting aside an allowance to account for non-Member catches from the TAC before allocating the remainder of the global TAC to Members and CNMs. The EC also agreed that members would account for any additional sources of mortality arising from their fisheries, termed "attributable catches", within their national allocation. Sources of attributable catches[1] were agreed in 2014 and members are expected to report on allowances to be set for attributable catches for 2016-17 quota year to the EC in 2016. Members have indicated that they will use the potential increase in TAC for the 2018-2020 quota block to fully account for attributable catches (Anon 2015).

The Extended Commission has identified 2 approaches for accounting for non-member fishing mortalities in TAC recommendations in 2019 and beyond (Anon, 2015, para 72):

- *"The first approach (the "Direct approach") is to estimate the non-Member catch and then set aside an allowance to take account of non-Member catch before allocating the remainder of the global TAC to Members and CNMs.*
- *The second approach (the "MP approach") is to re-tune the MP to different scenarios that cover the plausible scenarios of catches from non-Members and have the MP recommend a TAC that takes into account the uncertainties in the non-Member catch."*

The EC has requested that the ESC provide advice on the relative merits of these approaches in the longer term (i.e. for the 2019 setting of the 2021-2023 quota block and beyond), and how this might be influenced by, for example, increasing trend in participation by non-member fleets as the stock rebuilds, or for other reasons (Anon 2015 EC).

The EC has also asked the ESC to develop a new MP by 2019 (for the 2021-2023 TAC block and beyond). This will involve reconditioning operating models with the catches (i.e. 2018-2020) accounted for in the 2016 "direct approach" along with all other sources of mortality, including the new components of attributable catch. An MP tuned using these operating models is the equivalent of the "MP approach". The CCSBT has endorsed the need for an MP approach for management of the stock (Anon, 2015).

Integrating all sources of fishing mortality, historical and into the future, into the testing and tuning of an MP is central to the scientific approach to decision-rule based management advice. This ensures, to the extent possible, that the MP selected and implemented is robust to the levels of catch occurring in the fishery (i.e. is likely to meet the rebuilding objective of the EC) and provides greater certainty and stability to members on future TACs.

The direct approach proposed by the EC operates outside of the MP context, in that the historical and future catches have not been incorporated into the conditioning of operating models and tuning of the MP (if they were incorporated, it would be the "MP approach"). The "direct approach" is however, a more precautionary implementation of the recommended TAC in the absence of re-tuning, compared with making no allowance for non-member catches.

The timeframe set in 2014 for defining the total fishing mortalities to be accounted as attributable and non-member catches (Anon 2014b, para 53) did not anticipate that the 2015 EC would request development of a new MP in 2016-2019, and that this would require updated operating

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[1] Attributable catch is defined as: "*A Member or CNM's attributable catch against its national allocation is the total Southern Bluefin Tuna mortality resulting from fishing activities within its jurisdiction or control including, inter alia, mortality resulting from: 1) commercial fishing operations whether primarily targeting SBT or not; releases and/or discards; recreational fishing; customary and/or traditional fishing; and artisanal fishing.*" (Anon 2014b)

models for MP testing. Some of the potential sources of additional fishing mortality identified in 2014 (Anon 2014, Attachment 5- See appendix 1) remain unresolved, and it has not been decided which sources and amounts of catch will be accounted for in a non-member catch allowance, or in member attributable catches. There is potential for additional unaccounted mortality from members and non-members, which should be accounted for if considered plausible. Both current and historical catches will need to be defined in time for the reconditioning of the operating models in 2017 for them to be included in the MSE testing of new candidate MPs. Additional fishing mortality that is not accounted for elsewhere could be included as part of the non-member UAM scenarios considered in the two approaches, as discussed below. If additional mortality is not accounted for in testing the new MP then the EC will be in a similar situation as present, where total catches are greater than the catches against which the MP was tested, which leads to consideration of exceptional circumstances in the meta-rules process and a need to re-test and review MP performance and re-tune the MP.

2 The approaches

2.1 “Direct approach”.

In the case of the “direct approach”, additional fishing mortalities from non-members are accounted for as an allowance from the recommended TAC, and the remainder of the TAC is allocated to members and CNMs for their attributable catches. This approach will require members reaching agreement on an amount of additional catch that will be deducted from the recommended TAC before allocation of remaining TAC to the members and CNMs.

This method operates outside of the management procedure framework because the historical and future components of these catches have not been incorporated into the testing of the MP. It requires a negotiated agreement on the TAC “allowance” to account for fishing mortalities from non-members. The performance of the MP using this method is unknown, however, it is more precautionary to account for additional mortality within the TAC than not account for it at all.

Data requirements: A single estimate of the likely current additional catch is required for the 2018-2020 TAC decision by the EC in 2016. The catch estimate has not yet been determined. Negotiated estimates of non-member catches would be needed for each implementation of the direct approach in future TAC recommendations, unless non-members provide catch data.

Selectivity: The direct approach assumes that the selectivity or length-classes taken in the additional catches matches the selectivity of the whole fishery (i.e. the combined selectivity of each fishery weighted by their relative allocation), which may or may not be true. Taking X tonnes of small fish, compared with X tonnes of large fish, will have different impacts on the rebuilding plan for the fishery depending on the age–structure of the population at the time the catches were taken. These impacts are unlikely to be accounted for in the direct approach as amount and size classes of the catch has not been decided prior to the ESC.

TAC Implications:

- The implications of using this method are that less of the MP recommended TAC will be available for member and CNM allocation, and the maximum change allowed for in the adopted MP (i.e. 3000t), may become restrictive.
    - In cases where the additional non-member catch amount is greater than the recommended increase in TAC, then it would follow that all members would incur catch reductions for their attributable catches.
    - If the TAC recommendation is a catch reduction, member’s allocations will be reduced further to account for the non-member catches. If the agreed additional catch amount is greater than the maximum TAC change then it may not be possible to reduce the TAC quickly enough to maintain the expected performance of the MP.
- This approach effectively provides a *de facto* allowance to non-members for their unreported and unregulated fishing mortality. The impact of the allowance for non-member fishing mortality is shared by all members.

2016 TAC decision: The direct approach has been adopted as an interim method to account for additional mortality in the 2018-2020 TAC block, as there is insufficient time for the re-tuning of the existing MP to account for these catches. As noted above, performance of this approach is unknown, but this is more precautionary than not accounting for additional mortality.

2019 TAC decision and beyond: The EC has requested that the ESC develop a new MP for use in 2019. This involves reconditioning of operating models and evaluating the performance of candidate MPs, therefore is equivalent to the "MP approach". Given this, the direct approach is redundant after the 2016 TAC decision as a new MP that has been demonstrated to be robust to specified levels of unaccounted mortality will be is scheduled to be in place for the 2019 TAC setting.

Accounting for future trends: Determining plausible increases and decreases with changes in stock size in the future would also need to be incorporated to address the Commission's concern about trends in unaccounted mortalities as the stock rebuilds (or for other reasons). This is best done as part of the MSE testing and selection of a new MP.

Science-based management: The Commission has endorsed proceeding with science-based management of the SBT stock through an MP and has requested development of a new MP to be ready to be used to recommend the TAC for the 2021-2023 TAC block in 2019. The "direct approach" operates outside of MP, and does not fit with the intention of the EC to incorporate all major sources of uncertainty and test the robustness of the current or future candidate MPs to these uncertainties.

2.2 "MP approach"

For the "MP approach" additional fishing mortality is included as part of the total catch taken in the operating models used to test and tune the MP. This could be done using catch scenarios or an implementation error approach. When an MP has been tested and tuned in this manner, there is no need for a separate allowance for additional catches to account for their impact on the stock. The recommended TAC is only allocated amongst members for their attributable catches and is robust to a specified level of uncertainty in non-member and/or additional fishing mortality. This is not the case for the current MP, as it assumes there are no additional sources of mortality beyond the TAC.

Data: Additional catch scenarios would need to be specified that encompass both plausible historical and future catches. Amounts can be added to the historical catches (in absolutes (i.e. tonnes) or as percentages) of the fishery with the closest matching selectivity to the additional catch scenario. Alternatively a new fishery could be added to the operating models to accommodate the additional catches. For future catches, catch multipliers can be applied to the matching projection model fisheries. The most plausible scenarios could be included as a new grid element in the reference set of operating models. Additional scenarios may also be included in robustness sets of operating models, and performance testing and tuning of the MP would be across these uncertainties in additional fishing mortalities to ensure to the extent possible that the candidate MPs are robust to these other sources of mortality.

An alternative to fixed catch scenarios is using a stochastic implementation error term in the simulation models. This may be implemented as a simple random variation around the TAC or a combination of a bias and CV, which would allow the implementation of scenarios for plausible trends in unaccounted/additional mortalities. The error term is applied to the recommended TAC during testing and tuning of the MP and would represent the likely scale of non-member or any other unaccounted catches. A number of replicates would be run for each model in the reference set. This method has been used (for example) in evaluation of harvest strategies for the key target species in the Eastern tuna and Billfish Fishery in Australia (Kolody et al, 2010; Hillary et al, 2016).

Selectivity: The assumed selectivity of the additional catches would be accommodated through assigning the additional catches to the closest matching fisheries as defined in the operating models.

TAC implications: For the MP approach, the likely impacts on TACs will be that recommended TACs are lower than TACs from MPs tuned not with additional catches. However, the full maximum increase (or decrease) in TAC (3000t in the current MP) would be available for allocation to members. The uncertainty in catches, identified in the scenarios/implementation error, will be encapsulated in the MP testing and the TAC recommended by the MP should be robust to this uncertainty, if the size and length classes impacted are adequately specified. There is no “allowance” in the TAC to non-members. As with the direct approach, the impact of additional catches is shared among all members.

If the EC is concerned about allowing for potential new members in the future as part of the testing of a new MP, this could be considered when setting up the MSE projection models. As noted above, it is necessary to account for both historical and future total catches in the Operating Models used in the MSE in order for the future MP to be robust. A proportion of the historical non-member catches can be included in the data input file to the MP to allow for potential new members or CNMs. The change is to the base catch level which the MP decision rule adjusts up or down. The recommended TAC from the MP would be for all members (including the new-member(s)). If all mortalities are included in the OMs it is less likely that there will be the need to retune the MP to account for such a development (i.e. additional members to the EC).

2016 TAC decision: The Commission has stated that it will use the direct approach in 2016 TAC setting.

2019 TAC decision and beyond: The MP approach allows for the inclusion of all sources of unaccounted mortality in the OMs, and the new MP will be tuned to be robust to these uncertainties.

Accounting for future trends: Catch scenarios need to include plausible future trends in additional catches, to address the Commissions concern regarding future trends in non-member catches, or other catches, as the population increases under the rebuilding plan. If we use the same method, i.e. the additional catch multipliers, used in projections of the unaccounted mortality scenarios in 2014, this will scale the additional catches up and down as TACs increase and decrease which we could assume is indirectly linked with associated increases/decreases in the population. This wouldn’t take into account changes in non-member effort or targeting of SBT. The implementation error method can also scale the additional catches in relation to changes in

TAC recommendations, and thus would indirectly take into account the potential trend in catches with increasing population size.

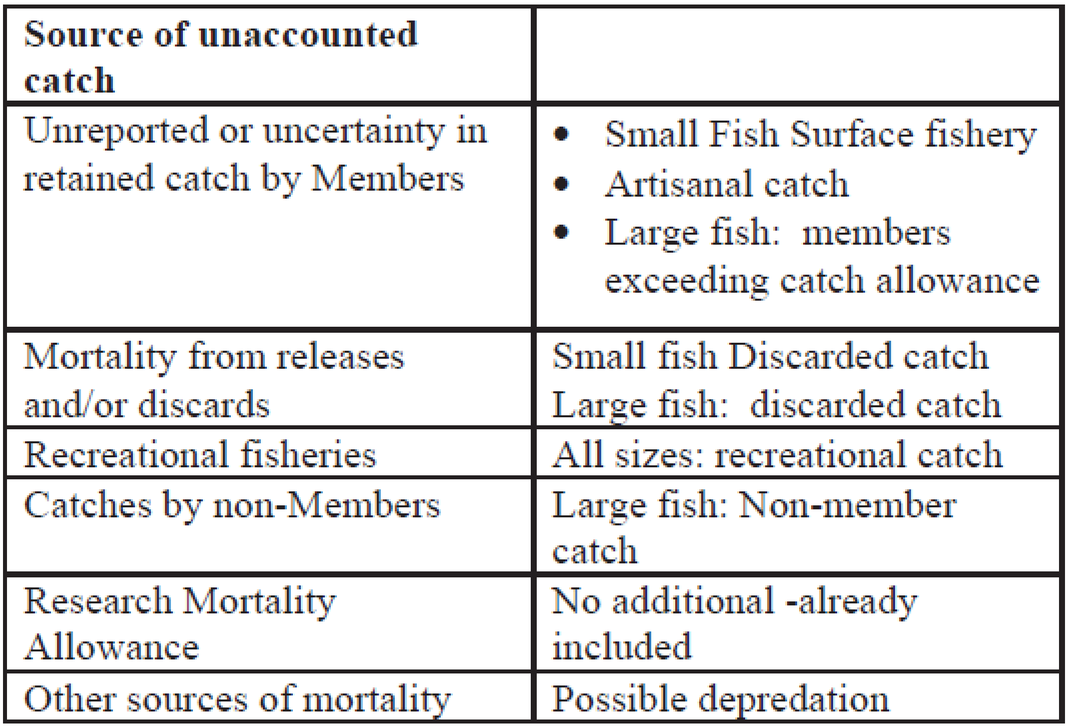
Science based management: The MP approach requires reconditioning of operating models, evaluation of performance and tuning the MP to be robust to additional sources of mortality and their uncertainties. Since the CCSBT has request that the ESC develop a new MP that uses new data, this work is already underway and scheduled within the CCSBT work plan, for completion prior to the next TAC decision in 2019. The CCSBT has endorsed the need for an MP approach for management of the stock, and the MP approach is consistent with this endorsement.

3 The available data

The data to inform the discussions of unaccounted mortalities and methods to account for them is limited, disputed or unavailable (Anon 2014). Very little new data has become available since the 2014 sensitivity tests on the impacts of potential unaccounted mortalities on MP and stock assessment advice (Preece et al 2014, Anon 2014).

Regardless of the method chosen for setting TACs in the future, the historical additional catches (not already accounted) need to be integrated into the updated OMs. When incorporating additional (member and non-member) catch estimates in the operating models we need to consider the data available, the method for estimating the catch amount, which fishery selectivity they reflect most closely, the years over which they are to be applied historically and how they are to vary in future with changes in stock size (Preece et al, 2014). For member's attributable catches, additional considerations for their technical implementation in the operating models include whether or not these scenarios might affect CPUE interpretation, age or length frequencies, or tag reporting rates (Preece et al 2014).

The sources of un-accounted mortality that have been considered previously by the ESC were included in table 1 from attachment 5 of the 2014 ESC report:



Source of unaccounted catch	
Unreported or uncertainty in retained catch by Members	• Small Fish Surface fishery • Artisanal catch • Large fish: members exceeding catch allowance
Mortality from releases and/or discards	Small fish Discarded catch Large fish: discarded catch
Recreational fisheries	All sizes: recreational catch
Catches by non-Members	Large fish: Non-member catch
Research Mortality Allowance	No additional -already included
Other sources of mortality	Possible depredation

In the absence of quantitative data to inform estimates, the 2014 ESC developed 4 scenarios for member and non-member unaccounted mortalities, for the sensitivity tests. The OMMP and ESC noted that the unaccounted mortality scenarios were based on very limited data for current or historical estimates and almost no information on how the unaccounted mortalities might vary over time, or continue into the future (OMMP4). The four scenarios were "added-catch", which incorporated many sources of additional mortality (details below), and 3 hypotheses for the uncertainty in the catch from the potential bias in size sampling for the Australian surface fishery (the three scenarios were 20%, 40% and 0% historical and future catch anomalies).

The 2014 “added-catch scenario” was developed to encompass all sources of member and non-member unaccounted mortalities. It was comprised of 1000t of “small fish” (to represent recreational catches, small fish discard mortalities), 1000t of “large fish” (to represent over-quota catches by members, discard mortalities, recreational catches), and the surface fishery 20% catch anomaly and related changes in catch–at-age for that fishery. This “added catch scenario” gradually ramps up catches from 1990 to 2013. The “small fish” and “large fish” specifications are used to assign the additional catch to fisheries that take a matching or similar size range of fish. This assignment to a particular fishery in the OMs is to ensure that the impact of the potential additional catches on the stock is appropriately represented. It does not necessarily attribute the additional catches to that fishery. In the projections, the future added-catch associated with this scenario stays at the same fraction of the accounted catch assumed for 2013. The “added- catch scenario” had the largest impact on performance of the MP. Further details of the discussion of sources of UAM are in Attachment 5 of the 2014 ESC report (provided in Appendix 1 of this paper) and in the 2014 OMMP report.

Some of the catch components from these scenarios will be accounted for in member’s future allocations of attributable catches. However, the historical components of attributable catches and any future uncertainties in these will still need to be incorporated in the operating models for MP testing. Research mortality allowance is already deducted from the TAC and accounted for in total catch in the operating models.

Methods for estimating catches by non-members through analysis of non-member effort and member catch rates, were proposed by the 2014 ESC. In 2015, 2 methods were used to attempt to quantify potential non-member catches in the Pacific and Indian Oceans (Chambers and Hoyle 2015; Hoyle and Chambers, 2015). The methods are based on using the catch rates of SBT from CCSBT members in similar areas, and applying these catch rates to the effort from non-members in the same regions. The mean total catch by non-members was estimated to be 120 to 580 t for 2011-13 using the two different approaches (Anon 2015).

These approaches have been revised and extended for the 2016 ESC (Edwards et al, 2016). The updated analysis includes the Atlantic Ocean using non-member effort data from ICCAT. Two different methods were applied and catch-rates from Japanese Longline and Taiwanese fisheries were used to provide results. Estimates from the two methods are now similar. There are substantial difference, however, depending on whether the Japanese or Taiwanese CPUE data are used to scale the non-member effort. The methods use some aspects of the historical catch data, which is highly uncertain given the historical over-catches.

The CCSBT has also funded a project investigating the presence of SBT in the markets in China. The results from this study were not available at the time of writing.

Specifying the historical and future catch estimates for the non-member fishing mortalities and the uncertain components of the member’s attributable catch will need to occur in time for the reconditioning of the SBT OMs in 2016-2017 so that these data can be used for updated stock status advice and in testing of a new MP in 2017. Catches taken, or assumed taken, would be incorporated in the regular CCSBT data exchange for updates of total catches reports and in data files for future updates of the OMs.

The EC has taken actions to account for the impact of non-member catches on the performance of the MP, with the approaches reviewed here, and in refining the definition of attributable catch. Un-resolved potential sources of additional fishing mortality remain an issue for full accounting of total fishing mortalities and their impact on the rebuilding performance of the SBT management procedure.

4 Conclusions

We recommend that the MP approach be adopted for accounting for the impact of non-member catches, and more broadly, for all sources of fishing mortality in future TAC advice. This approach is recommended because the ESC will initiate development of new candidate MPs in the coming 12 months, and technical methods for incorporating all sources of additional fishing mortality can be included and fully tested using updated and reconditioned operating models (i.e. via the MP approach). If sufficient levels of additional fishing mortality are incorporated into the operating models used in the evaluation of the new candidate MPs, the TAC advice from the selected MP will be robust to those levels of fishing mortality and uncertainties in them. Importantly, the safe guards provided by the meta-rules and over-arching MP framework will apply because the OMs will have a consistent accounting of additional catches in the both the conditioning and projections components. The MP approach will ensure best-practice science-based management of the fishery for which the CCSBT has been recognised as an international leader.

The data available to inform the catch estimates (for either approach) remains very limited and continues to constrain the level of specificity of the scenarios. The additional catch scenarios will need to encompass any unaccounted mortalities and uncertainties in catches that are not encompassed in the members “attributable catches”. Further advice from the Commission and Compliance Committee is a priority for 2016 to inform the updating of historical and future scenarios for reconditioning of operating models planned in 2017.

References

Anon. 2015. Report of the Extended Commission of the Twenty Second Annual Meeting of the Commission, 12-15 October 2015, Yeosu, South Korea.

Anon. 2014a. Report of the Nineteenth Meeting of the Scientific Committee, 6 September, 2014, Auckland, New Zealand.

Anon. 2014b. Report of the Extended Commission of the Twenty First Annual Meeting of the Commission, 13-16 October 2014, Auckland, New Zealand.

Anon. 2015. Report of the Twentieth Meeting of the Scientific Committee, 5 September 2015, Incheon, South Korea.

Chambers and Hoyle 2015 Chambers M, Hoyle S. 2015. Estimates of non-member catch of SBT in the Indian and Pacific Oceans. CCSBT-ESC/1509/10.

Edwards et al, 2016 Edwards C, Williams A, Hoyle S. 2016. Estimates of Southern Bluefin Tuna Catch by CCSBT Non-Member states. CCSBT-ESC/1609/BGD-02.

Hoyle and Chambers Hoyle S, Chambers M. 2015. Estimating Southern Bluefin Tuna Catches by Non-Members of CCSBT. CCSBT-ESC/1509/21.

Kolody DS, Preece AL, Davies CR, Hartog JR, Dowling NA. 2010. Integrated evaluation of management strategies for tropical multi-species long-line fisheries. Final report to the Fisheries Research and Development Corporation. CSIRO Marine and Atmospheric Research, Hobart.

Preece A, Davies C, Hillary R. 2014. Implications of unaccounted mortalities on stock status and projected rebuilding using the management procedure. CCSBT-ESC/1409/20.

Appendix 1 – Unaccounted mortalities considered in 2014

Attachment 5 of the 2014 ESC report:

“*This Attachment summarizes (1) the possible sources of unaccounted mortality, (2) what data currently exist that could be used to estimate unaccounted catch, (3) what data could be collected that would improve understanding of unaccounted catch, and (4) what analytic procedures could be used to calculate unaccounted catch*." (Anon 2014)

Unaccounted mortality

The possibility of unaccounted for mortality raises important issues for the rebuilding of the stock and the success of the management procedure. The current MP was tuned assuming that future catches equaled the amount indicated by the procedure. In addition a series of robustness trials have been run to show performance for some other possible levels of historic and future unaccounted mortality, as well as anomalies in inputs to the MP. Unfortunately, estimates of unaccounted for mortality are either incomplete, unreliable or disputed, or they do not exist. This Attachment summarizes (1) the possible sources of unaccounted mortality, (2) what data currently exist that could be used to estimate unaccounted catch, (3) what data could be collected that would improve understanding of unaccounted catch, and (4) what analytic procedures could be used to calculate unaccounted catch.

The following potential types of unaccounted for catch have been identified

Source of unaccounted catch	
Unreported or uncertainty in retained catch by Members	• Small Fish Surface fishery • Artisanal catch • Large fish: members exceeding catch allowance
Mortality from releases and/or discards	Small fish Discarded catch Large fish: discarded catch
Recreational fisheries	All sizes: recreational catch
Catches by non-Members	Large fish: Non-member catch
Research Mortality Allowance	No additional -already included
Other sources of mortality	Possible depredation

Small fish: Surface fishery

Existing data and analysis

Data are needed on the number, size, age and weight at transfer into grow-out cages.

Number at transfer is measured by counting fish as they are transferred from tow cages to rearing cages. Observers record mortality during the towing process.

Size and weight at the time of introduction into rearing cages is measured by the 40 (prior to 2013) or 100 (since 2013) fish samples, adding to a total sample of about 3,000 SBT per season. SBT under 10kg are not included in the samples. Australia applies the mean weight in the samples to the number of fish captured (number transferred from the towing cage plus number of fish that die during catching, towing and transfers) to estimate the total weight of fish captured. The exclusion of fish less than 10kg from the estimate of mean weight tends to positively bias the estimate of catch weight.

Japan has used mixed normal modal analysis to estimate the age composition of farmed fish sold into Japan using length frequency data of imports. The source of the length frequency data is considered confidential by Japan. The estimated age composition of imports is used to impute the weight of catch using information on length at age of wild fish and a weight-length function. Such estimates of catch have been challenged by some members because of concerns about the source and representativeness of length frequency data and other assumptions. This approach could be improved by using CDS data (length and weight at time of harvest), which are held by CCSBT but are, at present, not available to members. There are modes in length representing ages in the 40/100 fish sampling data and length frequency data of imports reported by Japan, in some years. If these modes are identified in the CDS data, modal analysis could be used to estimate catch and possible bias in catch reports resulting from the 40/100 fish samples.

Other data that exists and would need to be taken into account to assess results.

(1) Data on when fish are put into farms and how long fish are held in the farms
(2) Growth rate data from fish in farms compared to wild fish (other studies not CCSBT)
(3) Growth rates of tagged fish from SRP that are subsequently harvested in farms
(4) Feed conversion ratios for the farms
(5) Differences in growth rates of each age group
(6) Current wild growth rates

New data sources and analysis

Uncertainty in the surface fishery catch may be reduced by the use of a stereo video system to address estimates of Australian catch by the surface fishery. Australia has demonstrated the potential utility of this method which it had planned to use to replace 100 fish samples. However, the method has not been made operational to date.

Experimental trials comparing stereo video to the 100 fish sample could be used to investigate the accuracy of 100 fish sample.

Another approach would be to take a 100 fish sample just prior to harvesting all the fish in pens. The estimated weight from the 100 sample could be compared to the calculated weight of harvested fish using their length frequency and a weight-length relationship or the sum of the weight of harvested fish.

Process aspects

The ESC encourages all countries to make their CDS data available to facilitate and improve analyses.

Small Fish: Release and discard mortality:

Japan reports releases during its RTMP programme. At present there are observer estimates of the number of small fish released or discarded from some other fleets. These numbers could be evaluated under a range of estimated/assumed release mortality to estimate the mortality from release and discard.

Japan put forward a methodology and an associated estimate of 9% for release mortality. Other members noted that some studies of other tuna species suggest that this may be an underestimate. Some suggested that bounds on release mortality be 9% to 100%, given uncertainly on mortality rates. The same approach could be applied to other fleets.

Small and Large fish Catch by non members

At the meeting of the Operating Model and Management Procedure Working Group (OMMP5) in Seattle in July the working group discussed the request from the Extended Commission and noted that the working group did not have the information required to estimate all unaccounted mortalities. The working group summarised the methods and sources of information required to better inform unaccounted mortality scenarios (Attachment 5, OMMP5 report), and encouraged the ESC, Compliance Committee and Extended Commission to work towards filling the gaps in the information base.

The working group proposed that scenarios could be developed by applying SBT bycatch rates in longline fleets to the effort by non-Members in the same areas and months. The meeting agreed that Members should evaluate the SBT by-catch rate of their own longline fleets which target other species to inform this analysis (CCSBT 2014). These approaches are documented in WP 13. It is noted that these methods will not provide any estimates of IUU catch, where there is no effort reported to the relevant RFMOs.

The ESC requests that the Compliance Committee consider approaches to monitor and review markets in order to provide further information that may inform the ESC considerations.

Reported catch exceeding current allowances

Over the last few years members reported catch has been very close to the catch allocations.

Indonesia has reported that their catch exceeded their allowance for a total of 1074 t. over the four years 2010 to 2013.

Unreported catch by members

Member countries report effort to CCSBT for all targeted SBT fishing. Although, there is some additional fishing effort by some member countries in areas where SBT are known to occur, such bycatches are expected to be included in the SBT catches reported.

Australia presented a paper (ESC/1409/12) suggesting there may be discrepancies in the market data and there may be unreported catch. This is based on the assumptions in the Japan Market Review, agreed by the CCSBT, on fish reported to be domestic, imported wild caught from foreign fleets and farmed. Japan suggested that these imbalances are due to the difference between fish that go through the auction and those that are traded only on paper. Actually resolving this issue is beyond the scope of the ESC, but it is a very important issue for the reliability of the stock assessment and performance of the OMP. A high proportion of the ESC work is dependent on reliable data on actual removals.

New data sources and analysis

Other data and analyses exist that would assist in resolving this uncertainty. Given the scientific technical expertise of the ESC, further consideration of market monitoring is more appropriately considered by the Compliance Committee. The ESC requests the EC and CC consider reviews and analyses that will clarify key assumptions of market monitoring. This should include consideration of:

a) a review of the data from Japan's monthly monitoring at Tsukiji since 2008 to verify the assumptions regarding number, weight and source of fish;
b) monthly data on the number, weight and source country of frozen SBT auctioned and not auctioned at Tsukiji; and
c) undertaking independent market reviews at significant markets.

The ESC encourages all countries to make their CDS data and information on market monitoring available to facilitate and improve analyses.

The ESC requests the Compliance Committee provide the results of these to the ESC for consideration in future assessments of stock status, projects and reviews of the performance of the MP.

Recreational fishing

Australia makes some estimates of their recreational catch but is currently in the final year of a project to develop a better methodology.

Other Sources

Marine mammal depredation was raised as a possible other source of unaccounted catch. This could be considered a source of background natural mortality, but if the rate of depredation has been rising (for instance due to increasing marine mammal populations and learning by these animals) then it is a potential concern.

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Initial considerations on forms of candidate management procedures for SBT

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CCSBT-OMMP/1609/6, CCSBT- ESC/1609/BGD-5

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Abstract

At its 2015 meeting the Extended Commission agreed to implement a new recruitment-monitoring program, using gene-tagging, to estimate absolute abundance of 2 year olds. The impetus for this decision revolved around the cost and logistic frailty of the existing recruitment monitoring based the scientific aerial survey. The scientific aerial survey provides a relative abundance index for 2-4 year olds, which is used in combination with the standardised longline CPUE in the CCSBT "Bali Procedure". The change in the recruitment monitoring method means it will be necessary to develop a revised/new MP for implementing the Commission's stock rebuilding plan. The work program for the development, testing, selection and implementation of a new MP is ambitious: commencing at the 2016 OMMP Technical Meeting with the aim of completion in time to recommend the 2021-2023 TAC block with a new MP in 2019. In this paper, we summarise the process for developing and testing candidate MPs and selecting and implementing a final MP. We recap on the objectives for the Commission's rebuilding plan, their technical specification in the current Bali Procedure and the operational constraints included in the decision rule to achieve the desired behavioural characteristics from the MP. An important aspect of the last MP development exercise was the development of a wide range of candidate MPs for initial testing, followed by an iterative selection process. This had many positive benefits and we consider this an important aspect of the process for the ESC. We provide an overview of the characteristics of the available monitoring series for each component of the SBT population (i.e. recruits, sub-adults and spawning adults) that are considered appropriate for use in candidate MPs and the rationale behind the use of model and empirical decision rules in MPs. Finally, we offer some thoughts on the "process", both technical and engagement with the ESC and Commission, with a view of increasing engagement, understanding and collaboration.

1 The MP development process

At its 2015 meeting the Extended Commission agreed to implement a new recruitment-monitoring program, using gene-tagging, to estimate absolute abundance of 2 year olds. The impetus for this decision revolved around the cost and logistic frailty of the existing recruitment monitoring series, derived from the scientific aerial survey. The aerial survey provides the current recruitment index of relative abundance of 2-4 year olds, which is used in combination with the standardised longline CPUE in the CCSBT "Bali Procedure". The change in the method used to estimate recruitment means it will be necessary to develop a revised, or new, candidate Management Procedures (MP).

A management procedure is the combination of monitoring data, method for analyses of those data, the decision rule (Also known as Harvest Control Rule (HCR)) and its implementation (Figure 1).

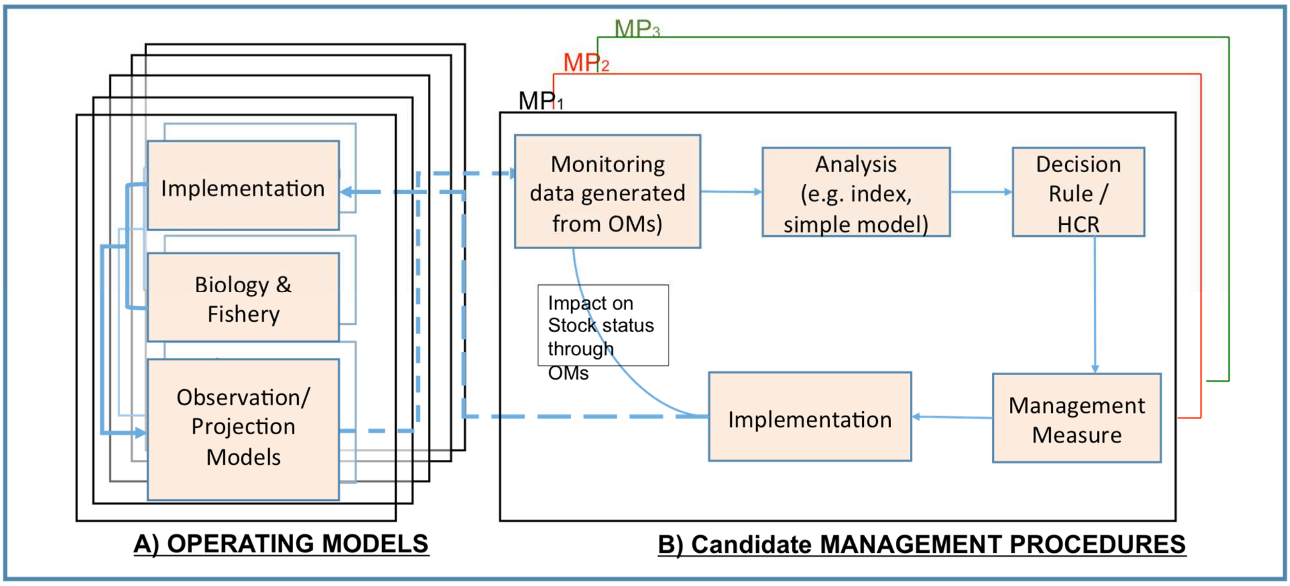

Figure 1: Schematic representation of the components of a) the Operating Models and b) Management Procedure used as part of Management Strategy Evaluation (MSE). The MSE process starts with development of multiple Operating Models, which define the status and dynamics of the stock, fisheries and monitoring data, including the plausible uncertainty in them. Multiple candidate MPs are developed, and their relative performance compared across a range of criteria, given that each candidate MP has been "tuned" to meet the CCSBT rebuilding objective.

Importantly, the development and implementation of effective MPs is generally very context specific and guided by decisions on the objectives for the rebuilding the stock agreed by the Extended Commission (EC). Implementation of the selected MP includes performance measures for review at a an appropriate time following implementation (e.g. for the Bali Procedure this was 6 years); the schedule of activities for TAC recommendations (every 3 years), assessment of stock status (every 3 years) and evaluation of meta-rules (annual); and examination of evidence of exceptional circumstances (annual). This implementation framework serves to ensure, to the extent possible, that operation of the MP is consistent with the conditions and manner in which it was tested.

The timetable for testing and selection of a new MP was developed by the OMMP Technical meeting in 2015, and subsequently recommended by the ESC to the EC (Anon. 2015a, Anon 2015b). The process of testing and selecting candidate MPs (known as Management Strategy Evaluation, MSE) involves reconditioning the CCSBT Operating Models with updated and/or new data, defining data generation methods for monitoring series for use in projections, defining performance measures for testing of the candidate MPs and tuning the individual MPs to the rebuilding objective of the Commission (Table 1) (see Anon 2009, 2010 and 2011 for most recent round of MP development, testing and selection).

Table 1. The schedule for development of a new MP. Note shaded events (numbered with suffix "i") represent an inter-sessional activity. Source: 2015 OMMP report, Anon (2015a).

No.	Activity/Meeting	Purpose	Timing
1i	Evaluation of potential recruitment indices	Provide detailed evaluation of the statistical properties of potential recruitment indices	Nov 2015-May 2016
2	OMMP7	Evaluate and select candidate indices	June-July 2016
2i	Initial conditioning	Initial conditioning, data generation etc.	
3	OMMP-ESC21	Review of initial conditioning, data generation for projection models and form of potential MPs. These MPs may need to be quite different from the existing MP.	Sept 2016
3i	Finalise conditioning	Update OM with most recent data. Complete data-generation and specification of candidate MPs.	
4	OMMP8	Finalise conditioning (coinciding with scheduled OM reconditioning), data generation and initial MP runs	June-July 2017
4i	Refine MP performance	Refine MP performance and robustness tests	
5	OMMP-ESC22	MP selection	Sept 2017
5*i*	MP TAC recommendation	Any refinements required from ESC	
6	Sp. Commission	MP adoption	
7	OMMP9	Refinement and final tuning, if required	June-July 2018
8	ESC23	Final review	Sept 2018
9	Commission	Final Adoption/Implementation	Oct 2018

The initial steps in the MP development process are considered here. We provide an overview the potential monitoring series (Table 2), and alternatives for analysis and decision rules that could be combined with these monitoring series to form alternative candidate MPs.

Relative to the last round of MP development that resulted in the Bali Procedure, there are three new potential data series to consider for inclusion in candidate MPs: i) gene-tagging as an absolute index of 2 year old recruits, ii) Parent-Offspring-Pairs, and ii) Half-Sibling Pairs from the Close-Kin Mark Recapture method. The potential information content of each of these new series has been examined in Hillary et al (2016a), and proposed methods for data generation are provided in Hillary et al (2016b).

Consideration will also need to be given to how to include implementation uncertainty (in this case, total catches being greater or less than the TAC recommended by the MP. The EC has requested advice on this issue in the context of the Bali Procedure and initial considerations on this are provided in CCSBT-OMMP/1609/05.

Finally, and very importantly, further consideration needs to be given to the consultation and engagement process at both the ESC and EC level for this round of MP development. We identify a number of issues that the ESC may wish to consider in further detail.

2 Monitoring series for Candidate MPs

The CCSBT and members have a history of strategic investment in collection of data to be used as monitoring series within an MP and address major uncertainties in the understanding of the stock and fishery. Current monitoring series include information on different life-history stages (recent recruits, sub-adults and adults), in relative and/or absolute abundance as well as information on fishing and natural mortality, from both fishery-dependent and fishery-independent sources. This provides a wide variety of combinations to consider in the development of candidate MPs. Selection of the data sources should consider their information content, reliability, biases (known and potential), cost-effectiveness, logistical frailty and how best to combine these with appropriate analyses/models and harvest control rules to form candidate MPs.

The first formal round of CCSBT MP development (2000-2005) used catch, effort, CPUE and size data as the monitoring series to construct candidate MPs. In the second round of MP development (2009-2011), this was extended to include the scientific aerial survey and a requirement for candidate MPs to include an index of recruitment, given the low status of the stock and the historically low recruitments at the turn of the century (Anon. 2009). While there have been positive indications in recruitment and the status of the spawning stock in recent years (Anon 2014), the ESC continues to consider a fishery independent index of recruitment an important component of the monitoring programs that provide data for the OM and of the MP (Anon 2015). This is a function of the late maturity of SBT and the current selectivity of the majority of the fleets being focussed predominantly on juvenile and sub-adult fish, which results in a substantial delay between catches being taken and the impacts propagating through to the spawning stock. Until recently, there was no direct monitoring of the abundance of the spawning stock. The advent of the Close-kin Mark –Recapture methods has filled this gap to some extent, providing the biological sampling programs that underpin the approach can be maintained and the quality control remain high.

2.1 Candidate recruitment monitoring series

2.1.1 Scientific Aerial Survey

In 2015, the OMMP meeting evaluated the importance of recruitment data in the adopted MP. A quantitative analysis of Aerial Survey data in the current MP demonstrated the value of a fishery independent recruitment index in the MP. Under plausible robustness tests for future poor recruitment and future CPUE catchability changes, a performance benefit was noted from including a recruitment index in the MP, particularly with respect to risk of further stock declines (Anon 2015 OMMP rep).The meeting considered, in detail, alternative indices of recruitment (Anon 2015 OMMP rep), that could be used in a new MP and summarised their qualitative attributes (see Table 5 OMMP rep Anon 2015).

The summary indicated that the aerial survey and gene-tagging indices may be the most useful for use in candidate MPs. The grid-type troll index was considered potentially useful, but the method required additional research and a design study. The SAPUE and Longline CPUE (age specific CPUE for 2, 3, 4 year olds) indices were not considered to be useful as recruitment indices in an MP (see Anon 2015 OMMP rep). The SAPUE index is from targeted commercial fishing operations, has shifted markedly in its area of operation over the past 4-5 seasons and CPUE standardisation cannot account for the potential biases (Basson and Farley 2015).The longline CPUE data is incomplete for these ages because age 4 or younger SBT are not consistently targeted or retained, if caught.

The ESC reiterated the need for a fishery independent index of recruitment given, the low status of the stock, historically low recruitments at the turn of the century, and the historical problems with the CPUE data. The scientific aerial survey data has been collected by a consistent scientifically designed line transect method over the years 1993-2000, 2005-2014 and in 2016 (Eveson and Farley 2011, 2016). Results of models of biomass per sighting and sightings per nautical mile are combined to provide a standardised relative abundance index of 2-4 year old SBT in the Great Australian Bight. The EC has agreed to fund the aerial survey in 2017. There is currently no commitment to fund the survey beyond 2017.These data are used in the SBT operating model as a relative abundance estimate of juveniles, and in the Bali Procedure as an index of recruitment.

Table 2: Candidate monitoring series for recruits, sub-adult and spawning adult life-history stages of SBT for potential inclusion in MPs.

Life-history stage	Candidate monitoring series	Measure	Age classes	Times series available by 2019	
Recruits	Aerial survey	Relative abundance juveniles	Recruitment 2,3,4 year olds	1993-2000, 2005-2014, 2016-2017	Fishery independent
	Gene-tagging	Absolute abundance Juveniles	Age 2 cohort	2016, 2017	Fishery independent
Sub-adults	CPUE LL	Relative abundance sub-adults	Sub-adults ages 4-8 or 4-11		Fishery dependent
Spawning Adults	POPs	Absolute/relative abundance adults	Adults	2002-2013	Independent
	HSP	Absolute abundance adults and adult mortality	Adults		Independent

2.1.2 Gene-tagging

Gene-tagging is a new method being trialled following a comprehensive design study in 2015 that indicated its potential to provide a more cost-effective recruitment monitoring series. It will provide an absolute abundance estimate for age 2 SBT in the year of release. It is a mark-recapture method that uses tissue samples from biopsy's at tagging and catch sampling to identify individuals caught in both samples. The genetics associated with the individual ID is well established, in that it is considerably easier to match an individual with itself than determine parentage as is required the close-kin methods. The ESC recommended the gene-tagging program was the best recruitment index in the near term, suitable for an on-going monitoring program to provide annual estimates of the abundance of recent recruits (i.e. the age 2 cohort) for use in monitoring the rebuilding of plan and use in future MPs.

2.2 Sub-Adults

2.2.1 LL1 CPUE

Longline CPUE data are used in the current MP as an index of the sub-adult, or "harvested" component of the population. The actual CPUE input data series used in the current MP is the average of two standardised CPUE indices that have been adjusted for an agreed unreported catch scenario (for the historical period where that applies). The CPUE combines data across age classes from age 4 upwards and is assumed to represent the relative abundance of sub-adult fish, as these have been the dominant age classes in this component of the fishery over the past few decades. CPUE indices are reliant on the collection of good quality data from the fishing industry. The relationship between CPUE and underlying abundance can potentially be biased through range contraction and changes in fishing behaviours that, generally, cannot be captured in the standardisation. Hillary et al., 2016b, examine the relationship between spawning stock biomass and CPUE and this analysis indicated weak information content between CPUE and spawner abundance over the last two decades of the SBT series.

2.3 Spawning Adults

The ESC agreed and included the close-kin parent-offspring (POP) data in the SBT operating models in 2013. The spawning abundance information currently included in the OMs is for the years 2002-2007, which were part of the original close-kin project. These data provide information on the adult abundance in the operating models (see Bravington et al 2014, Hillary et al 2012). In 2015, the CCSBT commissioned a design study on close-kin that investigated the use of next generation DNA sequencing techniques that could provide additional data from close-kin tissue samples collection (Bravington 2015). The design study described the information that could be gained on parent-offspring pairs and from half-sibling pairs and their potential use in future models and included a review by two prominent international referees.

The EC agreed to fund the 2016 collection of tissue samples (this has been on-going since the original project was completed), and to use the new genotyping method on the most recently collected tissue samples. CSIRO has proposed a parallel research project with the Australian

Fisheries Research and Development Corporation that will use the same genotyping method to process the historical (2006-2014/15) SBT tissues samples to provide a continuous time series on spawner abundance and mortality from 2002 to the present. The raw HSP and POP observations provide 2 separate and independent data sources on spawner abundance and/or total mortality that could be considered for use in candidate MPs.

3 Analyses, Models and Decision-rules

The current MP (the Bali Procedure) is a model-based rule. It uses 2 monitoring series as inputs (the AS and CPUE series) and generates recruitment and population growth estimates in a two-stage biomass random effects model. The decision rule takes the trends in these and compares the recruitment levels to historical lows and combines this information to recommend changes (up or down) to the TAC.

Empirical based MPs can use monitoring data and analyses to detect trends, or proximity to target or limit reference points, or indicators relative to threshold levels- directly from the input data and recommend changes in TAC (e.g. Anon 2013, Prince et al 2012, Kolody et al 2012).

Focussing on the CCSBT experience, both the 2005 (non-implemented) MP and the current MP were model-based. In the 2005 MP, which was set in a biomass dynamic model framework, there were problems with cases of model non-convergence, which required ad hoc solutions. The current MP solved this issue by having a simpler, relative abundance model that made non-convergence effectively disappear. However, as we have seen for the current MP we must update input parameters every time the MP is to be run, and check the estimation performance of the underlying model (see CCSBT-ESC/1609/18). This both increases workload and adds an additional requirement for members to understand when running the MP. There were performance advantages to using a model-based MP previously, but we suggest that in developing a new MP that the ESC consider the merits of both empirical and model-based MPs, as was the case in the most recent development exercise (2009-2011).

There will need to be a defined transition from the Bali Procedure to a new MP as the aerial survey ceases and gene tagging estimates of 2 year old recruitment become available. The gene-tagging data cannot simply replace the aerial survey data in the current biomass random effects model as they are fundamentally different forms of data (e.g. relative abundance of 2-4 year olds with a covariance matrix and absolute abundance of a single year class derived from mark-recapture data).

In addition to new sources of recruitment information from gene-tagging and the existing LL1 CPUE, there will potentially, be additional data sources on the spawning component of the stock from close-kin. A model-based MP that can incorporate all of these data sources and temporal shifts in their availability will be significantly more complex than the current model-based MP. So carefully consideration will need to be given to the both the combination of monitoring series and Analysis-Decision-rule used in candidate MPs. It may be better, for example to design an empirical–based MP that incorporates a combination of these potential data sources in a manner that delivers comparable performance to model based candidates and has the additional benefit of being easier for the ESC, EC and stakeholders to understand.

3.1 Recruitment index

Be it an aerial survey or gene tagging index, some kind of moving average makes sense in terms of the actual index that is used in the candidate HCRs. This is precisely how the aerial survey is currently used in the MP, where a 5-year moving average in future relative juvenile biomass is compared to the historical lows. In paper CCSBT-OMMP/1609/7 it was demonstrated that a similar 5 year moving average of the estimate of 2 year old absolute abundance from gene tagging was able to achieve very good correlation (always above 0.75) with the "true" simulated value across a wide range of future dynamics. Using the gene tagging index in this kind of relative fashion also has the benefit of providing a solution to the one potentially problematic "non-mixing scenario" in the gene-tagging design study.

3.2 CPUE index

In the current MP both trend and target approaches are used for the CPUE data series. The trend approach was better at dealing with catchability changes, whereas target approaches helped to avoid the MP getting "lost" in low abundance regimes (Hillary et al 2016c). On the basis of this experience with testing CPUE-based rules in the previous round of development it makes sense to explore both trend and target uses of the CPUE in future candidate MPs.

3.3 POP an HSP

Paper CCSBT-OMMP/1609/7 demonstrated (using data generated in a simulation model) that one can develop relatively simple indices (compared to the standalone CKMR estimation model) directly from the simulated POP and HSP close-kin data that correlate well with spawning abundance and, in certain instances, total adult mortality. For both the POPs and HSP abundance indices, and indeed even a hypothetical spawner survey, it appears that trends (such as log-linear trends) were not nearly as informative as moving averages for the underlying indices. This suggests that the two forms of close-kin indices would be best used as moving average if used in candidate MPs.

Target-driven approaches are also worth considering in the SBT context, given the aim of the rebuilding strategy is to rebuild the spawning stock to a target level of depletion (i.e. 20% of SSB). The CKMR half sibling pair data also potentially allows a situation of falling recruitment to be distinguished from high adult mortality in scenarios where the spawning population is declining (CCSBT-OMMP/1609/7). As an example, this could potentially be used via the "decision tree" form of MP used elsewhere (Davies et al 2008, Prince et al 2012; Kolody et al 2012) where the intent is to identify hyper-stability in the CPUE index in the used in the first step of the HCR.

3.4 General form of the HCRs

It makes sense to have a Markov approach to how we change the TAC via the MP. That is, the future TAC is the current TAC with some alteration based on the MP input data and analysis:

*TACy+1 = TACy * (Recruitment + CPUE + CK alterations)*

We currently specify a minimum change of 100t and a maximum change of 3,000t. These "hard wired" constraints on minimum and maximum TAC changes were based on feedback from the EC and SFM-WG following considerations of likely behaviour of candidate MPs. Given the potential rebuilding trajectories of the stock it might be more appropriate to translate these constraints from absolute quantities to agreed fractions of a change. For example, in 2011 the minimum and maximum changes were 1% and 30% of the then TAC of 9,449t; for the 2016 TAC decision for the 2018-2020 quota block they are 0.7% and 20%, respectively. The intent of these limits, especially the maximum change limit, is to entrain stability into the TAC for industry and to avoid large and potentially erroneous changes in the TAC driven by spurious short-term variation in the data. Percentage limits would be worth considering in more detail if a move to this type of control approach in the new candidate MPs is considered appropriate.

4 Engagement Process

Iterative consultation between Scientists, Managers, Industry and conservation advocates is an important component of MP development. The EC and ESC have changed since the Bali Procedure was adopted, with new members and new Commissioners, and with new staff within member's governance and science agencies. The MP implementation framework (schedule of TAC setting, stock assessments and meta-rule reviews, Anon 2013, Attachment 10), will need to be reviewed by decision makers, and some aspects of the existing framework may need revision. Commissioners will ultimately select the final MP for implementation based on technical advice provided by the ESC and member scientists.

The objective of the current MP is to rebuild the spawning stock to 20% of the initial spawning stock size by 2035. Given the uncertainties in the models and future projections, the management procedure has been tuned to meet this objective with a 70% probability. The reconditioned operating models and performance of new MPs may change our understanding of the potential speed and probability of rebuilding. Hence, the ESC and EC will need to consider the implications of this for the overall rebuilding plan.

The implementation framework for the Bali Procedure includes annual review of fishery and stock indicators and examination of evidence of exceptional circumstances and processes for action via the meta-rules. The MP TAC recommendations are used to set 3 year TAC blocks with a 1 year lag between calculation and implementation. A stock assessment is scheduled to be conducted every 3 years to provide updated advice on current stock status, and this is off-set from the TAC recommendation year. A review of the MP is scheduled to occur every 6 years to review performance of the MP. The rationale for the above decisions and any recommendations to change these in developing a new MP will need to be considered and revised to reflect the current circumstances and those that can be reasonably expected to arise in the near-medium term.

Managers will need to provide advice on their preferred objectives, Industry advice is required on operational feasibility of management actions, and Scientists will need to communicate the underlying concepts of management strategy evaluation and management procedures in science-based management, and the subtleties in performance and implications between final candidate MPs that will be presented to the EC.

With this context we identify three elements for discussion at the ESC:

i) **Schedule:** As noted above, the work program and time-table proposed by the ESC and agreed by the EC is very ambitious and provides very limited opportunity for iteration between highly technical tasks; review by the ESC and consideration/decision by the EC. The schedule reflects both the previously agreed schedule for MP implementation and constraints on resources. The ESC may wish to reconsider the current schedule in light of the information gained since it was proposed.

ii) **Policy-Science engagement:** In both previous MP development processes, there were resources allocated to consultation between the EC and ESC re: a) important aspects of MP design and performance and capacity building and b) capacity building in the fundamental concepts and their application. There has been considerable “renewal” at both the EC and ESC since the previous MP development exercises, so how to most effectively and efficiently achieve this should be given some specific attention by both the ESC and EC. In this regard, engagement or coordination with other MP/HS and MSE initiatives should be considered.

iii) **Technical Cooperation and capacity building:** The development, testing, selection and implementation of MPs is a conceptually and technically challenging process. The success of any process relies on harnessing the collective understanding of the monitoring, stock, fishery and management and the important uncertainties in each component. Aspects of the process are highly technical, but this should not be a barrier to effective participation by those interested in contributing and learning. The key to this is appropriate fora and time/opportunity for communication. In the decade since the first round of MP development, the time and resources available for the technical work and ESC engagement and review have decreased. The ESC and EC will need to consider how best to balance the need for engagement and understanding at the ESC level, which impacts on the ability of members to advise their Commissioner. In this context, thought should also be given to the technical process for developing alternative MPs. In the past rounds a “competitive” model has been employed. This has the advantage of generating a creative environment in which “MP developers” develop alternative MPs that can out-perform others and also, increases the level of rigour of technical review. Composition of MP teams do, however, tend to fall out along delegation lines, which is not always conducive to cooperative outcomes; nor does it promote conceptual or technical capacity building across delegations. We suggest the ESC may want to consider alternative processes, which take the positive elements of the competitive MP development team model and combine it with more collaborative elements that lend themselves to more cross-delegation technical engagement and capacity building.

References

Anon. 2013. Report of the 2013 ISSF Stock Assessment Workshop: Harvest control rules and reference points for Tuna RFMOs. ISSF Technical Report 2013-03. International Seafood Sustainability Foundation, Washington, D.C., USA.

Anon. 2015a. Report of the Sixth Operating Model and Management Procedure Technical Meeting. 30 – 31 August 2015, Incheon, South Korea.

Anon. 2015b. Report of the Extended Scientific Committee for the Twentieth Meeting of the Scientific Committee, Commission for the Conservation of Southern Bluefin Tuna, 1-5 September, Incheon, South Korea.

Bravington MV, Eveson, P. Grewe, P.M. and Davies, C.R. 2015. SBT Close-Kin Mark-Recapture: options for the medium term. Working Paper to the Extended Scientific Committee for the Twentieth Meeting of the Scientific Committee, Commission for the Conservation of Southern Bluefin Tuna, 1-5 September, Incheon, South Korea.

Bravington MV, Grewe PG, Davies CR (2014a). *Fishery-independent estimate of spawning biomass of Southern Bluefin Tuna through identification of close-kin using genetic markers.* FRDC Report 2007/034.

Hillary, Rich; Preece, Ann; Davies, C.R.; Bravington, Mark; Eveson, Paige; Basson, Marinelle. *Initial exploration of options for inclusion of the close-kin data into the SBT operating model.* 2012. CCSBT Extended Scientific Committee for the 17th Meeting of the Scientific Committee; 27-31 August 2012; Tokyo, Japan. 2012.

Hillary R, Preece A, Davies CR. 2016a. Reconsideration of OM structure and new data sources for 2017 reconditioning. CCSBT-OMMP/1609/4.

Hillary R., Preece A., Davies C.R. 2016b. Methods for data generation in projections. CCSBT-OMMP/1609/7.

Hillary, R. M., Preece, A. L., Davies, C. R., Kurota, H., Sakai, O., Itoh, T., Parma, A. M., Butterworth, D. S., Ianelli, J. and Branch, T. A. (2016), A scientific alternative to moratoria for rebuilding depleted international tuna stocks. Fish and Fisheries, 17: 469–482. doi:10.1111/faf.12121

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APPENDIX A6.

CCSBT-ESC/1609/BGD 04
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Reconsideration of OM structure and new data sources for 2017 reconditioning

Rich Hillary, Ann Preece, Campbell Davies

CCSBT-OMMP/1609/4

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Abstract

This paper details potential structural changes to the current CCSBT OM required to deal with new data sources and scenarios for the 2017 reconditioning and for the next phase of MP testing. In terms of new data scenarios we will have non-member and attributable catch estimates; in terms of new data sources we will have both gene-tagging and half-sibling close-kin data. We also outline some potential changes to current projection dynamics, specifically around fixed future selectivity and growth relationships.

1 Background

The SBT operating models (OMs) will be reconditioned in 2017 for an updated assessment of stock status and to allow for testing (management strategy evaluation) of a new Management Procedure (MP). The 2016 OMMP and ESC therefore needs to consider structural changes that might be required, or new data sources that need to be incorporated.

In terms of new data sources and scenarios we have (i) non-member catch scenario estimates, inferred from non-member effort and member catch and effort properties (ii) member's attributable catch, which may be a mix of both scenarios and actual direct estimates (iii) gene-tagging data, and (iv) the next generation of close-kin data relating to half-sibling pairs. The first two data sources will not necessarily require technical adjustments to the current OM. They can be either assigned to an existing fleet (in terms of non-member catch), or a new fleet can be defined (and selectivity parameterisation) to deal with attributable catch that is not similar enough to existing fleets to be incorporated into them.

For the gene tagging and half-sibling close-kin data new likelihood functions are required for the OM. In the design study for a gene-tagging program, it was recommended that a Petersen model be used to calculate absolute abundance of a cohort of juveniles. This choice was considered more cost-effective compared with tagging multiple cohorts [1] which could provide mortality estimates via a Brownie estimation model, as was done in previous conventional tagging programs. A suggestion for the likelihood function to use in the OM was outlined and tested using the 1990s and 2000s tagging data. Here we also consider a flexible beta-binomial likelihood that has over-dispersion as a fundamental parameter in the likelihood itself (like the current Brownie likelihood for the 1990s tagging data). For the half-sibling data we first outline the key factors that influence the probability of two juveniles being half-siblings. A beta-binomial likelihood is also suggested for the half-sibling data.

A key feature of the current OM projection model is that both selectivity and growth are fixed at the most recent values, even though both change quite noticeably over time. It is quite likely that the factors that potentially caused both to change historically (i.e. stock abundance) may cause similar changes in the future, if the stock recovers under the next MP-driven rebuilding strategy. We outline the key population and monitoring data that these changes can effect, how they could alter our perception of the rebuilding of the stock, and how to incorporate such changes in the OM projection model.

2 Material & Methods

2.1 New data sources

2.1.1 Non-member catch

Paper CCSBT-ESC/1609/BGD 02 [2] details the estimates of non-member SBT catch, using two contrasting model approaches and assumptions relating to whether the effort data (and catchability) in question was "Taiwanese" or "Japanese" in nature. Irrespective of the relative weightings given to each modelling approach, or assumptions about how much of the effort relates to either of the assumed catchability scenarios, their inclusion should be fairly simple given the current OM structure. The LL_1 and LL_2 fleets represent the fleets for which Japanese and Taiwanese long-line catches belong to in the OM. If we are willing to assume a given amount of non-member effort can be assigned one of these catchability parameters, and the mean weight in those fleets are used to convert between weight and numbers in terms of catch [2], then assigning them the same selectivity function seems equally plausible. The estimate of non-member catch may then be included as additional historical catches in the relevant fleet (LL_1 or LL_2).

2.1.2 Attributable catch

Attributable catch for various members might be less straightforward, in terms of OM inclusion. If the attributable catch comes from a fleet that is demonstrably similar to that for which reported catch is from, then the same approach as taken for the non-member catches would be appropriate: assign it the same selectivity and add the catch to the original reported catches. Where this approach will not work is when we cannot assume fleet-similarity for the attributable catch, relative to historically reported catches.

Focussing on the Australian example: recreational catches are not likely to have the same selectivity as the surface fishery. In fact, they are probably more biased to longer/older animals. If we were to include them as catch biomass in the OM, and assign them the surface selectivity, we would over-estimate the fishing mortality associated with those catches; the opposite would happen if we included them in terms of catch in numbers. For any member, attributable catch that cannot be assigned to an existing OM fleet must then be given an accompanying selectivity, or come with associated length/age frequency information from which selectivity can be estimated.

2.1.3 Gene Tagging

The driving idea behind the gene tagging is to be able to estimate the absolute abundance of age 2 fish using the well-established Petersen estimator [1]. Recall the basic abundance estimator as defined in the design study:

$$\widehat{N} = \frac{TS}{R}, \tag{2.1}$$

where T are the number of initially genotyped and released fish, S is the number of fish genotyped in the catch sample, and R the number of recaptures. The CV of this estimate of N will be approximately $R^{-1/2}$. The design study explored both the Brownie and Petersen models, but focussed on the Petersen design for an abundance estimate for juveniles, which required tagging a single cohort each year. The issue of bias from incorrect ageing was also explored. The likelihood proposed and tested in the gene-tagging design study was a gaussian model which could be corrected for ageing errors and for which over-dispersion could be incorporated after a number of years of data had been collected. The recommendation from the design study was to tag age 2 fish and take samples of the catch of age 3 fish, one year later, to obtain an estimate of the age 2 abundance in the original year of tagging.

Figure 2.1 shows the overlap in probable length distribution for age 2-4 fish. As noted in the design study, using a restricted length class of fish for tagging and catch sampling, and collecting otoliths at the time of catch sampling will help to understand the probable age distribution of both the tagged and scanned fish. Restricting the age-range of fish tagged to 2 and 3, and the catch sampled age-range to 3 and 4 would be achievable given what we know about current length-at-age in the GAB.

Some minor changes to the original estimator, while retaining the original general idea, are needed to incorporate age at length information. Let T_y, S_y, and R_y be the year-specific tagging, catch sample and recapture numbers. In terms of the sample length distributions we will have one each for the tagged and catch sampled fish: $p_{y,l}^{t,s}$. What we really need are the distributions of age-given-length so as to be able to probabilistically assign fish to specific cohorts when it comes to abundance estimation. There are a number of possible ways this could work, but let's proceed with one where we assume to already know the length-at-age distribution: $\pi_{l|a}$ (for our current application time-invariant but easily extendible). We need a prior age distribution for the sampled fish, $\pi_{y,a}^{t,s}$, to get the length-conditional age distribution we

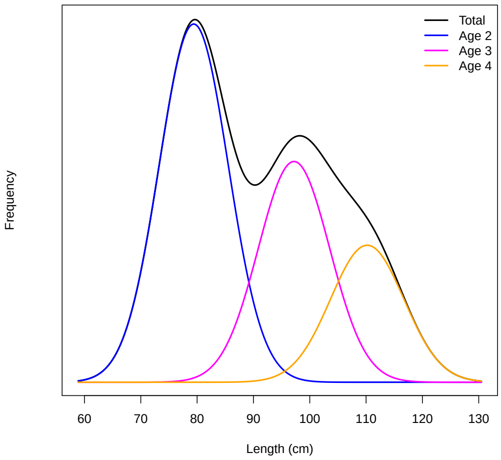

Figure 2.1: *Probably length distribution of ages 2, 3 and 4 year old fish in the GAB in summer given current mortality rates.*

really need:

$$\pi^{\bullet}_{y,a|l} = \frac{\pi_{l|a}\pi^{\bullet}_{y,a}}{\sum\limits_{a}\pi_{l|a}\pi^{\bullet}_{y,a}}, \tag{2.2}$$

and • denotes the specific sample i.e. tagged or catch sampled. For this set-up we will need to estimate $\pi^{\bullet}_{y,a}$ for each year and sampling stage. This can be done using the length distribution of the tagged and catch sampled fish, as the model-predicted length distribution will be $\sum\limits_{a}\pi_{l|a}\pi^{\bullet}_{y,a}$. We would then assume a multinomial likelihood for the length data and directly estimate the age prior, which is one of the approaches used to estimate the age composition of the surface fishery catch when length-at-age is assumed known. Age sampling of the catch sampled fish could make this a bit more involved, but the general idea is the same: obtain an understanding of the age-at-length distribution of all the fish in the study.

Now, instead of a simple single case as in the design study there would now be two plausible cases for the estimator, given the type of sampling regime: (i) where fish are sampled and recaptured the year after they were tagged; and (ii) where fish are sampled and recaptured two years after they were tagged (and this will only really be 2 year old releases). For the first case the modified estimator would be:

$$\widehat{N}_{y,a} = \frac{\left(\sum\limits_{l} T_{y,l}\pi^{t}_{y,a|l}\right)\left(\sum\limits_{l} S_{y+1,l}\pi^{s}_{y+1,a+1|l}\right)}{\sum\limits_{l} R_{y+1,l}\pi^{s}_{y+1,a+1|l}}, \tag{2.3}$$

whereas the second case would be

$$\widehat{N}_{y,a} = \frac{\left(\sum\limits_{l} T_{y,l}\pi^{t}_{y,a|l}\right)\left(\sum\limits_{l} S_{y+2,l}\pi^{s}_{y+2,a+2|l}\right)}{\sum\limits_{l} R_{y+2,l}\pi^{s}_{y+2,a+2|l}}. \tag{2.4}$$

In both cases, the inverse square-root of effective number of recaptures of that tagged age-class will be a good indicative estimate of the CV of the abundance estimate as before. A binomial likelihood is the most flexible option for the likelihood in the OM, where the probability of recapturing a fish released at age a in year y would be:

$$p_{y,a} = \frac{\sum_l T_{y,l}\pi^t_{y,a|l}}{N_{y,a}}, \tag{2.5}$$

and the associated sample size would be $\sum_l S_{y+r,l}\pi^t_{y+r,a+r|l}$, where, for the current sampling regime, $r = 1, 2$ depending on how many recapture events there are for that particular release event. The binomial is not only a natural choice for the base likelihood for the GT data, but can be easily extended to the beta-binomial model which can deal with over-dispersion (essentially process error). Some indicative over-dispersion scenarios were explored in the GT design study [1], and it was noted that it will take time to actually establish both the presence and - if true - extent of over-dispersion in the tagging data. As is the case with the 1990s tagging data, over-dispersion is calculated by a detailed analysis of the residual variance of the fitted recaptures [3]. A similar approach, requiring a number of years of release and recaptures, would be applicable for these data. The specifics of how to parameterise the beta-binomial distribution can be found in the Appendix.

2.1.4 Half-Sibling Pairs

The Parent-Offspring pair close-kin data (POPs) have already been incorporated into the CCSBT OM [3] and no proposed changes are suggested to the current likelihood for those data. The next generation sequencing methods that are replacing the previous micro-satellite approach used in the original CK data will permit the identification of half-sibling pairs (HSPs) among the juveniles [4]. While HSPs are clearly close-kin data, there are a number of important ways in which they are both different to - and potentially more informative than - POPs.

The actual identification of HSPs is much more involved than for POPs; POPs *have* to share at least one allele at a given locus on the genome, making their detection (relatively) more straightforward. We do not go into this more detailed procedure in this paper, and just assume that the identification of HSPs can be (and is) done. Interested readers way wish to read [4] for more details on this HSP identification procedure. For SBT, we will look for HSPs in the juveniles (already collected for the POP approach). So, we assume that we have juveniles i and j, and that they were born into cohorts c_i and c_j, respectively. Unlike the parent-offspring case, where overall spawner abundance and relative reproductive output (RRO) dictate the probability of finding a POP, with the half-sibling data there are more factors that influence their commonness, although these factors still ***all*** relate to adult, not juvenile, dynamics:

1. The expected total mortality accrued by an adult in the time between the two birth years c_i and c_j
2. The proportional increase (if any) in the relative reproductive output of an adult in the time between the two birth years c_i and c_j
3. The distribution of probable parents in the earliest cohort $c_{\min} = \min\{c_i, c_j\}$
4. The total spawning abundance in the latest cohort $c_{\max} = \max\{c_i, c_j\}$

Formalising this into a (sexually aggregated) probabilistic expression for whether the juvenile pair $\{i, j\}$ is an HSP:

$$p_{\text{hsp}} = \frac{4q_{\text{hsp}}}{S_{c_{\max}}}\left(\sum_a \left[\gamma_{c_{\min},a}\exp\left(-\sum_{y=c_{\min}}^{c_{\max}-1} Z_{y,a}\right)\varphi_{a+|c_i-c_j|}\right]\right), \tag{2.6}$$

where φ_a is the relative reproductive output as used in the POP probability [3], $S_y = \sum_a N_{y,a}\phi_a$ is the spawning abundance, and $\gamma_{y,a}$ is the age distribution of adults in year y:

$$\gamma_{y,a} = \frac{N_{y,a}\phi_a}{S_y}. \tag{2.7}$$

The HSP probability in (2.6) is quite complicated and it is worth discussing in detail - both to understand the factors involved and to begin to grasp the information content in the HSP data themselves. The first part of the equation is similar to the POP probability: the chance of finding the younger fish to be a half-sibling of the older fish is clearly, at some level, inversely proportional to the overall size of the spawning stock *in the younger fish's birth year*. The factor of 4, versus the factor of 2 one sees in the POPs, comes from the following observation: for a 50/50 sex-ratio the chance of finding a maternal or paternal HSP would be $1/(S/2)$ if $c_i \equiv c_j$, so adding these together (i.e. we don't distinguish between maternal and paternal cases) would yield a probability of $4/S$.

The terms inside the first bracket in (2.6) are where the HSP probability gets adjusted for three key factors: (i) we don't observe adults directly, so must integrate over all possible adult ages; (ii) for cross-cohort comparisons ($c_i \neq c_j$), all adults will have experienced some mortality between the two birth years in the comparison, making them less likely to be a future parent; and (iii) again for cross-cohort comparisons some adults will have increased their relative reproductive output, making them more likely to be a future parent.

The "catchability" factor, q_{hsp}, is included to account for the potential bias that might occur in estimates of adult abundance given systematic length-specific effects on relative reproductive ouptut of adults. This is not really an issue for POPs, unless such effects are somehow correlated with being captured. However, for HSPs because we are considering the output of the *same* individual at two points in time (i.e. the juvenile birth years), the relative reproductive potential of an adult that is lower/higher than average in the first birth-year could be similarly lower/higher than the average in the second birth-year. In future, a more detailed length-specific formulation of the HSP probability can be explored to deal with this bias potential directly, but for now this "catchability" approach will suffice - both for simulations and for the initial inclusion of the data in the OM.

In general, but especially for high-fecundity broadcast spawners like SBT, intra-cohort comparisons ($c_i = c_j$) are to be avoided. This is because of the potential for full/half-siblings from the same cohort to be far more probable than their cross-cohort counterparts - even in the absence of adult mortality and changes in reproductive output. Given the likely very high and very variable mortality rates of recently fertilised eggs, siblings fertilised at the same time, and in favourable conditions, are much more likely (relative to unrelated fish from the same cohort) to appear in the data. This would place a strongly downward bias on the abundance estimates if not accounted for. This effect can be dealt with, in principle, via the estimation of an intra-cohort inflation term for (2.6), but the simplest solution is not to make intra-cohort comparisons at all.

In terms of the likelihood for the HSP data, the binomial distribution is again a natural choice (as it was for the POPs) given the nature of the data (is it an HSP or not?). The extension to the beta-binomial distribution, to deal with over-dispersion if this is found to be present, can be done as outlined for the GT data in Section 2.1.3.

2.2 Structural changes for projections

This section focusses only on potential structural changes to the OM in projection mode that don't relate to new data generation, which are dealt with in [5], or UAM which is dealt with in [6]. Two substantial issues to consider are how to deal with time-varying selectivity and growth in projections. Currently, selectivity (for each fleet included in projections) and growth are fixed at their most recent values. At one level, this is a parsimonious approach: we do not have measurable (or easy to simulate) predictors that would be able to define what future levels of time-varying selectivity and growth might be. However, many of the reasons behind why both selectivity and growth have changed historically are likely to be linked to future stock dynamics (e.g. stock abundance).

2.2.1 Selectivity

All fleets have time-varying non-parametric selectivity, and this level of freedom in the selectivity functions is warranted given the clear shifts in the length/age distributions in the various fisheries that seem independent of recruitment or mortality drivers. Selectivity is assigned in blocks of years for each fishery, with differing degrees of flexibility within a given time-block across the fisheries. Selectivity can change because of things the fishermen do, in terms of targeting and fishing practices, and because the size distribution of the population in the various regions changes over time (even if mortality rates and abundance at the population level is unchanged).

There has been a general shift in the major long-line fishery (LL_1) towards smaller, younger fish over the period in which the stock exhibited a strong decline in apparent abundance. Whether driven by economics, relative availability, or a combination of the two, it is reasonable to assume that, if the stock does indeed recover, the fleet will react to these changes and with attendant changes in future selectivity, relative to the present.

If these changes do occur, as it is reasonable to assume that they will, they impact on a number of important MP performance issues:

- Interpretation of CPUE as an abundance index. The Historical CPUE has a complicated, time-dependent and non-linear relationship to historical spawner abundance (see [5]). This relationship change over time is dominated by changes in selectivity, and accounting for them historically is vitally important to interpreting CPUE as an index of abundance. Any MP with CPUE as an index is assuming that CPUE links *in some way* to spawner abundance, as is done in the current MP. Assuming a fixed selectivity in the future, when it is quite possible it will change, will make CPUE seem like a better standalone index of sub-adult/adult abundance than it actually might be.
- Relative impact of catch levels from an MP when selectivity is changing, for a fixed relative catch allocation scheme. Fisheries in projections have specific agreed allocations. A notable change in the selection pattern of a given fishery, especially one who's data is to be used in a candidate MP, could yield quite different harvest rates across the exploited age-range, and with different outcomes (rebuilding performance, catch variability etc.) in an MP performance sense, for similar overall TAC levels. A well-tuned MP should be able to react to such changes, but they could occur none the less.

There is no reason to change the reference OM from the current assumption that selectivity remains fixed in the future, but we should consider robustness tests that do allow for future variations. A fairly simple example would be to link age at maximum selectivity for the long-line fleets (particularly LL_1) to increase with increasing abundance.

2.2.2 Growth

Figure 2.2 shows the change in mean length-at-age over time for SBT. Since informative growth data began being collected in the 1960s (tagging, then ageing data) mean length has increased notably at the youngest observed ages (1–4) and slightly decreased at the oldest ages (12 and above). The functional form of the growth relationship has changed also, with a much more pronounced two-stage growth pattern (slower–faster–slower) from age zero upwards, relative to the historically more von-Bertalanffy like dyanmics of gradually decreasing growth rate with age.

The most recent distribution of length-at-age is used in the projections, and it has long been a point of discussion in the ESC as to whether this may or may not have an effect on the projections. There are three probable (and, possibly, interacting) reasons why growth might have changed over time: (i)

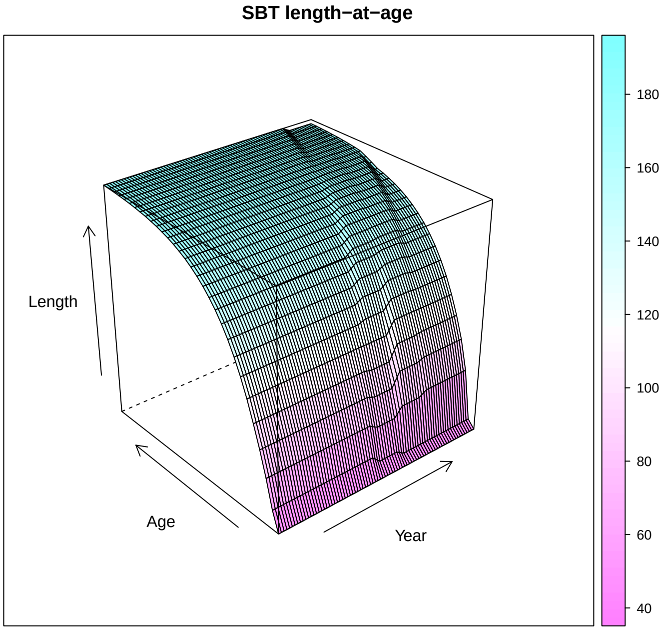

Figure 2.2: *Changes in mean length-at-age over time for SBT (ages 0–30 and years 1931–present).*

high historical exploitation removed slower growing individuals from the population (evolutionary effect); (ii) something fundamental in the ecosystem and/or surrounding environment changed the growth dynamics; and (iii) there are density-dependent growth dynamics present where competition for resources decreased, thereby increasing growth rates, as the overall stock abundance declined.

At least at the timescales the OM projections functions on, we can assume any evolutionary effect is quite likely to be effectively permanent. If an ecosystem/environmental shift occurred, and is very weakly dependent on SBT themselves, then the absence of information on the likely cause suggests the most sensible assumption is that it remains fixed in future. The density-dependent growth scenario is plausible (the correlation between mean length and overall abundance is approximately -0.8) and, if the stock recovers, is obviously incompatible with the assumption of fixed future growth dynamics. A major factor in deciding on robustness tests is their plausibility, relative to the reference OM assumptions and settings, and their potential for impacting the future dynamics so density-dependent growth is worth considering when viewed at in this manner.

Its potential impact is fairly simple to imagine. Current targets, in terms of stock rebuilding, mean trying to increase current spawner abundance to levels estimated in the late 1970s and early 1980s. Growth in this period was slower so, for the same natural mortality rates, the SSB-per-unit-recruit would be lower than it would be now, where growth is faster. The associated weight-at-age is also higher, so the same amount of catch biomass for a given selectivity-at-age will result in lower overall harvest rates. These two factors would, if density-dependent growth were true, tend to over-estimate how fast the stock could recover. As with the selectivity argument, a simple linkage between spawner depletion and mean length-at-age could be constructed to explore how much of an impact density-dependent growth might have, relative to our current fixed growth assumptions in the OM.

3 Discussion

This paper focussed on a number of issues relating to the inclusion of new data sources, and structural changes potentially required for the 2017 reconditioning and MP testing.

One of the key new information sources will be in relation to additional catch data - both from non-members and member-attributable. Estimates of non-member catch have focussed on assigning the relevant effort to be either “Japanese” or “Taiwanese” in nature [2], thereby assumed to have the same catchability and selectivity properties as those fisheries. This makes their historical inclusion in the OM fairly simple: the additional catch associated with the non-member effort is included in the reported catches for the relevant fleet (i.e. LL_1 or LL_2 in this case). For attributable catch, the situation is slightly more complex. If the catch can be demonstrated to be similar enough to an existing fleet it may be included there; if not, we have to either estimate (via composition data) - or agree on - an assumed selectivity for that attributable catch.

The gene tagging design study [1] focussed on releases and recaptures of age 2 and 3 fish, respectively, however we need to incorporate the complexities of probabilistically assigning age to tagged and catch sampled fish. Given what we know about the distribution of length-at-age of fish likely to be in the GAB in summer we can focus on tagging *mostly* age 2 fish and some age 3, and looking among *mostly* age 3 and some age 4 fish for subsequent recaptures. The specifics of how to adjust the estimator for this were outlined, as well as how information over multiple years that relates to the abundance of the same cohort can be included. A generic beta-binomial likelihood is defined for the gene tagging data that will be able to deal with over-dispersion directly if required.

The next-generation close-kin data focusses on identifying half-sibling pairs (HSPs) between juvenile-juvenile comparisons, as opposed to looking for parent-offspring pairs (POPs) between juvenile-adult comparisons. These data - independently of POPs - have the potential to be extremely informative on not just adult abundance, but also mortality rates [4]. The HSP likelihood is more complicated than for the POP case and is outlined in detail in this paper and - similar to the gene tagging case - we opt for a flexible beta-binomial likelihood for these data.

There are two key time-varying features in the current OM in terms of historical dynamics: selectivity and growth. Both are estimated to vary substantially over time, and accounting for this variation is vital to understanding both abundance trends in the data, and the estimation current stock status. One continuing issue for the OM in projection mode is that these factors remain fixed at their most recent values for all future years. Given that the reasons for the change in both these relationships over time is likely to be indelibly linked to changes in the population over time - most notably abundance - we explore hypotheses and options for how they might be simulated to vary in the future.

4 Acknowledgements

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References

[1] Preece, A., Eveson, J. P., Davies, C. R., Grewe, P. G., Hillary, R. M., and Bravington, M .V. (2015) Report on gene-tagging design study. *CCSBT-ESC/1509/18*.

[2] Edwards, C. T. T., Williams, A., Hoyle, S. *et al.* (2016) Updated estimates of southern bluefin tuna catch by CCSBT non-member states. *CCSBT-ESC/1609/BGD 02*.

[3] Hillary, R. M., Preece, A., and Davies, C. R. (2014) Assessment of stock status of southern bluefin tuna in 2014 with reconditioned operating model. *CCSBT-ESC/1409/21*.

[4] Bravington, M. V., Skaug, H. J., and Anderson, E. C. (2016) Close-kin mark-recapture. *Stat. Sci.* (in press).

[5] Hillary, R. M., Preece, A., and Davies, C. R. (2016) Methods for data generation in projections. *CCSBT-OMMP/1609/7*.

[6] Preece, A., Davies, C. R., and Hillary, R. M. (2016) Advice on incorporating UAM in stock assessment and MP evaluation and implementation. *CCSBT-OMMP/1609/5*.

5 Appendix

In terms of the likelihood function required for the beta-binomial, we first begin by assuming that the *true* sampling probability, $\tilde{p}$, is described by a beta distribution: $\tilde{p} \sim B(\alpha, \beta)$. If there is no additional variability in the true sampling distribution, $\tilde{p}$, relative to the model-predicted sampling distribution, $\widehat{p}$, then with sample size n the mean and variance of the distribution (of recaptures in this case) are $n\widehat{p}$ and $n\widehat{p}(1-\widehat{p})$, respectively. To deal with additional variance we can introduce a new parameter, $\omega = (\alpha+\beta)^{-1} > 0$, so that while the mean of the distribution remains the same, the variance of R can be expressed as follows:

$$\mathbb{V}(R) = \frac{n\widehat{p}(1-\widehat{p})(n\omega+1)}{(1+\omega)}, \tag{5.1}$$

and so the inflation factor in the variance, the over-dispersion factor ϕ, is

$$\phi = \frac{(n\omega+1)}{(1+\omega)}. \tag{5.2}$$

It is ϕ that is usually estimated from the residuals in some way [3] and ω is easily solved for:

$$\omega = \frac{(\phi-1)}{(n-\phi)}. \tag{5.3}$$

The actual values of α and β for the distribution of $\tilde{p}$ are, after a little algebra, given by the following:

$$\alpha = \frac{(n-\phi)\widehat{p}}{(1-\widehat{p})(\widehat{p}+(1-\widehat{p})(\phi-1))} \tag{5.4}$$

and

$$\beta = \frac{n-\phi}{\widehat{p}+(1-\widehat{p})(\phi-1)}. \tag{5.5}$$

In terms of the final likelihood, we would like to integrate over the random variable $\tilde{p}$, and obtain the likelihood of observing the given recaptures, R, in terms of n and $\widehat{p}$. Fortunately, the marginal likelihood we are interested in (i.e. when integrating over $\tilde{p}$ in the joint beta-binomial likelihood) is of a known form:

$$\ell\,(R\,|\,\widehat{p}) \propto \frac{\Gamma(R+\alpha)\Gamma(n-R+\beta)\Gamma(\alpha+\beta)}{\Gamma(n+\alpha+\beta)\Gamma(\alpha)\Gamma(\beta)}, \tag{5.6}$$

where $\Gamma(\bullet)$ is the gamma function, and α and β are as defined in (5.4) and (5.5), respectively.

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Methods for data generation in projections

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Abstract

The CCSBT ESC is about to begin a new round of MP development and testing. A number of new data sources are being collected for use in the OM. This paper details how they can be simulated in the OM projections and their potential information content for use in a new MP. We outline a flexible model for simulating the gene tagging data that can incorporate additional variance. For the parent-offspring close-kin data we detail a flexible simulation approach and also how to use the empirical data (numbers of comparisons and detections) as an indicator of spawning abundance. The simulation of the next generation of close-kin data, finding half-sibling pairs among juveniles, is outlined. We also show how these data, again in their empirical form, can be developed into very informative indices for both relative spawning abundance - independent of the POP data - and mean adult total mortality rate.

1 Background

The Extended Commission has requested the development of a new MP, by 2019, which will potentially use a new recruitment index and other sources of data. [1]. This paper focusses on the data generation of indices that can be considered for potential inclusion in any future candidate MPs. This will allow for simulation testing of new MPs using data generated in the OM projections. This paper should be read in conjunction with the paper focussing on required structural changes to the OM to incorporate new data sources [2]. To simulate the various data sets we employ an SBT-like Operating Model. We use a simplified OM with all the key life-history and fishery characteristics of SBT (growth, reproductive output, natural mortality, population selectivity across all fisheries) and with the same current spawner abundance. We explore the main population change drivers: three similar trends (in terms of logarithmic change) for both mean recruitment and overall fishing mortality in the future. This allows us to see the potential information content in the various data sources across a plausible range of overall abundance change scenarios, and given the two obvious drivers: mortality and recruitment.

Gene tagging has been recommended as an essential recruitment index for a new MP, following extensive work done both for and at last year's ESC which demonstrated the need for such an index [1]. The general design study for the pilot gene tagging program can be found in [3] and the successful release of 3,800 fish occurred in January of this year. In [2] we outlined the mathematical and statistical features of the gene tagging estimator, and the associated beta-binomial likelihood we suggest for the OM in conditioning mode. In this paper we propose to use the same generic likelihood in the OM in projection mode. We also explore the information content in the simulated gene tagging data, with respect to trends in mean recruitment under a variety of future scenarios.

In both the OM and the adopted MP, the major index of non-juvenile abundance is the long-line CPUE. Figure 1.1 shows that these data have a complex, non-linear relationship to the OM-estimates of spawner abundance. Only from 1969 to the mid-1980s (i.e. higher SSB levels) is the relationship close to being linear. From that point on to the present (where CPUE levels drop below 1 consistently), and even before factoring in the additional uncertainty in CPUE given the over-catch in the majority of this period, there is little strong correlation between CPUE and spawner abundance. The more recent long-line CPUE data are very clearly important indices relating to the sub-adult fish and, given the general move to target younger, smaller fish over the last two decades (although slightly different in 2015), are also more informative on recruitment than they once were. Future changes in targeting as the stock recovers might increase their information content with respect to mature animals, but presently they are not as informative. With only gene tagging and long-line CPUE we have no potential indices for inclusion in an MP that overlap significantly with the major reproductive age-classes (an issue we faced with the current MP also). The primary focus of any current candidate MP is, however, to drive the recovery of the spawning population to Commission agreed levels (in terms of both overall level and probability of attaining it).

The Commission has agreed to continue the collection and genotyping close-kin tissue samples [4]. Ef-

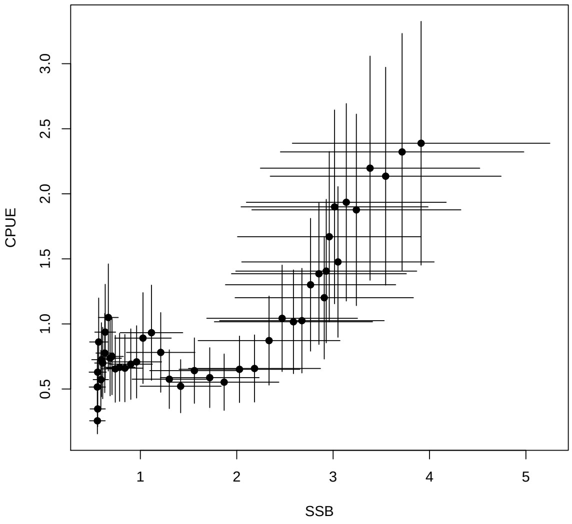

Figure 1.1: *CPUE observations (y-axis) versus current OM estimates of SSB (x-axis) in terms of median and 80%CI.*

forts are underway to process the historical backlog of samples using the next-generation sequencing technology that is both cheaper than the original microsatellite approach and will allow us to find both parent-offspring pairs and half-sibling pairs among the juvenile samples. The primary use of the POP data has been in the OM [5], where they have been very influential with respect to both current absolute and relative spawning abundance, but also adult mortality rates. The half-sibling pair (HSP) data have the potential to be very influential given they directly relate to spawner abundance, adult mortality, and relative reproductive output (RRO) *independently* of the POP data [6]. In this paper we also explore the potential information content in both the POP and HSP data in an empirical setting - methods to structure the data in such a way as to be informative on relative spawner abundance (POPs/HSPs) and mean adult mortality (HSPs only).

2 Material & Methods

The same simulation model is used for all data sources so we outline the specifics of that model first. It is an annual age-structured model, with the same key life-history and fishery characteristics as the CCSBT OM:

- The model has the same median M-vector, length-at-age distribution, recruitment variability (σ_r), and RRO (φ_a) as the SBT OM
- A single selectivity, constructed by normalising across current fleet-aggregated fishing mortality, is assumed
- Initial Fs are set so as to obtain an initial spawning abundance very close the median current spawning abundance predicted in the reference OM

We omit a stock-recruit relationship for simplicity, and we purposely explore trends in both mean recruitment and F. We are not testing the performance of candidate MPs or stock rebuilding times; we are exploring the generation and information content of data sources focussed on monitoring recruitment and spawner abundance. For both the mean recruitment and annual F multiplier we explored three simple scenarios: constant, and $\pm 1\%$ log-scale trends over time. We cross these scenarios with each other to obtain 9 scenarios in total, and each one is explored for all three data sources. This allows us to efficiently, but also simply, explore a number of scenarios for both fish entering the fishery for the first time (where gene-tagging is focussed), and for the spawning stock and where abundance trends can have differing and antagonistic/synergistic drivers (i.e. recruitment and/or mortality).

2.1 Gene Tagging

For the gene tagging design study [3] a simple Petersen estimator was outlined, where we assumed we can target age 2 releases and age 3 recaptures perfectly. In [2] we detail the specifics of how the gene tagging estimator will work, where this idealised targeting of specific age classes will not be quite so clear cut. Figure 2.1(a) shows the probable length distribution of age 2, 3 and 4 in the GAB in summer and, given our OM assumptions, is also the same as that in our simulation model explorations.

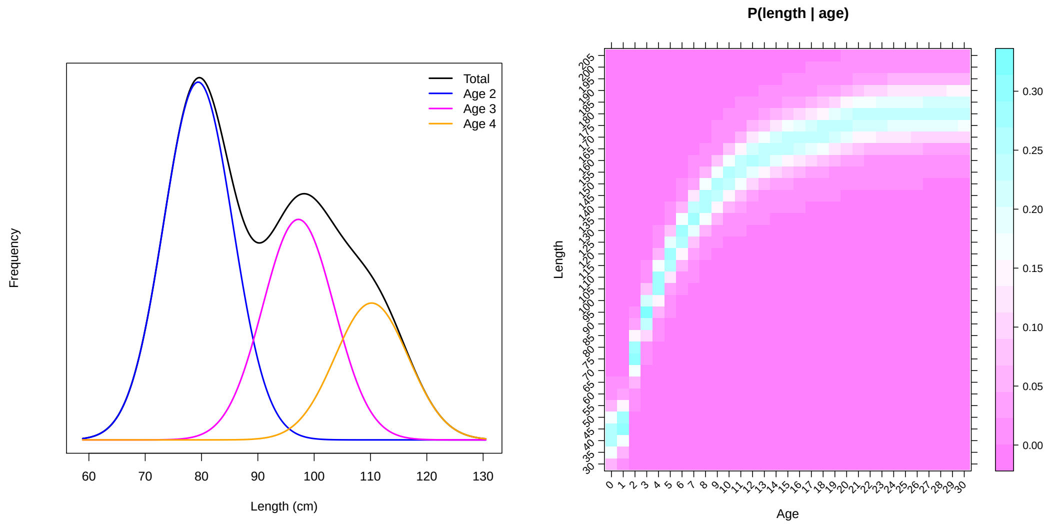

Figure 2.1: *(a, left) the probable length distribution of ages 2, 3 and 4 year old fish in the simulation model given current mortality rates; (b, right) the distribution of length-at-age assumed in the simulation model.*

The length partition used for the population is in 5cm bins, from 30cm to 210cm. The length-at-age distribution in the simulation model can be found in Figure 2.1(b). In terms of tag releases they are assumed to be uniformly released into the three length bins between 65 and 75cm (65-80cm). The subsequent recapture effort (1 year after the releases) focusses on the three length bins between 95 and 105cm (fish in sizes 95-110cm), so most likely to be age 3 fish, very very few age 2 fish, but with a higher chance of sampling age 4 fish as well.

The simple estimator we explore focusses only on *effective* numbers of recaptures of age 3 fish, tagged a year before at age 2. We say effective because we estimate the number of actual age 2 and 3 fish in the releases and recapture samples, respectively. Eqn. (2.2) in [2] outlines the distribution of age given length in the samples. We then estimate the (prior) age composition of the given length samples, for the length-at-age distribution (see Figure 2.1(b)), given the length distribution of both the release and scanned-for-recapture fish. This approach explicitly accounts for the potential information loss we are likely to get, in terms of not being able to target **only** age 2 releases and age 3 recaptures. As noted in [2] there will be additional information gained (via multi-year recaptures on the same cohort), but we focus on the MP-centric idea of getting an abundance index of age 2 fish. This information gain will feature more in an OM sense, but should not be ignored in the wider discussions of the merits or otherwise of these data.

The main potential bias identified in the gene-tagging design study can occur if some of the juvenile fish spawned on the spawning grounds never, or intermittently, spend the majority of their summers in the GAB between ages 2–4. The Global Spatial Dynamics project suggested the evidence for a significant part of the juvenile population behaving in this way was weak, but it is still an ongoing hypothesis. It was proposed in the Gene-Tagging design study that we could investigate this through a q factor for the proportion in the GAB. Alternatively, probably the simplest method is to impose a cap on the selectivity of the surface fishery. For a "fully mixed" population where all fish of the relevant ages visit the GAB at the time of the fishery, that selectivity will have a maximum of one, as is currently assumed in the SBT OM. We can explore scenarios where the maximum selectivity of the surface fishery is capped at some value $\zeta < 1$, and the true probability of finding a released tag in the GAB is then not proportional to $1/N$ but $1/\zeta N$. In this scenario $1-\zeta$ is the age-independent fraction of the juvenile population that never visits the GAB. Note none of the other mixing scenarios examined in the design study resulted in biased estimates of age 2 abundance - see [3] - but it is worth exploring results for this case detailed as scenario 2b in [3]. It is also testable in a non-spatial OM context (as described herein via capped selectivity).

For the purposes of data generation in the MP context we explore the information content in a simple moving average of relative recruitment, much as how the aerial survey is currently used. We explore the correlation of the gene-tagging derived estimates of (relative) age 2 abundance with their true simulation model counterparts, for all 9 recruitment and fishing mortality scenarios (below).

2.2 Parent-Offspring Pairs (POPs)

The original POP data have been officially included in the SBT OM since 2013 [5]. The current format for the data is as follows: we have juvenile sample, i, and an adult sample, j, each with either a direct estimate of age, or an expected age given its length. The probability of finding a POP will be the same for the same year of adult capture and age, and the juvenile birth-year (cohort), and the data are currently grouped in this manner. We use this (adult capture year and age, y and a, respectively; juvenile cohort, c) as the base disaggregation level for simulating the POPs. The probability of finding a POP for an juvenile-adult comparison $\{i, j\}$ is as follows:

$$p_{\text{pop}} = \mathbb{I}\left(c < y < c + a\right) \frac{2\varphi_{a-(y-c)}}{\sum\limits_{k} N_{c,k}\varphi_k}, \tag{2.1}$$

where $\mathbb{I}(\bullet)$ is the indicator function, and φ_a is the RRO at age a. There is a fairly obvious set of constraints about what kind of samples are legitimate, given Eqn. (2.1):

- If the distance between the birth year of the juvenile and the capture year of the adult exceeds the capture age of the adult - i.e. $(y - c) > a$ - that comparison cannot be made (the adult was not alive to potentially sire the juvenile).
- If the adult capture year was before the birth year of the juvenile - i.e. $c > y$ - then that comparison cannot be made (again the adult was not alive at the time of the juvenile's birth given sampling is lethal).
- Comparisons between adults caught in the same year as the juvenile was born - i.e. $y = c$ - are also not made (the adult could have been caught prior to spawning)

So, even if we describe the sampling regime in terms of M_i juveniles and M_j adults per year, we will always have less than $M_i M_j$ total comparisons given these rules for fair comparisons. The base likelihood assumed in the current OM is binomial, and the evidence for over-dispersion is estimated to be very weak [5]. However, in the MP context it makes sense to use the more flexible beta-binomial likelihood to simulate these data just in case we wish to explore some over-dispersion scenarios in a robustness test.

$\{R, F\}$ scenario	corr($\bar{N}^{\text{true}}_{y,2}$, $\bar{N}^{\text{gt}}_{y,2}$)
$\{0, 0\}$	0.92 (0.83–0.95)
$\{0.01, 0\}$	0.9 (0.77–0.95)
$\{-0.01, 0\}$	0.96 (0.93–0.98)
$\{0, 0.01\}$	0.92 (0.83–0.96)
$\{0.01, 0.01\}$	0.9 (0.81–0.96)
$\{-0.01, 0.01\}$	0.97 (0.93–0.98)
$\{0, -0.01\}$	0.91 (0.82–0.96)
$\{0.01, -0.01\}$	0.91 (0.8–0.95)
$\{-0.01, -0.01\}$	0.97 (0.93–0.98)

Table 3.1: *Temporal correlation (median and 80%CI in brackets) for first 50 years of projection between the GT-derived 5 year moving average of age 2 abundance and its "true" model counterpart.*

2.3 Half-Sibling Pairs (HSPs)

The likelihood for the comparison of two juveniles i and i', assumed to come from different cohorts c_i and $c_{i'}$, is detailed in [2] and is given by the following:

$$p_{\text{hsp}} = \frac{4q_{\text{hsp}}}{S_{c_{\max}}} \left(\sum_a \left[\gamma_{c_{\min},a} \exp\left(- \sum_{y=c_{\min}}^{c_{\max}-1} Z_{y,a} \right) \varphi_{a+|c_i - c_{i'}|} \right] \right), \tag{2.2}$$

where $S_y = \sum_a N_{y,a}\phi_a$ is the spawning abundance, $c_{\max}$ is the most recent cohort, $c_{\min}$ is the earliest cohort, q_{hsp} (with default value of 1) is a "catchability" term explained in [2], and $\gamma_{y,a}$ is the age distribution of adults in year y:

$$\gamma_{y,a} = \frac{N_{y,a}\phi_a}{S_y}. \tag{2.3}$$

With the POP data there are certain combinations of juveniles and adults that are not fair comparisons, but this is not the case with the HSP data. The only stipulation we enforce is that all comparisons are *cross-cohort* - i.e. $c_i \neq c_{i'}$ - for the reasons explained in [2]. We have no empirical evidence either in favour or against over-dispersion in the HSP data, unlike the POP case. We therefore use the beta-binomial as the simulation distribution, as with the GT and POP data, with the reference case being no over-dispersion.

3 Results

For all three data sources we explored 3 scenarios - *status quo* and $\pm 1\%$ - for the (logarithmic) trend in mean recruitment and overall fishing mortality, so 9 in total when crossing them. In terms of notation, a scenario labelled as $\{0.01, -0.01\}$ would denote mean recruitment increasing by 1% and total fishing mortality decreasing by 1%, whereas $\{0, 0\}$ would imply no change in either over time. Figure 3.1 details the spawner abundance dynamics for each of these future recruitment and fishing mortality scenarios.

3.1 Gene Tagging

For the gene tagging data, we set the following sample sizes for releases, T, and the scanning of recaptures, S: $T = 4,000$ and $S = 8,000$. Note these are slightly lower than recommended for the actual SBT pilot study [3] because the corresponding age 2 abundances in this particular model are slightly lower than for SBT. The sample sizes here will still produce the same level of expected recaptures (around 16–25) and, hence, precision as in [3] for "current" model abundances. This will ensure that the simulated correlation between the GT-derived and "true" age 2 abundance trends are meaningful in the real-world SBT context.

We simulate the GT data for each of the 100 projection years, given the sample sizes outlined, and with year 99 the last year of an estimate (given it needs recaptures from year 100). The default assumption

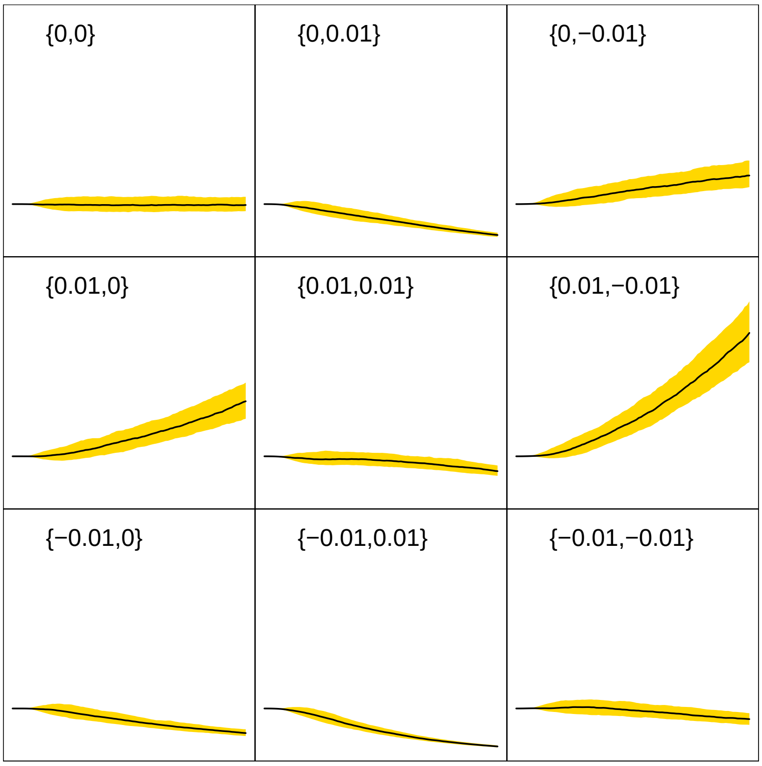

Figure 3.1: *The spawner abundance projections (100 years, median and 80%CI) for each of the 9 mean recruitment and total fishing mortality scenarios. Each simulation starts with the same spawner abundance (purposely set at the current SBT level) and the minimum level in the plot is zero. The first and second terms in brackets at the top of each panel denote the log-scale mean recruitment and total fishing mortality trends, respectively.*

was no over-dispersion and the actual index we focus on is a moving average of the GT age 2 estimates:

$$\bar{N}^{\text{gt}}_{y,2} = \frac{1}{\tau} \sum_{i=y-\tau+1}^{y} \widehat{N}_{i,2}, \tag{3.1}$$

where $\widehat{N}_{y,2}$ are the GT estimates of true age 2 abundance. We choose a 5-year ($\tau = 5$) moving average time-scale, just as is done in the current MP with respect to the aerial survey part of the rule. Table 3.1 summarises the results, in terms of the temporal correlation between the trends in true (simulated) and GT-derived moving average age 2 abundance, across all the 9 scenarios.

Median correlations across all scenarios are 0.9 or higher, with the lower 10%ile never going below 0.75. If mean recruitment, and obviously age 2 abundance, experiences a downward trend the median correlation rises to above 95% (and almost always above the 0.9 level). This is driven by an increasing number of recaptures and, hence, a more accurate estimate of current true abundance. Even if mean recruitment increases (eventually by 50% at the end of the simulations), the median correlation still holds at 0.9, for these fixed sample sizes, there were and with very very few - less than 0.1% - years in the simulation where no recaptures were detected.

3.2 Parent-Offspring Pairs (POPs)

The GT data are easier to generate into a workable mean recruitment index, given we already have a simple, workable estimator in place. The close-kin data, in both the POP and HSP settings, require detailed population dynamic and statistical models to estimate actual abundance and mortality [6]. In the

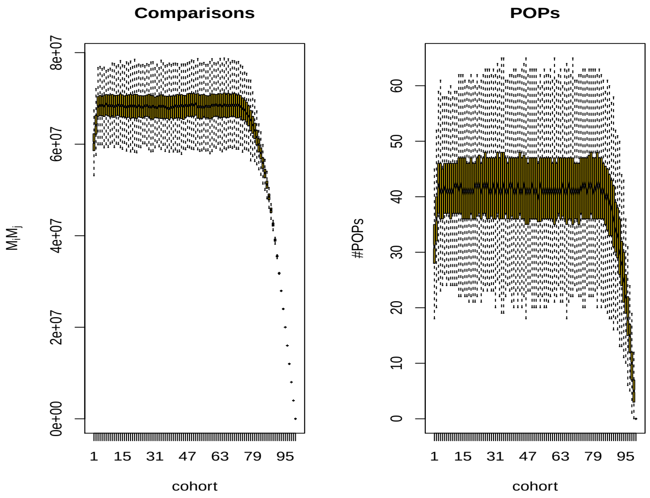

Figure 3.2: *Number of comparisons (left) and the number of POPs (right) for the full suite of 99 cohorts simulated for the* $\{0, 0\}$ *recruitment/fishing mortality scenario.*

following two sections we explore options for generating empirical indices from the close-kin data (of both types) that are (potentially) informative on relative spawner abundance and adult mortality.

For the POP data we define a simple, time-invariant sampling strategy: the number of juvenile (age 3) fish sampled is $M_i = 2,000$, and the number of adult samples taken is $M_j = 2,000$ also. The raw POP data are simulated for the 100 year projection period, and all 9 scenarios, using the beta-binomial likelihood with probability defined by Eq. (2.1), but with over-dispersion set to zero. Figure 3.2 shows the number of effective comparisons and resultant POPs across the future cohorts of interest in the projection model, for the full *status quo* $\{0, 0\}$ recruitment/fishing mortality scenario. Both the number of effective comparisons and POPs increase quite rapidly with increasing cohorts observed and equilibrate for many years, then rapidly decreasing as the number of observations (and, hence, POPs) of the very last cohorts goes to zero. The important feature for the purposes of this paper, is what happens to the ratio of effective comparisons to POPs - for this example it holds very steady over time, much as the spawner abundance does.

For the simple relative spawner abundance index we propose to basically use a modified version of the original "cartoon" estimator [6]:

$$\widehat{N} = \frac{2M_iM_j}{R}, \tag{3.2}$$

where R is the number of POPs and $\widehat{N}$ is the adult abundance. We use this fundamental idea, that the ratio of comparisons to POPs is informative about spawner abundance, when constructing the index. For each juvenile cohort, c, and year, y, and age, a, of adult capture we have a number of comparisons, $M_{c,y,a}$, and detected POPs, $R_{c,y,a}$. In a given year, the age distribution of samples is assumed to be multinomial with probability given by the adult age distribution, $\gamma_{y,a}$, and sample size M_j.

To construct the index we first sum over the adult capture ages:

$$M_{c,y} = \sum_a M_{c,y,a}, \tag{3.3}$$

$$R_{c,y} = \sum_a R_{c,y,a}, \tag{3.4}$$

$$I_{c,y} = \frac{M_{c,y}}{R_{c,y}}. \tag{3.5}$$

To finally obtain an index that focusses on the particular cohort, we use a weighted sum:

$$I_c = \sum_y I_{c,y}\omega_{c,y}, \tag{3.6}$$

where the weighting term $\omega_{c,y}$ is defined as follows:

$$\omega_{c,y} = \frac{R_{c,y}}{\sum\limits_y R_{c,y}}. \tag{3.7}$$

This makes the weighting effectively proportional to the inverse square of the CV of the cartoon estimate and, as such, a simple proxy for an inverse variance type weighting (more POPs, more weight effectively). As with the GT we focus on the first 50 cohorts, in terms of examining the relationship between the index (and statistics derived from it) and the spawner abundance, to avoid complications in the latest years when sampling and, hence, POPs reduces to zero.

The first analysis we did was to explore the evidence for the following relationship between the POP index, I_c, and the true spawner abundance, S_c, and looked at the following form: $\log S_c = \alpha \log I_c$. If the index is a "good" spawning index we would want it to approach zero as S does and be as close to linear in real space (i.e. $\alpha = 1$) as possible. For all 9 scenarios, and across all the random samples simulated, α was both highly significant and ranged from 0.96–0.99. We cannot explain why the relationship is very slightly sub-linear across all population scenarios explored, but what is clear is that the base index is **very** close to linearly related to spawner abundance.

To offset to some degree the sampling variability in the single-cohort index we explore to alternatives:

1. A moving average index, similar to the GT index:

   $$\bar{I}_y^{\text{pop}} = \frac{1}{\tau} \sum_{c=y-\tau+1}^{y} I_c, \tag{3.8}$$

   and here we explored $\tau = 7$, mostly because changes in spawner abundance will be on a slower time-scale than for age 2 abundance and so we can afford to average over a longer time-scale

2. Estimating the log-linear trend λ_y in the cohort-specific index, much as we do in the trend part of the MP with respect to CPUE:

   $$\lambda_y^{\text{pop}} = \frac{\sum\limits_{c=y-\tau+1}^{y} \left((I_c - \bar{I})(c - \bar{c})\right)}{\sum\limits_{c=y-\tau+1}^{y} \left((c - \bar{c})\right)^2} \tag{3.9}$$

   where $\bar{I}$ and $\bar{c}$ are the respective means of the index and cohort over the relevant time-frame, but we use a $\tau = 10$ time-scale here. The reason behind this is for the same reason as using a longer time-scale for the moving average index above: changes will be slower and we will, in principle, follow less noise by doing this

We look at the correlation between these derived indices and their true counterparts from the OM over the first 50 years in the simulation. For some perspective on what these correlations might imply, we also compare them to a hypothetical unbiased survey of the spawner abundance with a CV of 0.3. Obviously, we cannot achieve this kind of index in practice, but it will hopefully give an indication of what we can obtain by comparing it to a more familiar type of abundance index.

Table 3.2 details the correlations for both types of derived index (moving average and log-scale trend), for the POP-derived and hypothetical survey "raw" indices, relative to their "true" model counterparts.

$\{R,F\}$ scenario	corr($\bar{S}_y^{\mathrm{true}}$, $\bar{I}_y^{\mathrm{pop}}$)	corr($\bar{S}_y^{\mathrm{true}}$, $\bar{S}_y^{\mathrm{surv}}$)	corr($\lambda_y^{\mathrm{true}}$,$\lambda_y^{\mathrm{pop}}$)	corr($\lambda_y^{\mathrm{true}}$,$\lambda_y^{\mathrm{surv}}$)
$\{0,0\}$	0.4 (-0.14–0.73)	0.52 (-0.01–0.73)	0.09 (-0.28–0.4)	0.26 (-0.08–0.56)
$\{0.01,0\}$	0.68 (0.13–0.89)	0.73 (0.29–0.92)	0.1 (-0.24–0.42)	0.32 (-0.04–0.61)
$\{-0.01,0\}$	0.73 (0.29–0.89)	0.74 (0.28–0.89)	0.09 (-0.25–0.45)	0.32 (-0.05–0.61)
$\{0,0.01\}$	0.75 (0.29–0.92)	0.75 (0.39–0.91)	0.1 (-0.25–0.45)	0.29 (-0.07–0.6)
$\{0.01,0.01\}$	0.42 (-0.14–0.74)	0.53 (-0.04–0.82)	0.08 (-0.27–0.41)	0.26 (-0.09–0.57)
$\{-0.01,0.01\}$	0.91 (0.74–0.97)	0.88 (0.73–0.95)	0.13 (-0.3–0.5)	0.4 (-0.03–0.58)
$\{0,-0.01\}$	0.59 (0.04–0.84)	0.68 (0.16–0.89)	0.12 (-0.27–0.41)	0.31 (-0.09–0.57)
$\{0.01,-0.01\}$	0.84 (0.58–0.94)	0.87 (0.63–0.95)	0.12 (-0.24–0.45)	0.32 (-0.02–0.6)
$\{-0.01,-0.01\}$	0.44 (-0.13–0.78)	0.51 (-0.02–0.84)	0.08 (-0.3–0.43)	0.28 (-0.12–0.58)

Table 3.2: *Temporal correlation (median and 80%CI in brackets) for first 50 years of projection between both the 7 year moving average and the log-scale linear trend and their "true" model counterparts, for the POP-derived index and a hypothetical unbiased survey with a CV of 0.3.*

Focussing on the moving average trend first, the hypothetical survey index marginally outperforms the POP-derived index for scenarios where little to no change in spawner biomass occurs over time, with median correlation values for both types of index all at 40% or above in these cases. For scenarios where spawner biomass is changing over time, be it up or down, the POP-derived index is at least as good as, and sometimes better than (for pessimistic scenarios), the survey-based index. For the log-scale linear trend the survey consistently outperforms the POP-derived index across all scenarios, with median correlation levels 2.5–3 times that of the POP-derived index. What is very noticeable about the log-scale index trends, however, is the overall poor performance of either index - POP-derived or survey-based. Median correlations never exceed 0.4 for the most pessimistic scenario, with the lower 10%ile permanently sitting at between -0.3 to -0.05 for either index across all scenarios.

3.3 Half-Sibling Pairs (HSPs)

One very important point to make first is that the HSP data are **independent** of the POP data. Whatever we may derive from the HSP data, even though it is informative on the spawning population, it can be used alongside - and, potentially, in combination with - any POP indices we care to use. The HSP data present more of a challenge than the POP data, which really relate to spawner abundance in a given year. The HSP data, when considering the comparison of two juveniles i and i', informs us about spawner abundance in the most recent juvenile cohort *and* the cumulative mortality of the adult population in between the two cohorts. In conjunction with other data (catch biomass and composition, abundance data) it could also inform us on the RRO ogive as it is free from adult sampling effects (like selectivity) [6]. Given the likely information content of the HSP data, and the results of the POP-derived indices, we explore the following two possibilities as potential candidates as input series for candidate MPs:

- Derivation of a relative spawner abundance index, similar in concept to that derived from the POP data
- Derivation of an adult mortality index, which can only be attempted for the HSP data (and is not derivable from any hypothetical survey)

We simulate the sampling of $M_i = M_{i'} = 2,000$ juveniles per year, so the total number of comparisons between two cohorts is always $M_i M_{i'} = 4e+6$, and never compare two samples from the same cohort. Figure 3.3 outlines two plots of the simulated HSPs for the $\{0,0\}$ full *status quo* recruitment and fishing mortality scenario: (i) the total number of HSPs relating to each of the first 96 cohorts of interest (recall the target is sampling age is 3, so we cannot have information for any cohorts after 96); and (ii) the number of HSPs found between the first cohort and all the subsequent ones.

A number of key points can be made using Figure 3.3:

- There will be, for the current proposed sample sizes and in general, more HSPs than POPs - they are a weaker (genetically) relationship than parent-offspring and, therefore, more common. In this

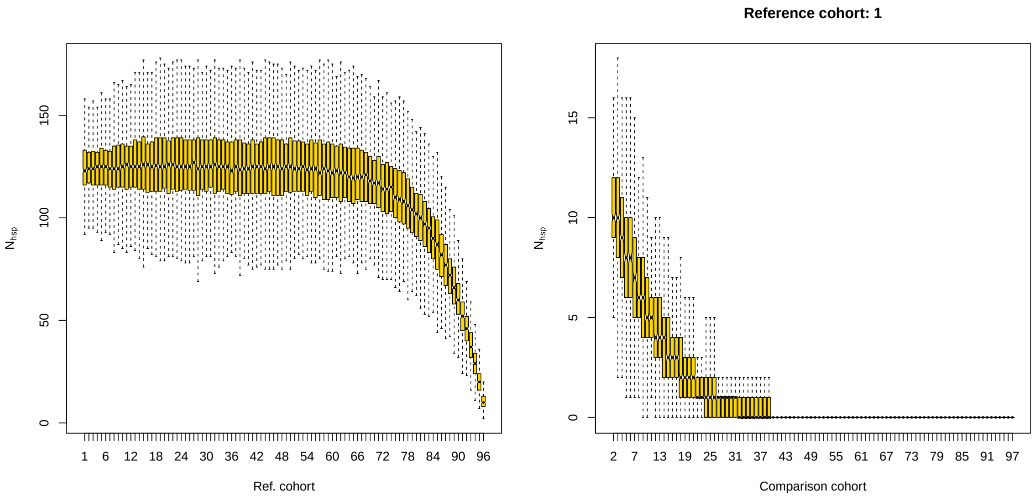

Figure 3.3: *Number of HSPs for each of the 96 cohorts (left) and between the first cohort and all the subsequent ones (right). In each case the number of total comparisons made between each cohort is 4e+6.*

example almost 3 times as common. In the cartoon it is 2 times as many *but* when accounting for lost comparisons in the POP framework, whereas none save intra-cohort comparisons are lost when comparing juvenile samples, we actually obtain more than 2 times the number of HSPs. This means any comparable HSP-derived indices are likely to be more informative than for the POP-derived ones based on sample sizes alone.

- Looking at the plot on the right of Figure 3.3 we see the adult mortality effect in the HSP data. As we compare progressively more distant cohorts, the number of HSPs found between them declines because the probability of an adult living that long (which it would have to for there to be any HSPs) becomes smaller and smaller. There is a sort-of-analogy with catch curves here, where catches often decrease down a cohort with total mortality. The **crucial** difference with the HSPs is that they are **not** biased by selectivity effects, which catch-curves are.
- The *status quo* scenario is the easiest with which to make this distinction between the abundance and mortality signals in the data. With changing abundance and/or adult mortality over time these two will inevitably alias for one another. The key is how do we derive the two indices to see if we can tease the signals apart? To make the most of the HSP data in an empirical sense we want to derive two indices that could reflect abundance and mortality effects as independently as possible.

The HSP spawner relative abundance index for a given cohort, c, is derived as follows:

$$I_{c,c'} = \frac{M_c M_{c'}}{R_{c,c'}}, \tag{3.10}$$

$$I_c = \sum_{i=c-\nu}^{c-1} I_{c,i}\varepsilon_{c,i}, \tag{3.11}$$

(3.12)

where $c' < c$, ν is a back-averaging time-scale, and $\varepsilon_{c,c'}$ is a weighting proportional to the number of HSPs found between the two reference cohorts c and c'. The parameter ν is set at 3 - it should not be set too large so as to avoid including mortality trend effects in the abundance index. The actual abundance index, $\bar{I}_c^{\text{hsp}}$, is defined much as the POP index as a moving average of the "raw" index I_c (with the same time-frame of $\tau = 7$. The time-frames over which the HSP index actually works are somewhat different to

$\{R, F\}$ scenario	corr($\bar{S}_y^{\mathrm{true}}$, $\bar{I}_y^{\mathrm{hsp}}$)	corr($\bar{S}_y^{\mathrm{true}}$, $\bar{S}_y^{\mathrm{surv}}$)	corr(Z_y^{true},$\mathcal{Z}_y^{\mathrm{hsp}}$)
$\{0, 0\}$	0.79 (0.48–0.91)	0.58 (0.07–0.85)	0.08 (-0.14–0.32)
$\{0.01, 0\}$	0.89 (0.68–0.96)	0.79 (0.41–0.92)	0.05 (-0.2–0.3)
$\{-0.01, 0\}$	0.92 (0.77–0.97)	0.77 (0.44–0.91)	0.1 (-0.13–0.32)
$\{0, 0.01\}$	0.92 (0.77–0.97)	0.84 (0.59–0.93)	-0.38 (-0.58– -0.09)
$\{0.01, 0.01\}$	0.77 (0.4–0.92)	0.59 (0.1–0.84)	-0.38 (-0.58– -0.08)
$\{-0.01, 0.01\}$	0.97 (0.94–0.99)	0.93 (0.83–0.96)	-0.37 (-0.61– -0.09)
$\{0, -0.01\}$	0.85 (0.63–0.95)	0.75 (0.31–0.91)	-0.02 (-0.28–0.24)
$\{0.01, -0.01\}$	0.94 (0.86–0.98)	0.9 (0.78–0.96)	-0.03 (-0.29–0.25)
$\{-0.01, -0.01\}$	0.79 (0.5–0.93)	0.57 (0.03–0.81)	-0.04 (-0.3–0.22)

Table 3.3: *Temporal correlation (median and 80%CI in brackets) for first 50 years of projection between the 7 year moving average, and the "true" model counterparts, for the HSP-derived index and a hypothetical unbiased survey with a CV of 0.3. Also included is the correlation between the true weighted mean adult total mortality and the HSP-derived index.*

the POP index. For the raw index we are initially summing over cohorts that *precede* the reference cohort c, and we do not compare within a cohort, so $c = 4$ is the first year we can derive a raw index point for. For the moving average we than add $\tau = 7$ years to this so $c = 11$ is effectively the first year we get an HSP index for. For the POP data it is $c = 8$, given we do not compare juveniles and adults from the same year of capture (ruling out $c = y = 1$).

The adult mortality index is more subtle. For unrelated pairs (UPs) of juveniles i and i', the likely time between their respective birth years (cohorts), $\Delta_{i,i'} = |c_i - c_{i'}|$, is unaffected by adult abundance and mortality; for HSPs it is strongly affected - see Eq. (2.2). The expected value of $\Delta_{i,i'}$ is, for the example of no changes in adult abundance, always going to be smaller for HSPs than UPs because of the adult mortality effect (see also the r.h.s. of Figure 3.3 for this effect). To derive and adult mortality index using this idea we explore the following:

$$\mathcal{Z}_c^{\mathrm{hsp}} = \log\left(\frac{\mathbb{E}\left(\Delta_{i,i'}^{\mathrm{hsp}}\right)}{\mathbb{E}\left(\Delta_{i,i'}^{\mathrm{up}}\right)}\right), \tag{3.13}$$

where the expection in Eq. (3.13) is taken over the cohorts c to $c - \psi + 1$, and we chose a time-frame of $\psi = 10$ for this example (thus making $c = 11$ the first cohort with the index available). The mean adult total mortality rate, $\bar{Z}_y$, that we explore for correlation with $\mathcal{Z}^{\mathrm{hsp}}$ is calculated via

$$\bar{Z}_y = \sum_a \gamma_{y,a} Z_{y,a}, \tag{3.14}$$

where $\gamma_{y,a}$ is the relative age distribution of the adults in year y.

Table 3.3 summarises the correlations of the HSP (as well as the POP and hypothetical survey) derived abundance indices, and the adult mortality index, with their "true" model counterparts. Unlike the POP example, the HSP-derived abundance index outperforms an unbiased survey with a CV of 0.3 in all cases - not just for declining abundance scenarios. For the HSP index median correlation never goes below 0.77 and the lower 10%ile never less than 0.4; for the survey-derived index comparison the minimum median correlation is 0.58 and the minimum lower 10%ile is 0.03.

For the adult mortality index, where if there is a relationship the correlation should be negative, the situation is very case dependent. For scenarios where F (and, hence, Z) is time-independent we see no obvious linkage, as one would expect given the nature of the index and the level of sampling variability inherent in it. For decreasing Z we see a very very weak effect (marginally negative correlation). It is only for the case of increasing adult Z that we see a clear and consistent signal. This is to be expected given both the comparatively low levels of adult Z overall, and the signal in the HSP data. For increasing Z the distribution of the temporal distance between cohorts of the HSPs begins to increasingly contract over time, resulting in the relationship (negative correlation) we see in Table 3.3. From the originally fairly low level, if Z decreases the opposite widening effect in the cohort difference distribution of the HSPs is *much* weaker, resulting in the minimally negative correlations in Table 3.3 for these scenarios.

4 Discussion

This paper focusses on the statistical specifics of the generation of new data sources, specifically gene-tagging and both POP and HSP close-kin data. It also explores on their potential information content for use in an MP, exploring the derivation of empirical indices of relative spawner abundance and adult mortality. Given the impending cessation of the current MP, and the initialisation of a new round of MP and OM development to replace it, we decided that the SBT OM and constant catch projections was not the best way to explore the generation of new data sources and their potential information content. Instead, we employed an SBT-like OM with very similar life-history, overall fishery selectivity, and current spawner abundance properties as the SBT OM. This permitted us to efficiently explore a wide range of future abundance scenarios, as well as a wide range of potential indices given sampling regimes directly relevant to the current SBT situation. We explored three different mean recruitment and overall fishing mortality trends (*status quo*, ±1% log-scale) and crossed them for a total of nine scenarios to obtain a very wide variety of future dynamics for both the stock and fishery from which to generate the new data sources.

In relation to gene tagging, we employed a hypothetical sampling regime with the similar release and recapture properties (overall expected range of recapture numbers) as outlined in the design study [3]. The default assumption was a straight binomial distribution (no over-dispersion at this stage) for simulating the recaptures of age 2 releases, with the associated information loss likely to result from imperfect cohort identification included directly. In terms of indices for more MP related purposes, we explored the correlation of a 5-year moving average of relative age 2 abundance with its simulated counterpart. For all future recruitment and fishing mortality scenarios median correlation over the first 50 years were all at 0.9 levels or above, with the lower 10%iles all above 0.75. These correlations will hold true even if there is some fixed (or lightly varying mean) fraction of the overall recruits that never enter the GAB - absolute abundance may be biased in these extreme mixing scenarios but the relative trend is well represented in the actual empirical data. This suggests the gene tagging data have the potential to be a highly informative recruitment index for use in any candidate MPs.

For the close-kin POP data we explored a variant on the original “cartoon” abundance estimator [6] to generate a relative spawner abundance index. The cohort-specific index, weighted over adult recapture years using the relative number of POPs linked to each year, was compared to a hypothetical survey of spawning abundance with a (non-autocorrelated) observation error CV of 0.3. Both were converted to moving averages with a 7 year time-frame to reduce sampling error effects. For scenarios where spawner abundance was not changing very much over time, the survey marginally outperformed the POP-derived index. For scenarios where spawner abundance was changing quite strongly over time (both up but especially down) the POP-derived index performed at least as well, and sometimes better than, the survey. Median correlations over the first 50 years of the simulation were never lower than 0.4 and sometimes as high as 0.9 for the POP index. An alternative index, focussed on the log-scale linear trend in the two indices over time, performed poorly. The survey performed better, in terms of relative magnitude of correlation, but never exceeded a median correlation of 0.4 - even for strong trends in spawner abundance. A likely reason the POP-derived trend index performed consistently worse than a hypothetical survey is the more temporally complex and compound sampling error (in terms of both adult age sampling and in relation to POPs, given the juvenile and adult samples). Another curiosity relating to the POP index in general is that it will experience a period of precision increase over time as the number of POPs relating to a particular cohort build up in the data set. The impact of this would be observed in a full MP testing context, but this initial work was focussed only on generating the data and their overall information content.

For the HSP data we explored both a relative abundance index (independent of, but complimentary to, the POP index) and a mean adult mortality index also. This is, in principle, made possible by the additional information content inherent to the HSP data. A similar weighted approach as that used for the POP-derived index was used to generate the HSP abundance index, and a 7 year moving average also used to compare to the hypothetical spawner survey. In this case the HSP abundance index universally outperformed the survey across all scenarios: median correlations with true spawner abundance never fell below 0.75 and the lower 10%ile never fell below 0.4. This improvement in performance, relative to the POP index, is driven by both a higher overall number of HSPs relative to POPs (and, therefore, lower variability) and no additional sampling variability arising from having to sample the adults across their age-range (as is the case in the POP framework). The HSP adult mortality index was derived using the relative difference in the distribution of times between birth years for both unrelated and half-sibling pairs. The HSP mortality index was shown to correlate fairly well with mean adult mortality *only* in cases where it was increasing over time. This is because of the asymmetric nature of what happens to the distribution of cohort differences across unrelated and half-sibling pairs when adult mortality changes over time for this particular example.

In terms of operational changes required in the projection component of the current OM to accommodate these new data sources, we will require additional routines in `sbtproj.tpl` to simulate and store in external files similar to the current `sbtOMdata` format. These changes are fairly straightforward, and certainly possible using the current `ADMB` software structure, but will need some care to ensure the temporal build up of data in the POP paradigm, as well as the combination of actual historical and simulated close-kin data (be it POP or HSP related), is correctly handled.

The results in this paper clearly demonstrates that the gene tagging data have the potential to be a very informative data source on relative recruitment levels and, therefore, for use as input data series to candidate MPs. Using them in a manner similar to that employed for aerial survey in the current MP, a 5-year moving average, results in indices that show strong correlation with the true average age-2 abundance over time. As seen clearly in Figure 1.1 the CPUE index exhibits a complicated and highly non-linear relationship with estimated spawner abundance over time. Over the last two decades, and for future spawner abundance levels we are likely to be able to rebuild to over the next two decades, the relationship between CPUE and spawner abundance is very far from being linear. Given the CCSBT has funded the collection and genotyping of future C-K samples, and plans are underway to process historical ones, it makes sense to explore if we can generate actual indices of spawning abundance from these data.

The close-kin POP data have clearly been informative with respect to absolute abundance and adult mortality in the SBT OM [5], and the new HSP data could be very informative also [6]. In this work we have also demonstrated their empirical potential, in relation to indices that can be derived from the raw data and considered as input series to candidate MPs. This would be in addition to their value in either the standalone models [6] or the SBT OM [5] in terms of estimating absolute adult abundance and mortality. From the POPs we can derive a relative spawner abundance index that performs close to, and sometimes better than, a high quality unbiased hypothetical survey with a CV of 0.3. From the HSP data we can derive a relative spawner abundance index that easily outperforms such a survey with a similar CV of 0.3. In combination - i.e. a combined POP and HSP index - we could obtain an index that correlates with true spawner abundance as well as a high quality survey with a CV of 0.2–0.25. In addition to this, using the HSP data we can derive an index that can detect if mean adult mortality is increasing over time, providing a basis to separate causes of decline in spawning abundance.

5 Acknowledgements

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References

[1] Report of the 20th Meeting of the Scientific Committee. CCSBT, Incheon, South Korea, September 2015.

[2] Hillary, R. M., Preece, A., and Davies, C. R. (2016) Reconsideration of OM structure and new data sources for 2017 reconditioning. *CCSBT-OMMP/1609/4*.

[3] Preece, A., Eveson, J. P., Davies, C. R., Grewe, P. G., Hillary, R. M., and Bravington, M .V. (2015) Report on gene-tagging design study. *CCSBT-ESC/1509/18*.

[4] Report of the 22nd Annual Meeting of the Commission. CCSBT, Yeosu, South Korea, October 2015.

[5] Hillary, R. M., Preece, A., and Davies, C. R. (2014) Assessment of stock status of southern bluefin tuna in 2014 with reconditioned operating model. *CCSBT-ESC/1409/21*.

[6] Bravington, M. V., Skaug, H. J., and Anderson, E. C. (2016) Close-kin mark-recapture. *Stat. Sci.* (in press).

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