

Southern Bluefin Tuna Inter-sessional Science 2017-18

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A joint paper was prepared on reconditioning the SBT operating models with Scientists from the National Research Institute for Far Seas Fisheries:

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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 2017/18 included:

- An updated stock assessment, which indicated positive results for stock rebuilding. The current CCSBT stock assessment indicates that current spawning stock biomass (SSB) is 13% (11-17%, 80% CI) of the unfished spawning biomass, up from 9% (8-12%, 80% CI) for the 2014 assessment (SSB is used here as a proxy for the relative Total Reproductive Output (TRO)).
- 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 2017 ESC and technical Operating Model and Management Procedure (OMMP) meetings, SBTMAC and Industry meetings.
- Otolith reading (ageing) and estimates of age-frequency for the Australian surface fishery.

CSIRO prepared a series of papers for the OMMP, ESC and Strategy and Fishery Management Working Group (SFMWG) meetings which were funded through contracts with AFMA, Department of Agriculture and CCSBT. Ann Preece, Campbell Davies and Rich Hillary, from CSIRO, attended the OMMP, ESC and SFMWG 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 2017 and SFMWG 2018 included:

- An updated assessment of stock status
- No modification of the 2018-2020 TAC recommendations (17,647t) in relation to the review of exceptional circumstances.
- Continued support for the CCSBT Scientific Research Programs including collection of monitoring data through gene-tagging and close-kin research projects.
- The work plan and preliminary rebuilding targets for testing candidate MPs in 2018

These outcomes and recommendations were supported by the Commission.

This SBT Inter-sessional Science 2017-18 project covered the planned priority items in the 2017 CCSBT work program, the AFMA SBT strategic plan, and the work up to June 2018 on the CSIRO components of the CCSBT 2018 data exchange, and 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, SBTMAC, Australian Government and Industry and participates in Australian delegation contributions to the workings of the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) Extended Scientific Committee (ESC). In 2017, the major component of the prescribed regular scientific activities of the CCSBT is a fully updated assessment of stock status. The stock assessment includes reconditioning the CCSBT Operating Models with updated since the 2014 stock assessment and new data sources (including the new close-kin parent-offspring-pair (POP) and half-sibling-pair (HSP) data).

The CCSBT is also currently developing a new management procedure which will use a juvenile abundance index from the gene-tagging program. The 2017-18 work involves development of candidate management procedures and consultation with stakeholders on performance and trade-offs. A “Development of Candidate Management Procedures for SBT 2017/18” project, has been funded by the Department of Agriculture and Water Resources. These projects are strongly linked.

2 Need

The CCSBT ESC and inter-sessional science work schedule in 2017/18 included the scientific data exchange, evaluation of exceptional circumstances and indicators, 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.

In addition in 2017 the ESC schedule included an updated assessment of stock status. The stock assessment operating models incorporated new and updated data and agreements from the June 2017 OMMP meeting on the reference set.

The development of a new MP and the intensive domestic consultation associated with this process is a large piece of work, similar to the work undertaken in the years leading up to the 2011 adoption of the current MP. The development of candidate MPs in 2017-18 was covered in a separate project with the Department of Agriculture and Water Resources. Further work will be required after 2017-18 to complete selection and implementation of a new MP. Consultation with the Department, AFMA and stakeholders is an essential component of the MP process.

The SBT inter-sessional science project also included the work on routine otolith archiving, ageing and developing age-length keys for the Australian SBT surface fishery. These data are provided to the CCSBT by each member.

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, technical consultation, ESC and OMMP meetings, inter-sessional webinars, review of exceptional circumstances and provide scientific advice to AFMA, ABARES, Industry and the CCSBT.
2. Prepare and review a fully updated assessment of stock status.
3. Participate in the 2018 CCSBT data exchange.
4. Undertake the routine otolith archiving, ageing and developing age-length keys for the Australian SBT surface fishery and provide data to CCSBT.

4 Results and Discussion

The project results are discussed for each objective below:

4.1 Objective 1: 2017 ESC and OMMP preparation

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

CSIRO prepared and presented a set of papers (including Appendix A.1 – A.4) for the 2017 ESC and technical OMMP meeting (Indonesia), provided advice on the agendas and planning for the 2017 OMMP and ESC meetings and contributed to CCSBT inter-sessional webinars. Preece, Davies and Hillary (CSIRO) participated in a series of planning and consultation sessions with AFMA, ABARES and Industry, providing technical and scientific advice on SBT science activities, progress and work plans. Meetings were held in preparation for the OMMP meeting (14 June, 2017), informally during the OMMP meeting (19-23rd June), at SBTMAC in Port Lincoln (29th June), prior to and at the HSP webinar (18th and 21st July), in Canberra prior to the ESC (14 August, on stock assessment results, meta-rules considerations and MP re-tuning considerations), during the ESC (27 August - 2 Sept, 2017) and SBTMAC (26th September, 2017).

CSIRO (Davies, Hillary, Preece) participated in the June 2017 CCSBT OMMP meeting (Seattle) and September 2017 ESC/OMMP meeting (Indonesia). The CSIRO team led discussions on the 2017 reconditioning of the operating models, methods and results from inclusion of new data in the operating models, the updated stock assessment results and meta-rules considerations of exceptional circumstances (Hillary et al., 2017a,b; Preece et al., 2017a). CSIRO assisted the Australian delegation with rapporteuring of the major technical components of the ESC and OMMP reports. The ESC adopted the stock assessment results and concluded there was no reason to take action to modify the 2018-2020 TAC recommendations (17,647t) in relation to its review of exceptional circumstances.

CSIRO also presented papers to the ESC on recent research (funded through other agencies) on the development of a new Management Procedure (Davies et al, 2017a,b), the 2017 aerial survey (Eveson and Farley, 2017), the gene-tagging program for recruitment monitoring (Preece et al, 2017b; Bradford and Preece, 2017), age –length data from the Indonesian fishery (Farley et al, 2017) and Close-kin findings and genotyping updates (Bravington et al, 2017). A research plan for 2018-19 was provided to AFMA and presented to SBTMAC in Port Lincoln 29 June 2017. CSIRO updated this at the SBTMAC teleconference (26th September, 2017) following discussions at the ESC.

The ESC has proposed:

1. That an additional year is added to the to the MP development timetable to allow for sufficient iterations of consultation and review of performance of candidate MPs with managers and stakeholders.

2. A full reconditioning of the operating models with updated data is conducted after the 2019 data exchange for use in the tuning of the selected MP prior to the 2021-2023 TAC recommendation.

3. There is no lag between setting the TAC and implementation for the 2021-2023 TAC block (the Bali procedure is implemented with a 1 year lag), to allow for the next TAC decision to be delayed until 2020. This will primarily impact Australia because the TAC for 2021, which is implemented in Australia in December 2020, will be set by the Commission in October 2020.

During the ESC additional information was provided on the maturity research undertaken by members and the numbers of samples collected (Farley and Eveson, 2017; Farley et al. 2014). Australia is leading this work, defining the sample collection design and methodology for reading the histology. There is excellent engagement on this project across the members and a CCSBT workshop has been proposed for 2019, to meet and share the histology results from each of the fisheries, and develop a maturity schedule. The maturity schedule will be used in the close-kin analyses and will also be used to provide stock status advice using the more familiar term of spawning stock biomass (in addition to reporting relative total reproductive output (TRO)).

In addition to the progress made at the 2017 ESC (Preece, Davies and Hillary) have participated in a series of planning and consultation sessions with AFMA, ABARES, the Department and Industry, providing technical and scientific advice on development of a new management procedure. In preparation for the CCSBT's Strategy and Fishery Management Working Group (SFMWG) meeting (March 2018), CSIRO prepared a paper to guide discussion (Davies et al., 2018) and background briefing notes for the Australian delegation. In preparation for the OMMP meeting (Seattle, June 18-22nd 2018) CSIRO hosted a meeting for AFMA, ABARES and the Department (29th May 2018, Hobart) to discuss progress in development of candidate management procedures. The MP development project is funded by the Department of Agriculture and Water Resources and CSIRO.

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 and research priorities.

4.2 Objective 2. Updated assessment of stock status.

Prepare and review the 2017 stock assessment with reconditioned Operating Models (OM).

CSIRO updated the reconditioning of the operating model, ran diagnostics on the fits to data, and ran the agreed reference set of models and sensitivity tests defined at the OMMP meeting in June 2017. Advice was provided to Australia on the updated assessment of stock status. A joint paper was prepared with Japan (Hillary et al., 2017b) on the updated stock assessment for presentation to the CCSBT ESC. Interpretation of the results of the stock assessment was included in the meta-rules paper (Preece et al, 2017a) and discussed in preparatory meetings with AFMA, the Australian government, ABARES and Industry (Canberra, 14th August).

The full stock assessment included all the newly available close-kin data (Bravington et al, 2017), including the new half-sibling pair data that have not previously been incorporated in the operating models. These data came from the backlog of samples that had been collected since the completion of the first close-kin project for SBT. The genotyping method provided additional information that allowed for the detection of half-sibling pairs and other kin relationships. These

data were incorporated into the model after the OMMP meeting in June, and a webinar was held to discuss the formulation for their inclusion in the model, and fits to the data.

The stock assessment results, for the first time, show signs of rebuilding of the spawning stock biomass (SSB). Results in the paper are provided in terms of the relative total reproductive output (TRO) of the stock, but here we use SSB as a proxy for TRO. SSB is estimated to be between 11% and 17% of the initial SSB (SSB_0). It has risen in the last 2 stock assessments: 2011 3-8%, 2014 7-12%. Estimates of recent recruitments, observed in the aerial survey, are well above average. The 2017 aerial survey abundance estimate was above the average but lower than the very high 2016 estimate, and will be the last in the series as the survey will not be funded from 2018 onwards (Eveson et al., 2017). It will be several more years before the strength of these recruitments are corroborated by data from the longline fisheries, as these cohorts are only just becoming available to these fisheries.

Projections using the Bali Procedure (the currently adopted MP), indicate that rebuilding may be more rapid than originally anticipated. If confirmed, this higher than expected rate of rebuilding may cause some difficulties for tuning and comparing performance of candidate management procedure. Therefore, the SFMWG has discussed objectives for the post-rebuilding stage to incorporate into the development and testing of a new MP. These issues were discussed prior to, and at, the SFMWG meeting in March 2018, and will require substantial ongoing consultation with AFMA, the Department of Agriculture and Water Resources, Industry and other stakeholders (Davies et al, 2017; 2018). A plan for consultation in 2018 has been developed. The development of candidate MPs is funded by a project with the Department (DAWR).

4.3 Objective 3. Participate in the 2018 CCSBT data exchange.

CSIRO has provided to the CCSBT data exchange the raised catch at age for the Australian surface and longline fisheries and direct ageing data for the Australian surface fishery. The Japanese longline nominal CPUE series will be provided in June 2018, soon after the CCSBT provides the CPUE input data file (due 15th June).

All the updated data required for the OM have been exchanged. New data including new close-kin data and the first juvenile abundance estimate from the pilot gene-tagging program have also been exchanged. The SBT OM will not be reconditioned in 2018, instead the focus of the OMMP meeting is examination of the first candidate management procedures, and discussion of targets and performance measures.

Data files and software for running candidate MPs that use the new gene-tagging and close-kin POPs and HSP data have been updated. The code and structure for these files will be discussed at the OMMP meeting (June, 2018). Details have been provided to the OMMP Chair and technical working group email list maintained by the CCSBT. Preliminary discussion of technical issues was held in the margins of the SFMWG meeting in Canberra, March 2018, with the Advisory Panel (Ana Parma and Jim Ianelli) and Dr Itoh from Japan.

4.4 Objective 4. Australian surface fishery age frequency

Undertake the routine archiving, ageing development of age-length keys for the Australian surface fishery and provide data to CCSBT

The report for the 2016-17 ageing project was presented at the CCSBT ESC (Farley and Eveson, 2017). Over 100 otoliths have been collected and archived from the Australian surface fishery in 2018. Age (from otolith reading) and length data for the Australian surface fisher in the 2017 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.

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 7 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 2017, through this project, CSIRO provided an updated assessment of stock status and substantial input to the 2017 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 2017 stock assessment provides information on management and progress in rebuilding the SBT stock. In the meta-rules context is the stock assessment is used to identify exceptional circumstances and potential impacts for consideration of actions to modify TAC. No actions were recommended.

The 2017 stock assessment 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.

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 2018. 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 2017-18 project covered the identified priority items of SBTMAC for the 2017 CCSBT work program, and the work up to June 2018 on the CSIRO components of the CCSBT 2018 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 2017 OMMP technical meeting and ESC meeting, and provided briefings, consultation and advice to AFMA, ABARES, Industry and SBTMAC.

The 2017 stock assessment indicates that the stock is rebuilding and recent recruitments are above average. The size of the recent high recruitments will not be confirmed until these cohorts are fished in the longline fishery.

The Extended Commission has requested that the ESC transition to a new Management Procedure that will use gene-tagging data as the recruitment index. 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 new schedule for MP development aims to adopt a new MP in 2019 and use this to set the TAC in 2020.

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 2017 funding decisions and approach to the future work program.

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8 Appendices

- A.1 Hillary RM, Preece AL, Davies CR. 2017a. Updates required for new data sources and reconditioning of the CCSBT OM. CCSBT-OMMP/1706/4, 8th Operating Model and Management Procedure Technical Meeting, 19-23 June, Seattle U.S.A.
- A.2 Hillary RM, Preece AL, Davies CR, Takahashi N, Sakai O, Itoh T. 2017b. Reconditioning of the CCSBT Operating Model in 2017. CCSBT-ESC/1708/14, Twenty Second Meeting of the Scientific Committee, 28 August - 2 September, Yogyakarta, Indonesia.
- A.3 Preece AL, Davies CR, Hillary RM. 2017. Meta-rules and exceptional circumstances considerations. CCSBT-ESC/1709/15, Twenty Second Meeting of the Scientific Committee, 28 August - 2 September, Yogyakarta, Indonesia.
- A.4 Farley J, Eveson P. 2017. An update on Australian otolith and ovary collection activities, direct ageing and length at age keys for the Australian surface fishery. CCSBT-ESC/1708/11, Twenty Second Meeting of the Scientific Committee, 28 August - 2 September, Yogyakarta, Indonesia.

Appendix A.1

Hillary RM, Preece AL, Davies CR. 2017a. Updates required for new data sources and reconditioning of the CCSBT OM. CCSBT-OMMP/1706/4, 8th Operating Model and Management Procedure Technical Meeting, 19-23 June, Seattle U.S.A.



Updates required for new data sources and reconditioning of the CCSBT OM

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CCSBT-OMMP/1706/4

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Abstract

The CCSBT will be undertaking a stock assessment this year. The new MP development program will require both a reconditioning of the CCSBT OM and the inclusion - and future simulation - of new data sources. There are updates to longstanding OM data sets (catch composition, CPUE, aerial survey) as well as more parent-offspring-pair close-kin data. There are also completely new data sources coming online now (the half-sibling pair close-kin data) and for next year (the first gene tagging data). In this paper we detail the changes made to the current suite of OM code (conditioning and projection) to accommodate and then simulate these new data sources. We also outline an initial reconditioning of the OM given the available data sources to assist in defining the relevant structure and settings of the OM for the presentation of the stock assessment at the coming ESC meeting.

1 Background

The current timetable for the immediate work program of the ESC is: (i) stock assessment this year, including new and updated data sources; (ii) development of methods for generating data to be used in the MP testing work starting in 2018; and (iii) adoption and implementation of a new MP in 2019 [1, 2]. This paper will cover the continuance of the first two work items - the stock assessment/reconditioning of the OM and data generation.

2 Material & Methods

This section is itself split into three main sections dealing with new and updated data sources, changes required to the conditioning code to accommodate these data, and finally changes required to the projection code to simulate them in the MP testing context.

2.1 Data: new and updated sources

2.1.1 Aerial survey

The last stock assessment in 2014 [3] contained survey data up to and including 2014. For this year we will have new data for 2016 and 2017, but none for 2015 given the survey was not undertaken that year. Figure 6.1 summarises the mean-standardised survey data up to and including 2017 data. As before, the 2014 survey was about twice the historical mean; the 2016 index was just over 4 times the historical mean; and 2017 was just under twice the historical mean.

Looking at the most recent years of Figure 6.1, while we do not have the 2015 data point, there is an apparent indication of sustained higher than average recruitment covering the 2011–2015 cohorts (assuming ages 2 to 4 in the survey data).

2.1.2 CPUE

The new data has been circulated in papers and via the information in the CPUE webinar in early June 2017.

2.1.3 POPs

The original POP data were generated using microsatellites, and contained information on the spawning abundance for 2002–2007 (because these are the cohorts of the juveniles in the original samples). The new POP data are generated using single nucleotide polymorphism (SNP) approaches, where we now have thousands of loci from across the genome. We do not propose to go into an in-depth report of the various pieces of detailed work that go into generating these data, merely a summary of what we found at a level relevant to the OM reconditioning work - see [4] for the details.

The new SNP-derived POP data does have some overlap with the previous data set, in terms of juvenile and adult coverage. Obviously, we genotyped all the previous POPs to ensure we could detect them

again this time around, and for adult capture year 2010 and juvenile cohorts 2002–2007 there was some overlap. To avoid potential double counting, we simply excluded data in the most recent SNP set that overlapped with the previous microsat data, thus making it simple to append the SNP data to the original data and include it in the updated OM without any additional changes being required.

For the updated SNP data (minus the overlap with the previous microsat data) we found 32 additional POPs, given 40,542,889 comparisons (previously we found 45 POPs given 38,180,182 comparisons). Overall, the simple empirical POP “index” (ratio of comparisons to POPs with summation across adult ages and capture years) is a little higher now than before, suggestive of slightly more optimistic signals, but is consistent in trend where there is cross-over with the previous POP data (see Figure 6.2). Given the complex role adult age-structure plays in the dynamics of POPs we do not infer anymore from the index summarised in Figure 6.2, and this is covered off in the detailed summary of the fits to the POP data later on. Table 2.1 summarises the number of comparisons at the juvenile cohort and adult capture year aggregation level, and Table 2.2 summarises the POPs at the same level.

	2006	2007	2008	2009	2010	2011	2012	2013	2014
2002	31	204	213	200	168	0	0	0	0
2003	275	1826	1912	1789	1504	1410	765	1387	1340
2004	361	2324	2381	2290	1971	1380	749	1358	1312
2005	300	1986	2071	1947	1640	1422	772	1399	1352
2006	0	1856	1944	1816	1530	1394	757	1372	1325
2007	0	0	2070	1939	1633	1387	758	1375	1328
2008	0	0	0	0	984	986	535	970	937
2009	0	0	0	0	952	954	518	939	907
2010	0	0	0	0	0	944	513	929	898
2011	0	0	0	0	0	0	512	928	897
2012	0	0	0	0	0	0	0	958	926

Table 2.1: Number of juvenile-adult comparisons (in thousands) aggregated by juvenile cohort and adult year of capture.

	2006	2007	2008	2009	2010	2011	2012	2013	2014
2002	0	0	0	0	0	0	0	0	0
2003	0	5	1	2	0	0	0	1	0
2004	0	2	0	0	3	0	0	0	0
2005	1	4	5	4	1	0	1	1	2
2006	0	4	3	2	0	0	0	0	0
2007	0	0	3	4	1	3	2	0	2
2008	0	0	0	0	0	1	1	1	0
2009	0	0	0	0	0	1	1	1	0
2010	0	0	0	0	0	3	1	4	0
2011	0	0	0	0	0	0	1	2	1
2012	0	0	0	0	0	0	0	1	1

Table 2.2: Number of POPs aggregated by juvenile cohort and adult year of capture.

2.1.4 HSPs

The detail on the HSP detection progress can be found in [4].

2.2 Changes to OM conditioning code

2.2.1 Population dynamics

The only change we suggest to the actual population dynamics is how we define the relative reproductive output-at-age for the population. Before the CKMR data it was basically a step function that was proportional to weight above age 10 and zero below it. We modified this for the original CKMR model, given obvious signs that there were clearly parents aged less than age 10, and where the apparent output of offspring was skewed more towards older/larger animals than weight-at-age suggested. The basic idea behind the original formulation of how we calculate the RRO-at-age will be the same. Now though, instead of being pre-calculated and included within the OM as a fixed vector, it will be calculated within the OM, take account of the changing distribution of length-at-age over time, and have a control parameter included directly in the grid. The reasoning behind accounting for the changing length-at-age over time is because the fundamental assumption is that length is the primary driver of the reproductive dynamics, but age is the currency of the OM.

The core idea behind the drivers of the length-specific version (implicitly grouping sex), φ_l , are the same as before:

$$\varphi_l \propto w_l^\psi m_l,$$

where w_l and m_l are the length-specific weight and maturity relationships. The current model for m_l is a logistic relationship with $l_{50} = 150$ and $l_{95} = 180$ as previously used. The power parameter ψ is specifically there to permit cases where effective fecundity-at-length can be greater ($\psi > 1$) or less ($\psi < 1$) than proportional to weight - for example the notion of SSB would be $\psi = 1$. The current fixed value of $\psi \approx 1.72$ which was essentially chosen after looking at the predicted and observed POP adult age distribution, and was consistent with the stand-alone CKMR model in that the effective output of older/longer animals was far greater than a $\psi = 1$ model would have predicted. The reason for formally including it as a grid parameter is because, with the additional POP data over a long-time frame (we will have more POPs and more temporal coverage), we could - and arguably should - be estimating this key parameter. CKMR design work we have been doing here at CSIRO has demonstrated that you can, in principle, jointly estimate adult abundance, mortality and a parameter such as ψ fairly well with POPs, HSPs, and adult age data.

This defines the length-based setting for φ but we now need to translate this into an age-specific relationship for the OM. In the OM we have a time-dependent distribution of length-at-age, $\pi_{l|y,a}$, and following the idea that it is length that is the key driver for the reproductive dynamics, this implies we *should* be considering a time-varying setting for φ_a . This is calculated as follows:

$$\varphi_{y,a} \propto \int \varphi_l \times \pi_{l|y,a}, dl. \quad (2.1)$$

so that we integrate over the year-specific distribution of length-at-age to get the expected value of RRO-at-age for that year. As before, everything is normalised by the maximum value for each year so that $\varphi_{y,a}$ is an ogive having values between 0 and 1. The spawning potential in each year is then effectively a weighted sum of spawning adults:

$$S_y = \sum_a N_{y,a} \varphi_{y,a}.$$

To bring the ψ parameter into the grid is, we feel, a sensible first step to trying to estimate the parameter. It may be possible in later assessments to treat ψ as a fully free parameter (like M_4 or M_{30}), but it perhaps make sense to start with a grid approach for now (so we can use prior vs. likelihood weighting initially to explore information content). We propose an initial grid vector of three values: $\psi^{\text{grid}} = \{1.5, 1.75, 2\}$. Figure 6.3 shows the three associated vectors ϕ_a (including the current vector) for the most recent distribution of length-at-age, encompassing the CK data in the OM.

The range of values for φ_a is not large - for a total mortality $Z = 0.2$ the range in per-recruit spawning potential is about 20–25%. As with all grid elements, we can look at prior and likelihood weighting,

and augmenting or fundamentally changing the range as required. We just felt that this initial range encapsulated the historical values, while allowing for some uncertainty therein and a chance to explore information content in a stable fashion at first.

2.2.2 Revised grid configuration

At the moment we have a 6- d grid: $\theta^g = \{h, M_0, M_{10}, \omega, I^{\text{cpue}}, a^{\text{cpue}}\}$ with dimensions $5 \times 4 \times 4 \times 1 \times 2 \times 2 = 320$ unique combinations. Augmenting the grid $\theta^g = \{h, M_0, M_{10}, \omega, I^{\text{cpue}}, a^{\text{cpue}}, \psi\}$ and with 3 possible values for ψ would be a grid of size 960 (which is a lot). We propose a coarsening of the grid for steepness and M_{10} to ameliorate this augmentation to the grid:

- For steepness, instead of $h = \{0.55, 0.64, 0.73, 0.82, 0.9\}$, we propose $h = \{0.55, 0.67, 0.78, 0.9\}$ so a reduction from 5 to 4 elements
- For M_{10} , instead of $M_{10} = \{0.05, 0.075, 0.1, 0.125\}$, we propose $M_{10} = \{0.05, 0.085, 0.12\}$ so a reduction from 4 to 3 elements

This would give us 576 grid combinations, versus 320 as before but far less than the full 960 if we just added ψ into the grid and changed nothing else. We only sample from a uniform prior for steepness at the moment, so if we maintain the range (as above) but simply have one less element in the grid, we obtain the variation in resilience we had before without any obvious information loss or bias. For M_{10} , the most sampled values are the lower values, 0.05 and 0.075, with a much lesser weight being assigned by the OM to 0.1 and 0.125 at the moment. We feel we can sensibly reduce the number of options by 1 grid element, while again maintaining the sampled range. Any impacts of these changes can be evaluated in the proposed staged reconditioning of the OM, relative to the 2014 reference set and associated robustness tests.

2.2.3 HSP likelihood

In the two main OMMP papers on OM changes [5] and data generation [6] from last year we outlined what the HSP probability (when comparing juveniles belonging to different cohorts) would look like. It's worth restating that general probability here, and then outlining some of the modifications and accommodations we are likely to need to make in the OM log-likelihood to deal with the real world data.

For a number of reasons (highly variable larval survival of siblings, confusing N with effective breeding population N_b) we avoid doing within-cohort comparisons. When comparing juveniles i and j - belonging to cohort c_i and c_j , respectively - we only consider $c_i \neq c_j$. The probability of these two juveniles being HSPs (sharing a mother *or* a father) is:

$$p^{\text{hsp}} = \frac{4Q^{\text{hsp}}}{S_{c_{\text{max}}}} \left(\sum_a \left[\gamma_{c_{\text{min}},a} \exp \left(- \sum_{y=c_{\text{min}}}^{c_{\text{max}}-1} Z_{y,a+y-c_{\text{min}}} \right) \varphi_{y+\delta,a+\delta} \right] \right), \quad (2.2)$$

$$\gamma_{y,a} = \frac{N_{y,a} \varphi_{y,a}}{S_y}, \quad (2.3)$$

$$\delta = |c_i - c_j|, \quad (2.4)$$

$$c_{\text{min}} = \min\{c_i, c_j\}, \quad (2.5)$$

$$c_{\text{max}} = \max\{c_i, c_j\}. \quad (2.6)$$

In terms of an explanation of the various pieces of the HSP probability: we don't see the adult in this scenario, so we must integrate over all possible adult ages $\gamma_{c_{\text{min}},a}$ in the earliest cohort; we then account for the probability that an adult survives to the birth of the second, younger fish at time c_{max} (terms involving Z); we then, accounting for any additional increases in relative fecundity over that period between birth years, calculate the relative reproductive output of the adult at the time of birth of the later cohort ($\varphi_{y+\delta,a+\delta}$ and the term in $S_{c_{\text{max}}}^{-1}$ at the front). The factor of 4 comes from the following implication of

assuming a 50/50 sex ratio: If $N_{\sigma} = N_{\phi} = N/2$, then for the within-cohort case (even though we avoid it, but that doesn't affect the argument) then the probability of being either a maternal (share a mother) or paternal (share a father) HSP is $p^{\text{hsp}} = 1/N_{\sigma} + 1/N_{\phi} = 2/N + 2/N = 4/N$. So, the factor of 4 just comes from implicitly assuming a 50/50 sex ratio in the OM. If either the updated POPs *and/or* the HSP mtDNA data suggest this is not likely to be a reasonable assumption, we may need a pseudo-sex specific model to accommodate that, but we won't know that until we fit the models and look at the mtDNA results and see whether they are compatible with an approximately 50/50 sex ratio.

In an ideal situation, the HSP probability would define the Bernoulli likelihood in the OM for each individual comparison between juveniles i and j . The probability is the same for all such comparisons where the two key covariates, c_i and c_j are the same, so we can group these comparisons together into a binomial likelihood with probability p^{hsp} and sample size $n_{c,c'}$, which is just the total number of juvenile comparisons done between fish from cohorts c and c' . This would be feasible **if** we could cleanly identify **every** single HSP without there being any chance of false positive contamination from genuinely unrelated pairs or other types of kin (primarily half first-cousins or half auntie/uncles).

The original microsat approach to finding POPs used Mendelian exclusion - true POPs should share at least one allele at all locations. This resulted in a set of clear POPs (with a false positive rate of less than 1 POP) for that particular data set. With HSPs and SNPs (as opposed to microsats) the issue is a bit more complex. In the genetic inheritance sense, at any given locus we either share 0, 1 or 2 alleles that are identical by descent (IBD). A unique weight vector $\mathbf{k} = \{k_0, k_1, k_2\}$, which sums to 1, determines the chance that two individuals share alleles that are IBD at a given locus for all the different kin types (unrelated, parent-offspring, half-sibling etc.). For two unrelated individuals (UP) $\mathbf{k}_{\text{up}} = \{1, 0, 0\}$; for a POP $\mathbf{k}_{\text{pop}} = \{0, 1, 0\}$; for a full-sibling pair (FSP) $\mathbf{k}_{\text{fsp}} = \{0.25, 0.5, 0.25\}$; and for an HSP $\mathbf{k}_{\text{hsp}} = \{0.5, 0.5, 0\}$.

Using this information, we can construct a likelihood based statistic that can help us find if a specific comparison pair of individuals is actually of a specific kin type (e.g. HSP), relative to them being assumed to be unrelated (i.e. an UP). Specifically, we construct something called a pseudo log-odds ratio (hereafter PLOD) summed across all loci for a given comparison kin test (UP vs. HSP) between fish i and fish j : $\text{PLOD}(i, j \mid \text{HSP})$. This all sounds a bit esoteric at this point so we've included an example with a small data set. With SBT there are millions of comparisons and any summary plot would both be too big and impossible to see. However, for a PLOD summary plot (Figure 6.4) looking for HSPs in a sample of 116 juvenile river sharks (*Glyphis glyphis*) from a river in Northern Australia, the principle is much clearer to see we think. For n samples, there are $n(n-1)/2$ unique cross-comparisons so here we have 6,670 in total.

Looking at Figure 6.4 you see the vast majority of samples are distributed around the blue dotted line in the lower half of the figure. This is where the allele frequency model and the \mathbf{k}_{up} IBD model expects unrelated pairs' (UPs) PLODs to be, and that is where they appear. In the upper half of the figure we see the dotted magenta line which is where we would expect the HSP PLOD to be. If we had more loci (there are 1,500 used here as with the SBT SNPs this time around) there would be no overlap between the UPs and less related animals (cousins and uncles/aunties) at the bottom of the figure, and the true HSPs in the top of the figure. The threshold value of the PLOD at which we would not expect to see any true UPs is around -0.004. So, anything appearing above this line would be expected to be an related (in some way) pair - the three closest candidates being half cousins (HCPs who share a grandparent), half auntie/uncles (half-thiatric pairs or HTPs), or HSPs (and no more if all the repeat fish and FSPs have been removed). Look above this UP false-positive threshold level though and we see a disperse but continuous cloud of comparisons until we hit the likely true HSPs levels at the top of the plot. What we want is a threshold value of the PLOD statistic, call it η , such that we would expect to find effectively zero non-HSP kin (HCPs, HTPs) above this level - i.e. only HSPs. The cut-off for HCPs is just below the zero line; for HTPs (the most extreme cut-off) is around 0.008. So, in terms of the data we actually will use, we take

the comparisons above this cut-off of $PLOD > \eta \approx 0.008$ and discard any below this.

This is us actively controlling the false positive rate so that we have effectively less than 1 non-HSP appearing in the HSP data. The usual drawback in these cases is that you can control for false-positive rates, but you have to live with the resultant false-negative rate - this will definitely not be zero unless you are very lucky. We will discard some true proportion of the total set of HSPs and that needs to be reflected in the likelihood. What we need in the likelihood calculations later is the following: $\mathbb{P}(PLOD_{i,j} \leq \eta | HSP)$. This is the proportion of **true** HSPs we expect to lose by having to set η high enough so that we have effectively zero non-HSPs appearing in the pairs with PLODs above this threshold level. We calculate this probability in a two-step way:

1. Using the comparisons that appear above the magenta line ($\mathbb{E}(PLOD | HSP)$), compute the 1-sided variance as an estimate of the true variance $\mathbb{V}(PLOD | HSP)$ (which we can't predict theoretically, unlike for the UP case)
2. Assuming a normal distribution for the HSP PLOD statistic, calculate the probability of a true HSP PLOD being below η : $\mathbb{P}(PLOD_{i,j} \leq \eta | HSP)$

The quantity we need in the log-likelihood is $\pi_\eta = 1 - \mathbb{P}(PLOD_{i,j} \leq \eta | HSP)$ - i.e. the proportion of true HSP values found above a PLOD threshold of η . For each $\{i, j\}$ comparison group, we then modify the base probability in the binomial likelihood as follows:

$$\ell(k_{i,j} = HSP | \eta, \mathbf{z}, \dots) \propto \left(\pi_\eta p_{i,j}^{\text{hsp}}\right)^{K_{i,j}} \left(1 - \pi_\eta p_{i,j}^{\text{hsp}}\right)^{n_{i,j} - K_{i,j}}, \quad (2.7)$$

where $K_{i,j}$ is the number of comparisons with a PLOD above the cut-off η , and $n_{i,j}$ the total number of comparisons for the given covariates $\mathbf{z} = \{c_i, c_j\}$. So, what we are really modelling is not the HSP probability, but the probability of having a particular comparison's PLOD above the cut-off η . As with the POP likelihood, we have assumed a Bernoulli base likelihood, which forms into a binomial given the comparison grouping. This would be easy to extend to being a beta-binomial likelihood if required and we don't detail the algebra here.

There are a few select ways that could bias the information in the HSP data, with respect to absolute abundance. The first is non-HSP kin contaminating the sample, and we've outlined how to take care of that in the previous section. We calculate the relevant PLOD cut-off, η , and use only comparisons with a PLOD above this level. The resultant false-negative loss-rate is also factored into the likelihood. There will, however, given the empirical nature of the estimate of $\mathbb{V}(PLOD | HSP)$ and the choices required to choose the cut-off value, η , be some uncertainty in this estimate. This will get taken up in the estimate of q^{hsp}

Another plausible factor would be unexpected spawning-related juvenile dynamics. Specifically, we do not mean just the alternative juvenile dispersal hypotheses we explore in the gene tagging design work [7]. We mean a more complex situation where there are specific adults who spawn at a specific site/time, whose offspring recruit to say the GAB, and another subset of distinct set of adults who spawn at alternative sites/times whose offspring recruit to somewhere other than the GAB, and *never* spend time in the GAB as a juvenile. In this scenario, what we are really doing by sampling only the GAB-recruiting animals is effectively measuring the size and demography of the adults whose juveniles recruit to the GAB. For the POP data, we will still have something potentially strange going on by only looking at GAB juveniles *but* we would have covered all the spawning adults when doing so, and any bias would be different to the HSP case (where we are potentially indirectly looking only at a subset of spawning adults). Such an issue could be explored by sampling juveniles that were demonstrably *not* in the GAB during summer.

The one effect that we can probably say is likely to be true with the information we have now, and one where we can actively explore the level and direction of the bias, is individual variation in reproductive success. In this document, we assume length to be the key driver of reproductive success - itself a proxy

for weight really and keep this in mind for later. In the OM we integrate over the population distribution of length-at-age to get the expected age-specific relative reproductive output $\varphi_{y,a}$. However, if we assume (as contemporary growth models often do) that each animal has a specific length-at-age relationship, we are introducing a bias into the HSP probability. It's not a bias in the POP probability, but a source of over-dispersion. However, for HSPs we account for relative reproductive output *twice*: once at the birth of the older fish, and again at the birth of the younger fish. This bias effect is something akin to 'unmodelled heterogeneity in the probability of recapture' in mark-recapture models. Individual variation in RRO compounds here (sort-of-quadratically) in a way that it does not for the POP case. Using a basically identical life-history we simulated what effect this might have for SBT:

- Simulate HSP data with a resultant detection rate (i.e. number of comparisons to abundance ratio) the same as the current sampling program for SBT
- For one case, assume the population-level relationship for $\varphi_{y,a}$; for the other case sample a specific vector of $\varphi_{y,a}$ for each putative adult in the simulated comparisons (given φ_l and $\pi_{l|y,a}$)
- For both cases, back-estimate adult abundance and mortality

Our initial explorations suggest that, as we would expect, adult mortality is unbiased by this effect if it is not strongly dependent on length, but it can be dependent on age (senescence). There is a small positive bias in the estimates of adult abundance (not more than 5%), so we might be weakly over-estimating adult abundance if we ignore the effect. One major caveat is that this is the extreme case we consider here: we assume length as a proxy for weight and that this dominates the RRO relationship-at-age. When actually looking at the weight-at-length data in the adults, we actually see a weak *negative* correlation between observed length and individual values of the b parameter in the $w_l = al^b$ relationship. This suggests that, at least for SBT, there is some indication that lifetime shorter/longer animals are fatter/thinner in a relative sense (i.e. their 'condition' parameter b), which would - if weight is really the fecundity controller - act to ameliorate this effect in the HSP data.

For now, we recommend keeping q^{hsp} as a fully estimable parameter in the first exploratory round of including the HSP and the POP data together. If $q^{\text{hsp}} \approx 1$ and at levels we saw for the simulation testing, we feel we have some idea what might be causing it to differ from 1. If it is - for whatever reason - significantly different from 1 then we need to discuss why this might be the case. Having it as a fully estimable parameter will obviously reduce the HSP information content with respect to absolute adult abundance, but **not** on trend and adult mortality. We have the POP data for absolute abundance and relative reproductive output, so this might be a conservative but sensible route at this stage - in terms of actively estimating q^{hsp} in this round of work.

2.2.4 Gene-tagging likelihood

The nature of the gene tagging estimator (modified Petersen-type estimate) as well as the proposed likelihood structure (beta-binomial with over-dispersion and - eventually - tuned control parameter) have already been detailed in [5].

2.3 Changes to OM projection code

There are only minor changes required to the population dynamics code in the projection module to accommodate the new definition of RRO-at-age, $\varphi_{y,a}$. We make the usual assumption that the most recent values continue to be used into the future (as future growth and selectivity are currently defined). Major changes will, however, be required to simulate the GT and the POP and HSP data. Each data source is sample-size driven, which is itself a control variable that the CCSBT and its member scientists have differing degrees of influence over.

For the GT program, we have target levels of initial releases and follow-up catch sampling numbers the following year. The initial release numbers will be somewhat variable, given this is a highly dynamic

sampling arena (the GAB), and something we are going to improve at over time. For example, in 2016 we tagged almost 4,000 fish; in 2017 we tagged over 7,500 fish. The catch sampling part of the program is a more controllable process, and likely something we can expect to be less variable than the release side of the field operations. One of the primary motivations of the initial sample size numbers is to attain a general total level of samples in the 15,000 range, so the catch sampling can be modified if a short-fall in releases occurs, and we can “double-dip” the HSP CKMR juvenile samples at the catch sampling end of things if required. At the OMMP we can discuss a sensible set of scenarios from which to define simulation protocols for the GT sample sizes that cover off on this type of inherent variability - and associated catch sampling modifications - we are going to observe. In terms of simulating the data for a given sampling regime, we will use the likelihood function but also consider some additional robustness trials exploring potential bias scenarios [7].

For the close-kin sampling programs, these are more controllable than the GT case. The program samples M_i adults and M_j juveniles (within the age 3 length range) in Indonesia and Port Lincoln, respectively. The initial POP data compared adults and juveniles *only*, and the initial HSP data set will be juvenile-juvenile comparisons for now. Once these data are fitted within the model, we have a functional likelihood for both from which to simulate the data. We can also explore adaptive schemes for both the adult and juvenile sampling schemes to see what difference these make both in terms of overall POPs and HSPs found in the future, and the effect this might have on an MP using these data. One consideration, in this respect, is whether it would be sensible to explore the sample sizes required to have a reasonable expectation of a minimum number of POPs and HSPs for each cohort covered in the samples.

3 Results

We have broken down the results section in three main subsections:

1. How to get from where the OM results placed us in 2014 to the present, when we have a variety of new and updated data and structural changes planned for both the OM population dynamics model and the grid
2. Preliminary results and fits to the data for the putative reference set of OMs
3. Implications arising for data generation and the MP testing process for 2018

3.1 Preliminary results arising from reconditioning the OM

The suggested updated grid structure we used for the OM results presented in this subsection is summarised in Table 3.1. This is actually a modified grid, relative to the one suggested in Section 2.2.2 due to the fact that a large proportion of runs with $h = 0.55$ crashed on initial model explorations. This is presumably being driven by: more POP data and an overall slightly more optimistic outlook from these data; the two new aerial survey data points that suggest recent recruitment is well above the average; and recent CPUE data now at levels seen in the 1980s. The grid combinations with the lowest steepness are almost always the most pessimistic in terms of stock status and recent trends therein, so it is not that surprising that these values are generally incompatible with the updated data.

The final number of grid combinations is now 432 (versus 320 in 2014) and, in combination with the updated data and OM changes, takes a little longer to run a full set than before, though not significantly (something like 3.5–4 hours on a recent laptop with decent specifications).

Figure 6.5 shows the absolute spawner abundance and spawner depletion summaries (median and 80% PI) for the **base2016sqrt** grid and data configuration and Figure 6.6 shows the recruitment summary.

All fits presented are for the best-fitting grid cell. The fits to the relative abundance indices (long-line CPUE and the aerial survey) are summarised in Figure 6.7. The fits to the tagging data (aggregated to the cohort-of-release and recapture-age level) are summarised in Figure 6.8. Figure 6.9 summarises the

Parameter	Values	CumulIN	Prior	Sampling
h	0.65, 0.78, 0.9	3	uniform	Prior
M_0	0.35, 0.4, 0.45, 0.5	12	uniform	ObjFn
M_{10}	0.05, 0.085, 0.12	36	uniform	ObjFn
ω	1	36	uniform	Prior
CPUE	w0.5, w0.8	72	uniform	Prior
CPUE ages	4–18, 8–12	144	0.67, 0.33	Prior
ψ	1.5, 1.75, 2	432	0.25, 0.5, 0.25	Prior

Table 3.1: *New suggested grid structure for the OM.*

fits to the updated POP CKMR data at two aggregation levels: (i) the juvenile cohort level (aggregated across adult capture year and age); and (ii) the adult capture age level (aggregated across adult capture year and juvenile cohort). The juvenile cohort aggregation level will show if we are systematically over or under-estimating overall adult abundance. The adult capture age aggregation level will show whether we are getting the adult age structure in the POPs about right and, hence, the RRO-at-age model ($\varphi_{y,a}$) is adequate. Figure 6.10 details the fits to the age data sets (Indonesian and surface fisheries). Figure 6.11 details the fits to the length data sets (fisheries LL_{1-4}).

Fits to the long-line CPUE data are good (Figure 6.7), with the observed data -barring the historical minimum in 2007 - falling within the predicted 95% range. Fits the aerial survey data (Figure 6.7) are similar to before, with some of the lower points and the historical high of 2016 sitting outside the predicted 95%ile, but the overall trend fitted fine. The fits to the tagging data (Figure 6.8) are good and qualitatively unchanged from previous years - some minor tension between the 1994 and 1995 release cohorts, but the major recapture cohorts (1996 and 1997) are fitted well. The updated POP data are fitted well (Figure 6.9) at both the juvenile cohort and the adult capture age aggregation levels. This suggests that we are not over or under-estimating current spawning abundance as informed by the POP data. It also suggests we are getting the adult age structure in the POPs correct, and we can have some faith in the $\varphi_{y,a}$ parameters in defining the age-structure of the relative reproductive out (RRO). Fits to the fisheries with age data (Indonesian and surface) are generally good (Figure 6.10). Fits to the fisheries with length data (long-line fisheries LL_{1-4}) are similar to previous years. Fits to LL_1 and LL_2 are fine for most year, but for LL_3 and LL_4 - as before - there are years of clear misfit. These are linked to years with little to no sampling coverage (and which receive) no weight in the OM conditioning, and need adjusting to remove years with zero effective sample size.

3.2 Bridging analysis from 2014 to present

There are a number of routes that we could take to move from the 2014 OM to the present, given new and updated data sources as well as structural changes to the OM this time around. There are updated data sources (catch composition, CPUE, survey data) as well as what could be considered both new data and updated data (SNP derived POP data) and we think it sensible to consider splitting these for the moment, at least in terms of a bridging path from 2014 to the present. The structural changes to the OM are both in terms of population dynamics (the time-varying age-specific reproductive output parameter $\varphi_{y,a}$) and the grid (addition of a new parameter, ψ , as well as modifications to the ranges and values of the other grid elements).

The one major data-specific change (beyond updates of CPUE, aerial survey and catch composition) is new inclusion of the SNP derived POP data, alongside the microsat POP data from previous years. Figure 6.12 shows the absolute SSB and depletion relative to the unfished state for both all years and from 1985 to the present, with and without the new CKMR POP data. They are both very consistent, with the OM using all the POP data with a slightly higher spawner abundance than before (as we expected given the comparison-to-POP ration generally being a little higher now). Depletion levels are more similar,

though again with the OM using all the data slightly higher than the one using only the microsat POP data. This suggests that the revised POP data are very consistent with the previous data where they overlap, and that the projected recent increase in spawner abundance we saw in 2014 is actually validated with the new POP data (as they cover the period 2002–2012, not 2002–2007 as before).

3.3 Implications for data generation in MP testing

We have no current GT data in the model, so we cannot update any thoughts on the data generation model for these data. For the CPUE we see no obvious recent levels of misfit, though we are to explore the catchability change scenarios post-2008 for the MP work. For the POP CKMR data, the fits look good - though we have not yet done any full predictive analyses as in previous years to assess potential levels of over-dispersion in these data. Initial considerations suggest - as before - there is no clear over-dispersion in these data and that our current likelihood configuration will suffice for data generation purposes. We have no HSP CKMR data included in the OM as yet so we cannot comment on issues relating to these data and generation for MP testing.

4 Discussion

For the initial updated OM (in terms of both structure, grid options and updated data) we have been able to fit to all the updated data (in terms of indices of abundance, catch composition, and the CKMR POP data). Fits to the indices of abundance (CPUE, aerial survey) are similar to previous years. Fits to the 1990s tagging data are good and remain similar to previous OM reconditioning results. The fits to the updated CKMR POP data are good, suggesting we are getting the overall level of recent spawner abundance right as predicted by these data, and the age structure in the POPs also. This gives us some confidence not just in our recent spawner abundance estimates, but also in the revised form of the relative reproductive output model as defined by $\varphi_{y,a}$. The fits to the catch composition (both age and length) are fine and similar to previous years. In terms of spawning depletion, current levels (*ca.* 2017) are estimated to be 0.14 (0.11–0.18) in terms of median (and 80% PI) for the putative reference set. Recent recruitment (especially 2013) were estimated to be well above the expected level predicted by the stock-recruit relationship, driven by the high survey points in 2014, 2016 and 2017 and the increasing level of recent mean long-line CPUE also.

A factor we have not explored in this paper, or in the current OM runs, is finding kin (both POP and HSP and others) when comparing adults and adults in the POP and HSP sense, or juveniles and adults in the HSP context. As the CK data sets become larger, these comparisons are likely to begin to yield a number of matches that could become informative (*i.e.* not just abundance but M_{10} , RRO, senescence and so on). For example, take two adults that are found to be a POP (and we can sensibly discern which is the offspring and which is the parent). This contains information on adult abundance in the birth year of the offspring, which might be further back in time than the previous offspring found in the juvenile-focused POPs and therefore extends the information range of the data back beyond the current boundary of 2002 (the earliest juvenile cohort in the data). Another case is finding what we think is an HSP in an adult-adult comparison - this contains information on the period between the two birth years of the adults and, as before, could extend the information range historically. We might have to factor in the chance of this being a grandparent-grandoffspring pair (GGP) as these are indistinguishable from HSPs, genetically speaking. The main point is that, once we have both data sets in the OM and fitting together, we can consider a wider array of comparisons to that could increase both the information content and historical range of the CK data overall.

5 Acknowledgements

This work was funded by the Australian Fisheries Management Authority, and CSIRO Oceans & Atmosphere. Mark Bravington & Paige Eveson are thanked for all their work on the SNP design and kin finding pipeline.

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6 Figures

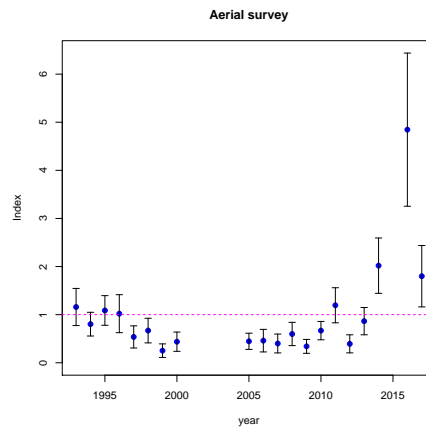


Figure 6.1: Summary (in terms of point estimates and approximate 95% CI) of the mean-standardised aerial survey for data up to and including 2017.

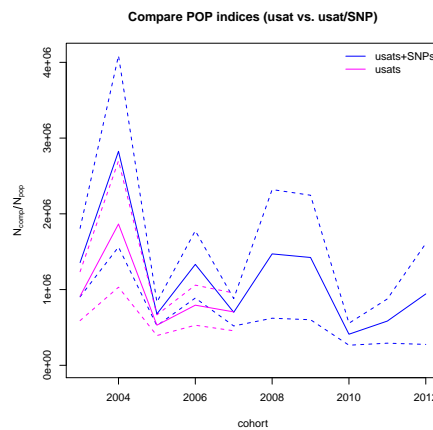


Figure 6.2: Simple, empirical POP “index” summary (ratio of comparisons to POPs for the relevant juvenile cohort, summed across adult capture years and ages). The full line is the actual index with the dotted lines an approximate ± 1 s.e. using the inverse number of POPs to calculate a CV (square-root thereof).

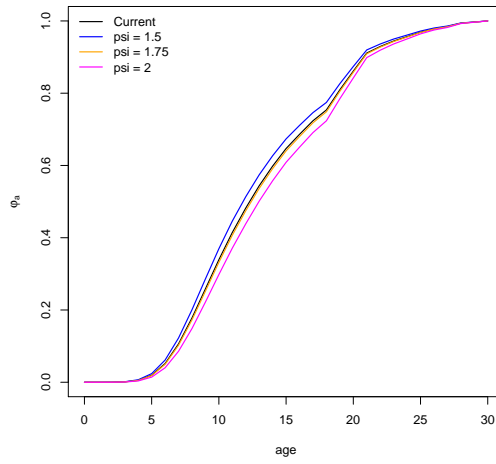


Figure 6.3: For the most recent distribution of length-at-age, covering the CK data in the OM, the three associated φ_a vectors given the proposed grid values of ψ , and the one currently used in the OM.

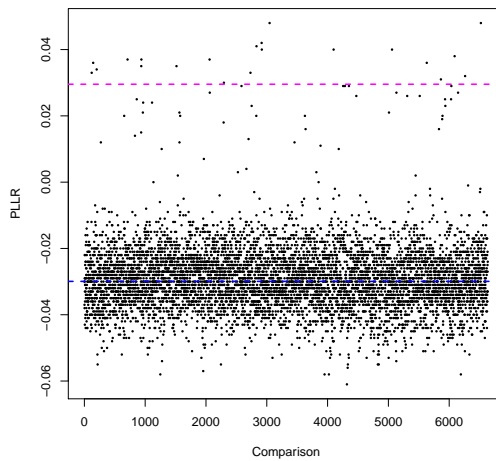


Figure 6.4: PLOD (PLLR) for 6,670 comparisons of 116 fish when asking whether they are UPs (in the bottom around the dotted blue line) or HSPs (in the top half around the dotted magenta line).

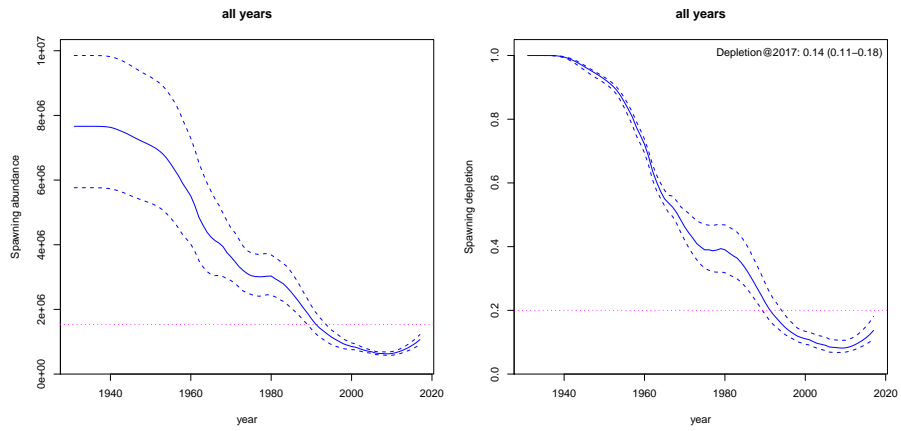


Figure 6.5: Median (full line) and 80% PI (dotted line) for absolute spawner abundance (left) and the relative depletion thereof (right) - the final year is 2017, the first 1931. The magenta dotted line is 20% of the unfished level (ca. 1931).

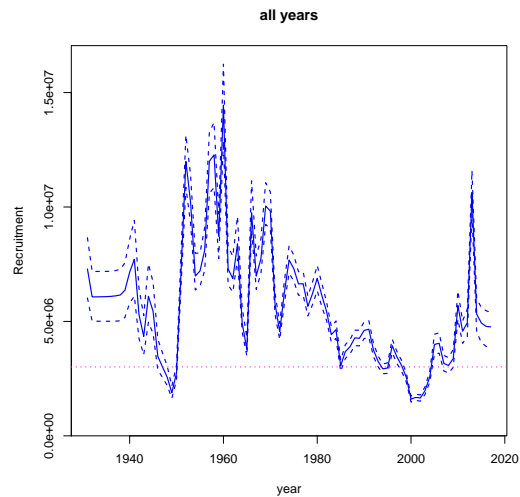


Figure 6.6: Median (full line) and 80% PI (dotted line) for recruitment - the final year is 2017, the first 1931. The magenta dotted line is 50% of the unfished level (ca. 1931).

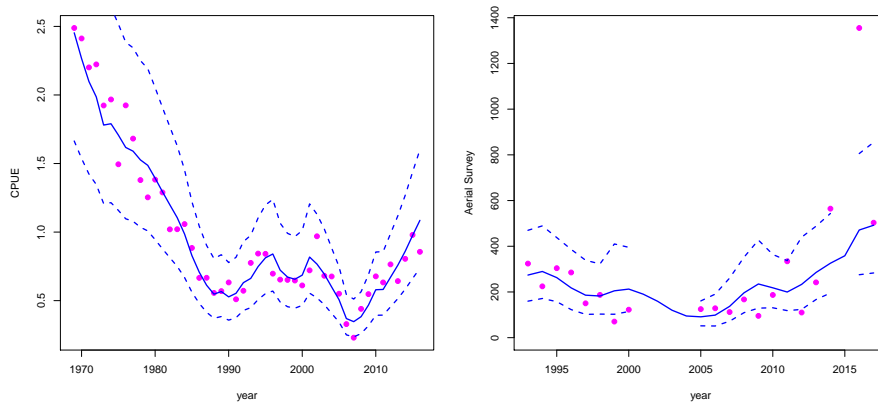


Figure 6.7: Fits (for the best-fitting grid cell) to the long-line CPUE (left) and aerial survey (right) indices. Magenta dots are the observed data and the model-predicted expected (full blue line) and approximate 95% CI (dotted blue line) index.

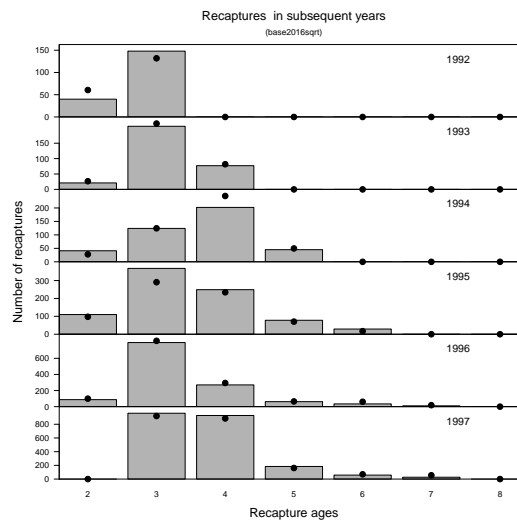


Figure 6.8: Fits to the tagging data, aggregated to the cohort-of-release and recapture-age level, for the best-fitting grid cell.

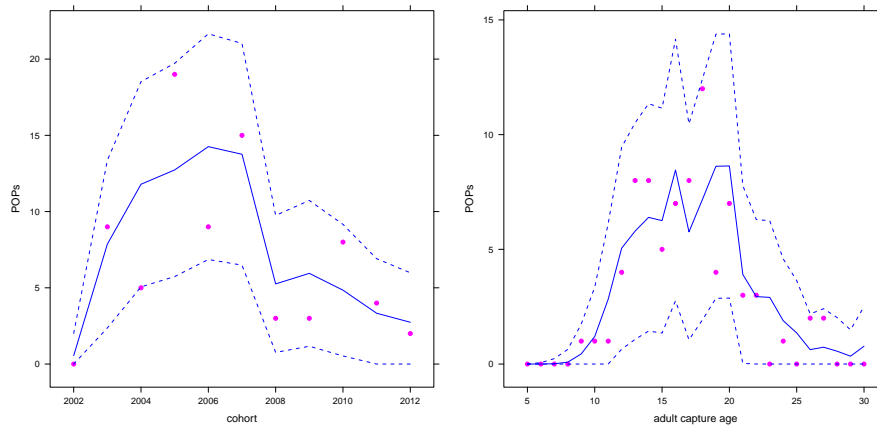


Figure 6.9: Fits (for the best-fitting grid cell) to the updated POP CKMR data. Magenta circles are the observed data with the model predicted expected value (full blue line) and approximate 95% CI (dotted blue line). On the left the data are aggregated to the juvenile cohort level (across adult capture year and age). On the right the data are aggregated to the adult capture age level (across adult capture year and juvenile cohort).

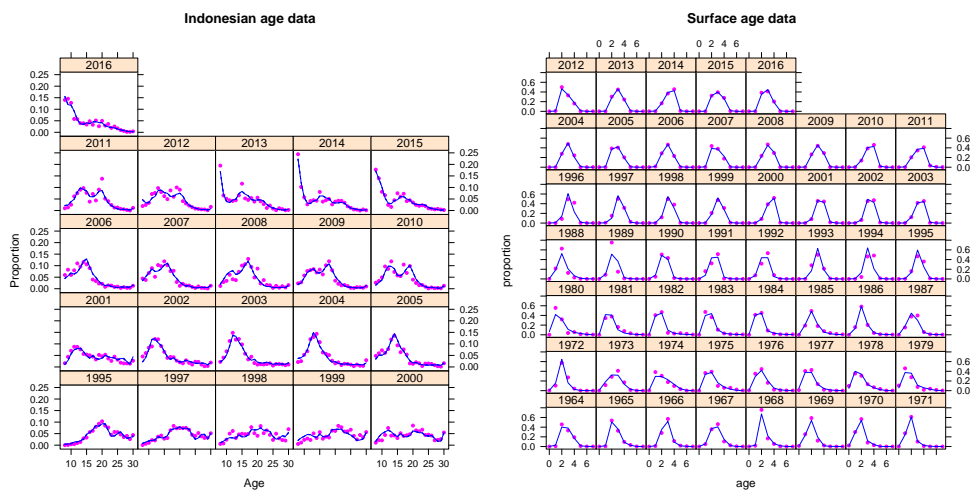


Figure 6.10: Fits (for the best-fitting grid cell) to the age data for the Indonesian (left) and surface (right) fisheries.

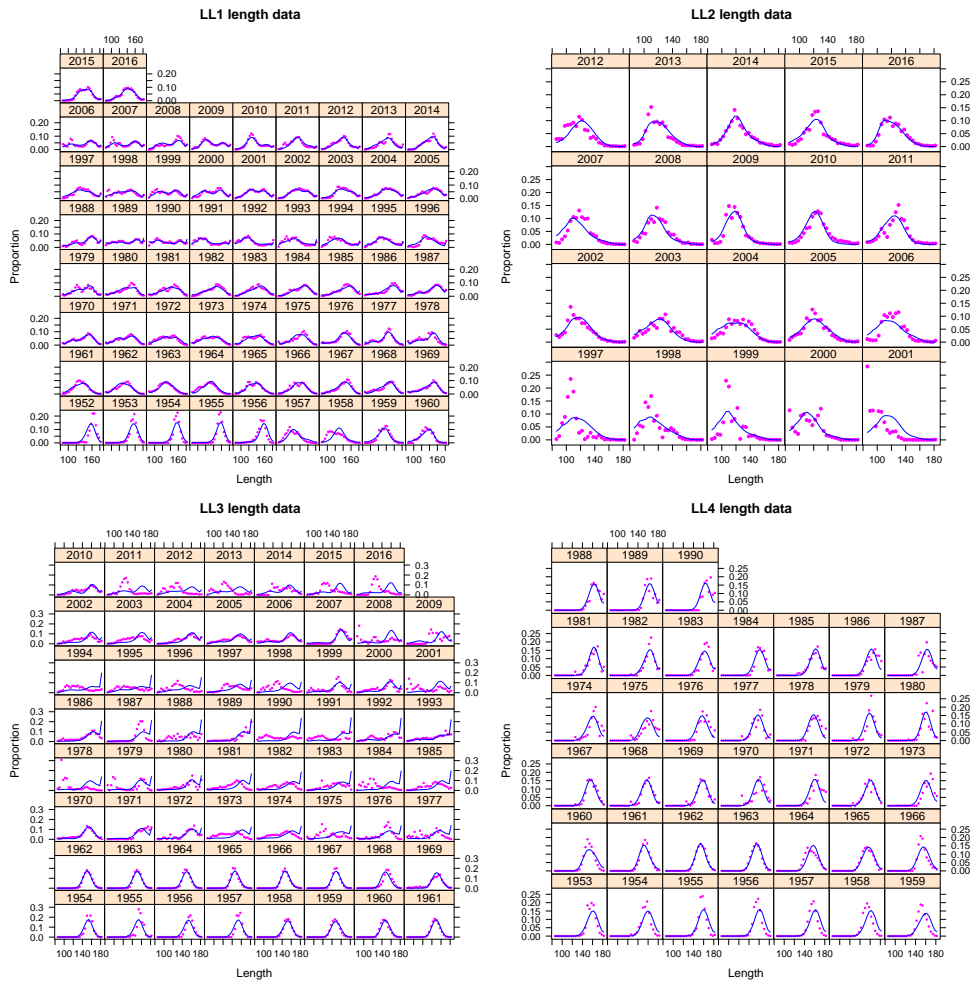


Figure 6.11: Fits (for the best-fitting grid cell) to the length data for fisheries LL_{1-4} .

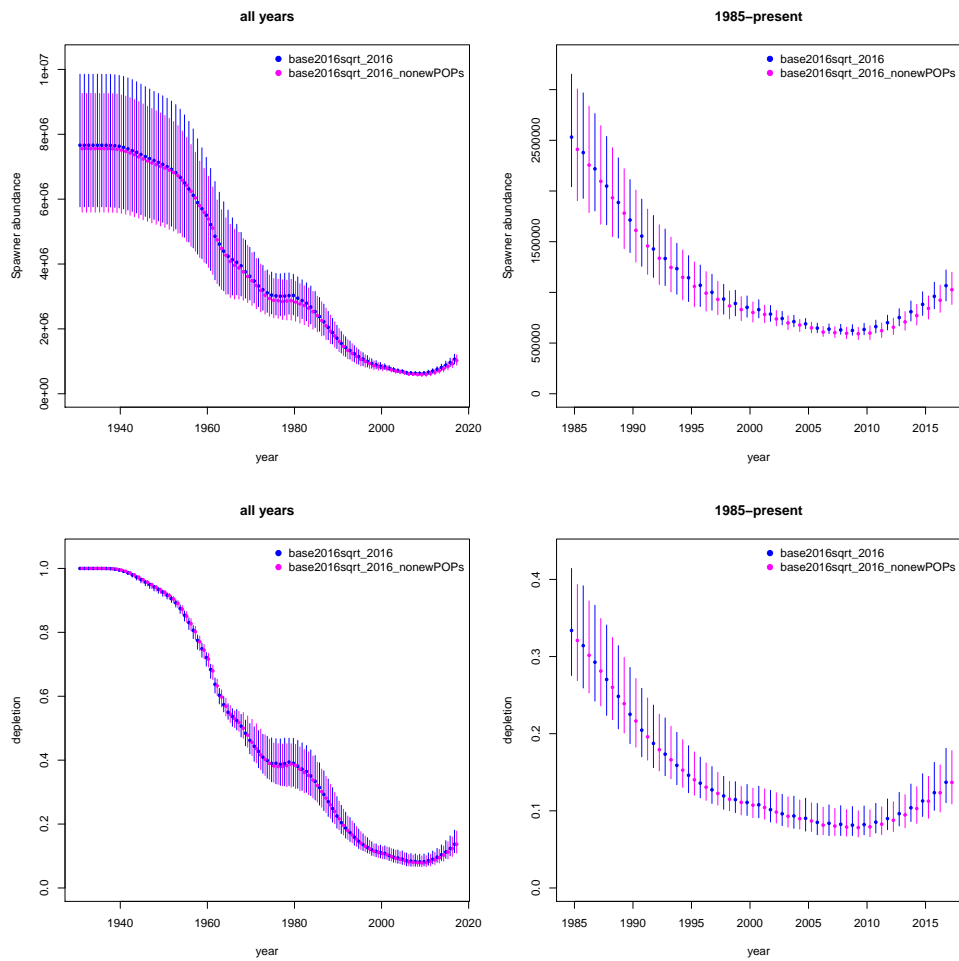


Figure 6.12: Median and 80% PI summaries for spawner abundance (top) and depletion relative to the unfished state (bottom) for both the full POP data set (**base2016sqrt2016**) and the one with no new POP data (**base2016sqrt2016nonewPOPs**) for all years (left) and from 1985 onwards (right).

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Appendix A.2

Hillary RM, Preece AL, Davies CR, Takahashi N, Sakai O, Itoh T. 2017b. Reconditioning of the CCSBT Operating Model in 2017. CCSBT-ESC/1708/14, Twenty Second Meeting of the Scientific Committee, 28 August - 2 September, Yogyakarta, Indonesia.

Reconditioning of the CCSBT Operating Model in 2017

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Abstract

The CCSBT Operating Model is scheduled to be reconditioned in 2017, with both new and updated data sources, as part of the scheduled assessment of stock status and for the next round of Management Procedure testing scheduled to begin in 2018. Updated data sources include the Japanese long-line CPUE index (up to and including 2016), the aerial survey index (up to and including 2017), catch by fishery and the age and length composition data for the various fleets. New data sources include close-kin parent-offspring pairs (covering the cohorts 2002 to 2012, not just 2002-2007 as before) and half-sibling pairs (covering the cohorts 2003 to 2011). The Operating Model was run for the reference set and agreed set of sensitivity tests from the 8th OMMP meeting. For the reference set of models, the current level of total reproductive output (relative to the unfished state) is 0.13 (0.11-0.18 80% PI), with recent annual recruitment estimated to be well above the average predicted by the stock-recruit relationship. Projections for the reference set using the Bali Procedure indicated that the CCSBT interim management target of recovery to 20% of the unfished stock by 2035 is achieved with a probability of 91% (using the total reproductive output measure, or 88% if using total biomass aged 10 or older). The data are generally explained well by the reference set, with no obvious consistent trends in the fits to the abundance indices, catch composition, tagging, or the close-kin mark-recapture data. The results across the sensitivity tests are all very consistent, with only the test relating to constant selectivity from age 20 for the Indonesian fishery being clearly more optimistic than all the other tests. In terms of issues relating to data generation for future Management Procedure testing, the likelihood functions in their current format seem more than adequate for this purpose, with the exception of the gene tagging data, which is currently not available, so will not be evaluated until next year.

Introduction

Given the agreed Management Procedure (MP) implementation schedule, the CCSBT Operating Model (OM) is due to be reconditioned in 2017. The previous reconditioning was undertaken in 2014 (Anon., 2014). Given the cessation of the aerial survey after 2017, a new MP is to be developed within the CCSBT and testing will begin in 2018. For this conditioning, there are both new and updated data sources. Structural changes to the Operating Model, including modifications to the adult population dynamics and additional likelihood functions required for new data sources, were undertaken, reviewed and accepted at the 8th OMMP meeting in June 2017 (Anon., 2017a), with the final addition of the half-sibling pair (HSP) data series agreed at a special HSP webinar in late July (Anon., 2017b).

New and updated data sources

New data sources include close-kin mark-recapture (CKMR) parent-offspring pair (POP) (covering the cohorts 2002 to 2012, not just 2002-2007 as before) and HSP data (covering the cohorts 2003 to 2011). The generation of and quality control analyses on these data are detailed in paper CCSBT-ESC/1708/12 (Bravington *et al.*, 2017).

Updated data sources include:

- Japanese long-line core vessels CPUE index up to and including 2016
- Aerial survey index up to and including 2017
- Age composition for the surface and Indonesian fisheries up to and including 2016
- Length composition for the four main long-line fisheries up to and including 2016
- Catch by fishery up to 2016

Structural changes to OM conditioning and projection code

The major change to the population dynamics in the OM conditioning (and projection) code was related to how relative reproductive output-at-age (the *per capita* contribution of each age class to the reproductive population) is defined. Prior to the initial inclusion of the CKMR POP data, this was defined to be the biomass of all fish aged 10+; for the inclusion of the original CKMR POP data it was a time-invariant ogive (between 0 and 1) informed by the CKMR data and available reproductive information on relative fecundity-at-length. Given we now have more CKMR data (both POPs and now HSPs) we expanded this model to include both a control parameter in the OM grid (controlling the degree to which increasing length relates to reproductive success), and the changing distribution of length-at-age over time within the OM. The mathematical details of this change are provided in CCSBT-OMMP/1706/4 (Hillary *et al.*, 2017). With respect to the projections, the final year value of the relative reproductive output-at-age (for a given grid cell) is used to define future values in the projections.

No changes were required to the likelihood function for the POP data. A new likelihood function was required to include the HSP data though. The probability of two animals being a HSP depends on a complicated array of information, including: relative adult abundance-at-age, the total reproductive output (TRO) over time and the adult total mortality rate-at-age. There is additional complexity required to deal with both potential biases in the absolute abundance information in the HSPs (relative to the POPs) and to account for the false negative rate we have estimated to ensure that no false-positive non-HSPs were included in the final HSP data set (Hillary *et al.*, 2017a). Papers specifying the proposed modifications were presented to the OMMP meeting in June 2017 in CCSBT-OMMP/1706/4, and were accepted by the OMMP group for inclusion in the OM. The grid configuration for the reference set of OMs, as agreed at the OMMP meeting is given in Table 1.

Table 1: Grid configuration for the agreed reference set of OMs for the 2017 stock assessment

Parameter	Value	CumulN	Prior	Sampling
H	0.6, 0.7, 0.8	3	Uniform	Prior
M_0	0.35, 0.4, 0.45, 0.5	12	Uniform	ObjFn
M_{10}	0.05, 0.085, 0.12	36	Uniform	ObjFn
Omega (ω)	1	36	Uniform	Prior
CPUE series	w0.5, w0.8	72	Uniform	Prior
CPUE age range	4-18, 8-12	144	0.67, 0.33	Prior
Psi (ψ)	1.5, 1.75, 2	432	0.25, 0.5, 0.25	Prior

An additional change that was required to the OM conditioning and projection code was ensuring that the right scale for the catchability parameter for the LL1 CPUE (q) is maintained between the conditioning and the projection code. The scale of the *estimated* catchability parameter ($\ln(q)$) was changed in 2014 from ‘real-space’ to one where predicted CPUE is rescaled by the historical mean, so that q is close to 1 instead of on a scale around $1e-6$. An issue in the projection code is that scale reverts to real-space (i.e. q * exploitable LL1 abundance) and so the estimated q values will result in CPUE levels of $1e+6$ in the future and lose their connection to the historical data. A simple additional nuisance variable is added to the OM in the conditioning phase, and then transferred via the .prj files to the grid files and the projection code to ensure that historical observed CPUE and future simulated CPUE are on the same scale.

Reference set and sensitivity tests

All 432 grid combinations were run, with confirmed estimation on all grid combinations, and then 2,000 samples were taken to generate the reference set of OMs. The issue with some combinations of steepness and the natural mortality parameter crashing, which was identified at OMMP8, was solved by both using an alternative starting estimate of M_4 (a directly estimated parameter) and more iterations in the initial phases of the estimation algorithm.

The list of sensitivity tests agreed at the OMMP8 meeting is reproduced in Table 2 below with edits to clarify updated specifications. There is a total of 20 sensitivity tests relating to issues, such as, over-catch and unaccounted mortality, CPUE interpretation and alternative indices, structural issues such as tag mixing, alternative data sources (like the Piston line survey), excluding data sources (like the POP and/or HSP CKMR data) and alternative weighting scenarios for specific grid parameters.

Table 2. Sensitivity tests for 2017 assessment and stock status advice (reproduced from Table 6, Anon. 2017).

Run name	Conditioning	Projections
UAMI	Added unaccounted catch mortality (UAM) in conditioning: 1000 t of small fish + 1000 t of large fish, ramping up from 0t of each size class in 1990 to 1000t in 2013, and 1000t in each year 2014-2016, in addition to 20% increase in the surface fishery.	Additional catch remains at the same proportion as in 2016.
SFOC40	40% overcatch by Australian surface fishery: ramps up from 1% in 1992 to 40% by 1999 and onwards to 2016. Adjust the age composition as was done for the 20% method.	Continued 40% overcatch in projections
SFO00	No historical additional catch in surface fishery	No future additional catch in surface fishery
LL1 Case 2 of MR	LL1 overcatch based on Case 2 of the 2006 Market Report	
IS20	Indonesian selectivity flat from age 20+	
High_aerialCV	In conditioning set process CV to 0.4	
Aerial2016	Remove the 2016 aerial survey data point	
Upq2008	CPUE q increased by 25% (permanent in 2008 due to individual quota system that went into effect in 2006)	
Omega75	Power function for biomass-CPUE relationship with power $\omega = 0.75$ (retain)	
S00CPUE	Overcatch had no impact on CPUE	
S50CPUE	50% of LL1 overcatch associated with reported effort	
Updownq	Increase in catchability (0.5) in 2009 then returns to normal in 2012 (when the pertinent quota was restored to pre-2009 level)	
GamCPUE	Use the "GAM CPUE" series provided from Australia under the 2017 CCSBT data exchange. This is the monitoring CPUE series 3.	
Base CPUE w/o area 7	As a sensitivity to note a possible concentration effect on CPUE	
Incomplete tag mixing	Sensitivity to incomplete mixing of tagged fish released in the WA and GAB. Increases fishing mortality of tagged fish in the surface fishery by 50% relative to the whole population for fishing season 1 (surface fishery).	
Piston line with high AS cv	Includes the piston-line troll survey index (updated to 2017) included as alternative sensitive to recruitment index (2017 data exchange)	
NoPOP&HSP	Exclude both close-kin data sets (POPs and HSPs)	
NoHSP	Exclude HSP close-kin data	
Psi	Grid sampling using objection function weighting psi	
Noh0.8	Change steepness (h) preference weighting to 0.5, 0.5, 0.0 to examine impact of excluding $h=0.8$ on projections.	

One additional sensitivity test that arose from the discussion during the special web meeting in July (Anon.2017b) was running the OM with the HSP scaling parameter (q_{hsp}) fixed at 1, instead of being freely estimated.

Status and fitting diagnostics for the reference set of OMs

Figure 1 shows the estimated relative TRO for the spawning stock and the recruitment for the reference set. For relative TRO (TRO in 2017 relative to TRO initial unfished), the median estimate is 0.13 (0.11-0.17 80% PI). The lowest point is around 2009, with a clear increasing trend from 2012 onwards. Estimates of recruitment from 2009/2010 cohorts have been above the mean level predicted by the stock-recruit relationship – particularly the 2013 recruitment.

Figure 2 summarises the historical estimates of maximum sustainable yield (MSY), the ratio of F to F_{MSY} , and surplus production. MSY has varied as population selectivity (a product of fisheries selectivity over time and relative allocation among fleets) and mean length-at-age has altered over time. The current estimate is between 32,000t-34,000t. The ratio of F to F_{MSY} has been steadily decreasing from ~1.5 in the mid-2000s to a current median of 0.5 (0.38-0.7 80% PI). Surplus production has been highly variable over time, as the stock abundance declined, recruitment varied, and fisheries characteristics changed. The most recent values of surplus production are just above 40,000t, well in excess of current catches, hence the current lower values of the F to F_{MSY} ratio. The current TRO (at 2017) to MSY ratio is also around 0.5 (0.37-0.7 80% PI), with the MSY to unfished TRO ratio estimated to be around 0.27 (0.22-0.32 80% PI) – i.e. the TRO at which MSY is produced is somewhere between a depletion level of 0.22 and 0.32. Figure 3 shows the likelihood profiles for steepness, M_0 and M_{10} , respectively. Figure 4 shows the level plot for the reference grid.

To summarise the fits to the abundance indices, tagging data, CKMR data and the catch composition we initially focussed on the best fitting grid cell (2312321 for information). We did, however, undertake more detailed predictive analyses across the whole grid for the data that are/were simulated for potential use in candidate MPs (CPUE, aerial survey, and the CKMR data). Figure 5 summarises the fit to the Japanese long-line CPUE and aerial survey, respectively. The CPUE are fitted well, with all the observed points sitting within (or just about on the edge of) the predicted 95% CI and with no consistent trends in the fits. The aerial survey data are fitted fairly well, with a few of the points just outside the 95% CI (assume a process error of 0.22) and with no consistent trend in the fits – the only obvious discrepancy is the inability of the OM to fit to the very large 2016 survey data point.

Figure 6 summarises the fit to the tagging data at the release year and recapture age disaggregation level. These fits are aggregated over the individual tagger and release age, but give the clearest indication of the consistency of information on cohort abundance and mortality informed by multiple release and recapture events (over both time and age). The fits are good, with the data mostly being fitted closely (especially the largest recapture events in numbers) and with no clear or consistent trends in the fits themselves. The tagging over-dispersion factor was re-estimated given the updated and new data sets. This was done as follows: for each recapture event (at the full disaggregation level) we calculate the standardised residual; we then calculate the variance in the standardised residuals; this value yields the multiplier by which we would alter the current over-dispersion factor ($\phi = 1.82$). The estimated value of the dispersion multiplier was 0.998, which is so close to 1 as to suggest we are fine to keep with the current value of 1.82. A more detailed analysis of the trends in the standardised residuals at the full disaggregation level found only one apparently clear trend: that for tagger 6 the residuals were consistently less variable (and, hence, with lower implied over-dispersion factor) than for all the other taggers. There were no apparent trends across release cohort, age or recapture age.

The CKMR POP data are, in the form they are used in the OM, the number of juvenile-adult comparisons (and POP matches) at the level of juvenile cohort/adult capture year/adult capture age (the POP probability is the same for these covariates). There are 1,728 such unique groupings with expected non-zero comparisons and only 77 POPs, so these data are *very* sparse. To summarise the fits to these data, we aggregate them (both the observations and the predictions) to more useful levels. For the POP data, we aggregate to the juvenile cohort (across adult capture year and age) and the adult capture age (across adult capture year and juvenile cohort) levels. The cohort level gives us an indication of whether we are getting the overall adult abundance level right over time, and the adult capture age level covers whether we are getting the age distribution of the adults in the POPs (and, by implication, the relative reproductive output-at-age) about right given the data. Figure 7 summarises the fits to the CKMR POP data at these two aggregation levels. For both, the observed data sit within the approximate 95% CI and with no obvious or consistent trend in the fits.

The CKMR HSP data, in the form they are currently used in the OM, are aggregated at the level of the number of juvenile-juvenile comparisons (and HSP matches) between animals of a given cohort/birth year. We show the fits to these data at the OM level and where we estimate the total number of HSPs found between a reference cohort (the earliest one) and the subsequent cohorts it is compared against. Figure 8 summarises the fits at these two aggregation levels and, as with the CKMR POP data, the data lie (almost exclusively) within the approximate 95%ile and with no obvious or consistent trends in the fits.

Figure 9 summarises the fits to the age composition data for the surface and Indonesian fisheries. As in previous years, the fits to these data are generally very good.

Figure 10 summarises the fits to the length composition data for the other 4 long-line fisheries. As with previous years, the fits to the LL1 fleet are good, with some misfit in the LL2 data, and also with the earliest data from the LL3 and LL4 fleets. As in previous reconditioning exercised, there is very little variation in the fits to both the age and length composition across the grid cells.

For previous reconditioning of the OMs, we have undertaken more detailed predictive analyses of the data that are being considered for inclusion in candidate MPs. In the previous MP, this has meant the long-line CPUE and the aerial survey (Anon., 2011), but we also extended this analysis to the CKMR POP data to explore whether these data display additional process error. Given the agreed set of data series to be used in the next suite of candidate MPs (CPUE, gene tagging, CKMR POP and HSP data) we advanced the original CKMR predictive analyses to look at the data at the various levels of aggregation of interest (juvenile cohort and adult capture age) and also for the HSP data as well. The principle is fairly straightforward:

- 1) Simulate the data (at the required aggregation level for the CKMR data) from the likelihood model used in the OM
- 2) Calculate two residuals: the first is the simulated data minus the expected value; the second is the actual data minus the expected value
- 3) Calculate an appropriate “discrepancy” measure for each of these residuals, Δ^{sim} and Δ^{obs} , and we use the median absolute deviation (which is non-parametric)
- 4) Do this for each of the 2,000 grid samples and calculate $\mathbb{P}(\Delta^{\text{obs}} > \Delta^{\text{sim}})$

If the simulated data are very similar (not just in terms of expected prediction but also in terms of the variance properties) to the observed data this p-value will be close to 0.5 (i.e. just as likely to be more or less variable than the data). If the data are consistently more variable than the predictions (i.e. over-dispersed/possess process error) then this value will be greater than 0.5; *vice versa* if the data are less variable than the predictions. Based on Gelman et al. (1995) it is only when values are outside the range 0.05-0.95 in terms of p-values that there is a strong indication of something not

right with the likelihood model. The relative shape of the “cloud” of discrepancy values can also be instructive as to whether the likelihood might be misspecified – for example one assumes a normal distribution but the data appear to show a more fat-tailed distribution, even if their p-values are close to 0.5.

For the long-line CPUE and aerial survey indices, the predictive distributions of the data (Figure 11) across the grid look very similar those predicted for the best fitting grid cell in Figure 5. This suggests that there is good consistency of fit across the grid samples, relative to the best fitting grid cell. As for the p-values, the long-line CPUE is 0.07 and the aerial survey is 0.72 suggesting that we are moderately under-weighting the CPUE and moderately over-weighting the survey. This is not surprising, given the empirical CV in the CPUE residuals is around 0.16 (not the fixed minimum value of 0.2), and the process error in the survey CV in the survey is around 0.36 not 0.22 as currently assumed. This is similar to previous such analyses and has been accepted practice to account for potential additional uncertainty in the CPUE, given the assumptions required to account for the over-catch term, and to give a little more weight to the aerial survey, given it is both fishery independent and the earliest data set to inform on recruitment trends currently in the OM.

Figure 12 summarises the predictive discrepancy statistics and p-values for the CKMR POP and HSP data at the main levels of aggregation: POPs at the juvenile-cohort and adult capture age level; HSPs at the initial cohort level. For the POPs at the cohort level the p-value is 0.91 suggesting the data are more variable than the predictions, though Figure 8 shows the data are all within the 95% CI for the best fitting grid, so this effect is not likely to be strong. For the POPs at the adult capture age level, the p-value is 0.59 suggesting the OM is explaining the data well at this level. For the HSP data at the initial cohort level the p-value is 0.28, suggesting that the data are in fact slightly *less* variable than the predictions. In all three cases, the spread in the discrepancy for the predictions is wider than for the data. A possible reason for this is the algorithm used to combine the individual binomial probabilities together at the relevant aggregation level (Butler and Stephens, 2016) is exact, but assumes that the binomial probabilities themselves are independent. In reality, given the correlation between TRO and adult mortality over time and age this will not be the case. This correlation would likely decrease the variability in the discrepancy, but not accounting for it could result in the kind of wider spread we see in the plots.

For both the abundance indices (CPUE and the aerial survey) and the CKMR POP and HSP data the predictive analyses all look fine – there is nothing obviously troubling about any of the discrepancy distributions. This supports using the currently defined likelihoods for these data for simulation purposes in the next round of MP design and testing. For the gene tagging data, we will perform similar analyses when these data are available in 2018.

Projections for the reference set of OMs

Based on the OM conditioning result for the reference set, future projections were conducted using the Bali procedure (MP3 for the projection code name) to provide an indication as to whether the overall estimate of stock productivity has changed since the previous assessment.

Figure 13 shows historical and projected trajectories of the reference set for recruitment, biomass of age 10+ fish, and TRO. For comparison, those of the previous assessment were also plotted. All trajectories of recruitment and spawners for the 2017 projections have increasing trends with respect to the medians. Compared to the results of the 2014 assessment, the overall increasing trends for the 2017 projection is shifted upward for both recruitment and spawners. For the 2017 projection, the CCSBT interim management target of recovery to 20% of the unfished stock by 2035 is achieved with a probability of 91% (using TRO, or 88% using B10+) (Table 3). This target is achieved by 2025 with a probability of 81%. Projected future TAC trajectories for the reference

set are plotted in Figure 14. With respect to the median values, the future TAC continues to increase toward 2035. The average TAC over 2018-2035 is predicted as 22,570t (18,767-25,147t 80% PI) (Table 3).

Summary of sensitivity tests

The results for the reference set of OMs and agreed sensitivity tests are summarise in Table 3 using the following statistics: (1) Relative Total Reproductive Output (Rel.TRO) in 2017, (2) Relative biomass of age 10+ fish (Rel. B10+) in 2017, (3) ratio of current TRO (2017) to TRO at MSY (TRO-to-TRO_{msy}), (4) ratio of TRO at MSY to the unfished level (TRO_{msy}/TRO₀), (5) ratio of current F to F at MSY (F-to-F_{MSY}), (6) Maximum Sustainable Yield) (MSY), (7) Relative TRO in 2035, (Rel. TRO (2035)), (8) the probability that biomass of age 10+ fish is greater than 20% of the unfished state in 2035 (the original tuning objective; P(B10+ >0.2B₀)@2035), and (9) mean TAC under the Bali Procedure between 2018 and 2035.

Table 3: Summary table for Reference Set and the sensitivity tests from OMMP8 and webinar. Medians are listed first, with the 80%PI included in the bracket as appropriate. Definitions of sensitivity tests are in Table 2 and summary statistics in text above. ¹The piston line could only be run to completion (i.e. convergence of all grid combinations) with the higher aerial survey CV.

Run	Rel. TRO (2017)	Rel. B10+ (2017)	TRO-to-TROmsy (2017)	TROmsy /TRO0	F-to-FMSY (2017)	Median MSY (t) (2017)	Rel. TRO (2035)	P(B10+ > 0.2B0) @ 2035	Mean TAC (2018-2035)
Reference	0.13 (0.11-0.17)	0.11 (0.09-0.13)	0.49 (0.38-0.69)	0.27 (0.22-0.32)	0.5 (0.38-0.66)	33,036	0.3 (0.21-0.46)	0.88	22,570
UAM1	0.13 (0.1-0.17)	0.11 (0.09-0.13)	0.49 (0.37-0.67)	0.27 (0.22-0.32)	0.57 (0.43-0.74)	33,471	0.28 (0.18-0.43)	0.80	22,025
SFOC40	0.14 (0.11-0.18)	0.11 (0.09-0.14)	0.52 (0.38-0.71)	0.27 (0.22-0.32)	0.53 (0.4-0.7)	35,120	0.31 (0.21-0.48)	0.89	22,707
SFOC00	0.12 (0.1-0.16)	0.1 (0.09-0.12)	0.46 (0.35-0.64)	0.27 (0.22-0.32)	0.48 (0.35-0.63)	30,865	0.29 (0.20-0.45)	0.87	22,319
LL1 Case 2	0.13 (0.11-0.16)	0.11 (0.09-0.13)	0.48 (0.37-0.66)	0.27 (0.22-0.32)	0.5 (0.38-0.63)	33,526	0.31 (0.21-0.47)	0.90	22,627
IS20	0.18 (0.15-0.22)	0.14 (0.12-0.17)	0.64 (0.46-0.97)	0.28 (0.23-0.33)	0.41 (0.3-0.57)	34,304	0.38 (0.26-0.59)	0.96	23,224
High Aerial CV	0.12 (0.1-0.16)	0.11 (0.09-0.14)	0.47 (0.35-0.67)	0.27 (0.22-0.32)	0.58 (0.43-0.78)	32,799	0.26 (0.16-0.41)	0.72	21,745
No AS 2016	0.13 (0.1-0.16)	0.11 (0.09-0.14)	0.47 (0.36-0.66)	0.27 (0.22-0.32)	0.59 (0.44-0.78)	33,140	0.26 (0.17-0.40)	0.74	21,455
Upq2008	0.11 (0.1-0.15)	0.09 (0.08-0.12)	0.42 (0.35-0.65)	0.27 (0.22-0.32)	0.56 (0.42-0.75)	32,552	0.26 (0.17-0.42)	0.73	22,635
Omega 75	0.12 (0.1-0.16)	0.1 (0.08-0.13)	0.46 (0.35-0.65)	0.27 (0.22-0.32)	0.49 (0.36-0.65)	33,799	0.31 (0.21-0.48)	0.88	21,847
S00CPUE	0.15 (0.12-0.19)	0.12 (0.1-0.15)	0.55 (0.41-0.76)	0.27 (0.22-0.32)	0.46 (0.35-0.6)	34,126	0.33 (0.23-0.52)	0.94	22,665
S50CPUE	0.12 (0.1-0.15)	0.1 (0.08-0.12)	0.45 (0.41-0.76)	0.27 (0.22-0.32)	0.54 (0.4-0.71)	32,458	0.28 (0.19-0.44)	0.82	22,444
Updownq	0.13 (0.11-0.17)	0.11 (0.09-0.13)	0.49 (0.38-0.69)	0.27 (0.22-0.32)	0.5 (0.38-0.66)	33,036	0.3 (0.21-0.47)	0.88	22,569
GAM CPUE	0.14 (0.12-0.18)	0.12 (0.1-0.14)	0.53 (0.43-0.76)	0.27 (0.22-0.32)	0.51 (0.36-0.62)	32,774	0.31 (0.22-0.47)	0.91	23,168
CPUE w/o A7	0.12 (0.1-0.15)	0.1 (0.08-0.12)	0.45 (0.35-0.62)	0.27 (0.22-0.32)	0.54 (0.4-0.71)	32,734	0.29 (0.19-0.44)	0.83	22,246
Tag mixing	0.13 (0.11-0.17)	0.11 (0.09-0.14)	0.49 (0.38-0.68)	0.27 (0.22-0.32)	0.48 (0.36-0.64)	33,165	0.31 (0.22-0.53)	0.90	22,540
Piston Line ¹	0.14 (0.11-0.2)	0.13 (0.1-0.18)	0.54 (0.4-0.81)	0.27 (0.22-0.32)	0.59 (0.44-0.8)	33,086	0.35 (0.22-0.53)	0.93	23,499
No HSPs	0.13 (0.11-0.17)	0.11 (0.09-0.13)	0.49 (0.38-0.68)	0.27 (0.22-0.32)	0.5 (0.38-0.66)	33,039	0.30 (0.21-0.47)	0.88	22,565
No POPs/HSPs	0.12 (0.1-0.15)	0.1 (0.08-0.11)	0.47 (0.34-0.61)	0.28 (0.22-0.33)	0.52 (0.4-0.67)	34,168	0.29 (0.19-0.45)	0.79	23,148
Psi (ObjFn)	0.13 (0.11-0.17)	0.11 (0.09-0.13)	0.49 (0.38-0.69)	0.27 (0.22-0.32)	0.5 (0.38-0.65)	33,064	0.30 (0.21-0.47)	0.88	22,601
No h = 0.8	0.13 (0.1-0.16)	0.11 (0.09-0.13)	0.44 (0.36-0.58)	0.31 (0.27-0.32)	0.57 (0.44-0.67)	32,512	0.28 (0.20-0.43)	0.83	22,220
q(HSP) = 1	0.15 (0.12-0.18)	0.12 (0.1-0.14)	0.54 (0.4-0.75)	0.27 (0.22-0.32)	0.48 (0.36-0.65)	33,396	0.31 (0.21-0.5)	0.92	24,585

In terms of relative TRO (depletion) the results are very consistent. The median estimates are between 0.11 and 0.15 with only the IS20 test clearly higher (median level of 0.18). Lower quantiles never dip below 0.10 and most range up to around 0.17 to 0.18. The relative biomass of age 10+ fish shows similar stability, albeit with median estimates and overall probability intervals being on average around 0.02 to 0.03 lower than relative TRO. Interestingly, the case where both sources of the CKMR data are not included (no POPs or HSPs) the answers are only slightly less optimistic than for the reference set. The current TRO to the TRO at MSY ratio is also consistent across almost all the trials (median levels between 0.45 and 0.55) – again, only for the IS20 test is it clearly different and higher (median of 0.64). The relative TRO level at which MSY is produced (TRO_{msy}/TRO_0) is very consistent – the median and range for almost all trials is 0.27 (0.22-0.32) apart from the IS20 and no CKMR data trial where it was 0.28 (0.23-0.33), and for the no steepness of 0.8 run where it was 0.31 (0.27-0.33). Current median F to F_{msy} ratios mostly range between 0.45 and 0.55 with only the IS20 trial having a clearly lower (and more optimistic) value of 0.41. MSY is very consistent across the trials, with a median range between around 30,000t to 34,000t and low variation across grid samples. In terms of the projection results across the sensitivity tests, median relative TRO levels by 2035 are projected to be between 0.26 and 0.34 (with the lowest of the lower 10%ile being 0.19). In terms of the original tuning objective - the probability of the relative level of the biomass of age 10+ fish being greater than 20% by 2035 – values are generally in the 0.8 to 0.9 range apart from the two trials relating to discarding the 2016 aerial survey, or with a higher value of the aerial survey CV, and the Upq2008 trial where they are 0.74, 0.72, and 0.73, respectively. Expected levels of the TAC across the years 2018 to 2035 are consistent, varying between around 22,000t to 26,000t.

Discussion

The CCSBT OM was reconditioned in 2017 to include new and updated data sources. The reference set and associated sensitivity tests were agreed at the OMMP meeting in June (Anon., 2017a) and were successfully run, including projections using the Bali Procedure. In terms of the reference set, current levels of median relative TRO are estimated to be 0.13 (0.11-0.17 80% PI); recent recruitment is estimated to be well above the expected level, especially 2013; the ratios of the TRO and fishing mortality to their MSY counterparts are 0.49 and 0.5, respectively; and recent surplus production is just above 40,000t (a historical high). In terms of projections, using the Bali Procedure, by 2035 the median (and 80% PI) for relative TRO is 0.3 (0.21-0.46); the probability that the biomass of age 10+ fish is above 20% of the unfished state (the 2011 tuning objective) is 0.88; the year in which the probability that the relative TRO is above 20% of the unfished state with a probability of 0.7 is 2023; and the mean TAC between 2018 and 2035 is 22,570t.

The data are generally explained well, with the only notable instances of misfit some years for the early length frequency data (as in previous reconditioning work) and for the 2016 aerial survey point (which the OM under-estimates). The CKMR data, both POP and HSP, are explained well at all relevant aggregation levels, which suggests we are getting adult abundance and the relative reproductive output of each of the adult age classes about right, given these data. Detailed predictive analyses for the data currently in the OM and likely to be used in the next round of candidate MPs (long-line CPUE, CKMR data) suggested that the current likelihood structures will certainly be adequate to simulate them in projections.

Across the sensitivity tests, medians (and ranges) of relative TRO and the biomass of age 10+ fish are consistent – 0.12 to 0.15 for the former, 0.1-0.13 for the latter. The only different looking trials are the “IS20” and “Fix qhsp = 1” trials – both results are, in general, more optimistic in their depletion statistics. As with the depletion statistics, the MSY ratios (both TRO and fishing mortality) are broadly consistent with the reference set. Estimates of the ratio of TRO at MSY to the

unfished level are *very* consistent, with the only real difference being for the “no $h = 0.8$ ” trial, where this ratio is around 0.31, not 0.27. Estimates of MSY range between 31,000t and 35,000t. With respect to projections, the results are also consistent with the reference set, with only the “no 2016 AS”, “high aerial CV” and “Upq2008” trials resulting in slightly lower levels of biomass rebuilding, and with none failing the tuning objective (whether TRO or age 10+ biomass based). Future levels of TAC are likely to be between 22,000t to 26,000t.

An interesting outcome of the sensitivity trials has been that now, as opposed to when the CKMR POP data were first included, there is only a slightly less optimistic outlook for the case where we remove the CKMR data altogether. This might seem odd initially, but two things to remember are: (i) we are not really performing a test without the data *entirely*, given how many structural changes we have made to the OM (M_{10} range, relative reproductive output model etc.) *because* of the CKMR data, (ii) we now have more of the non-CKMR data (CPUE, surveys etc.) than we had in 2012. The first is arguably the most influential change, but the second is instructive also as it suggests that - with the appropriate structural changes in the OM - with more recent optimistic data there is a consistency across the various data sources now that was not apparent in 2012.

The reconditioning of the OM suggests that recent signals are positive, there is a clear upward trend in the adult population, recent recruitment is above the expected level, and current levels of fishing mortality suggest future rebuilding will be somewhat faster than initially envisaged in 2011. There is a marked consistency across the suite of sensitivity trials which, while positive, may have implications for considering robustness tests for MP testing. In relation to the Bali Procedure’s performance across the sensitivities, in all cases the 2011 rebuilding objective was met (and exceeded, sometimes significantly) and so would the same objective if referenced in terms of relative total reproductive output.

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Figures

Figure 1: Relative level of total reproductive output (left) and recruitment (right) for the reference set of OMs and covering the years 1931-2017.

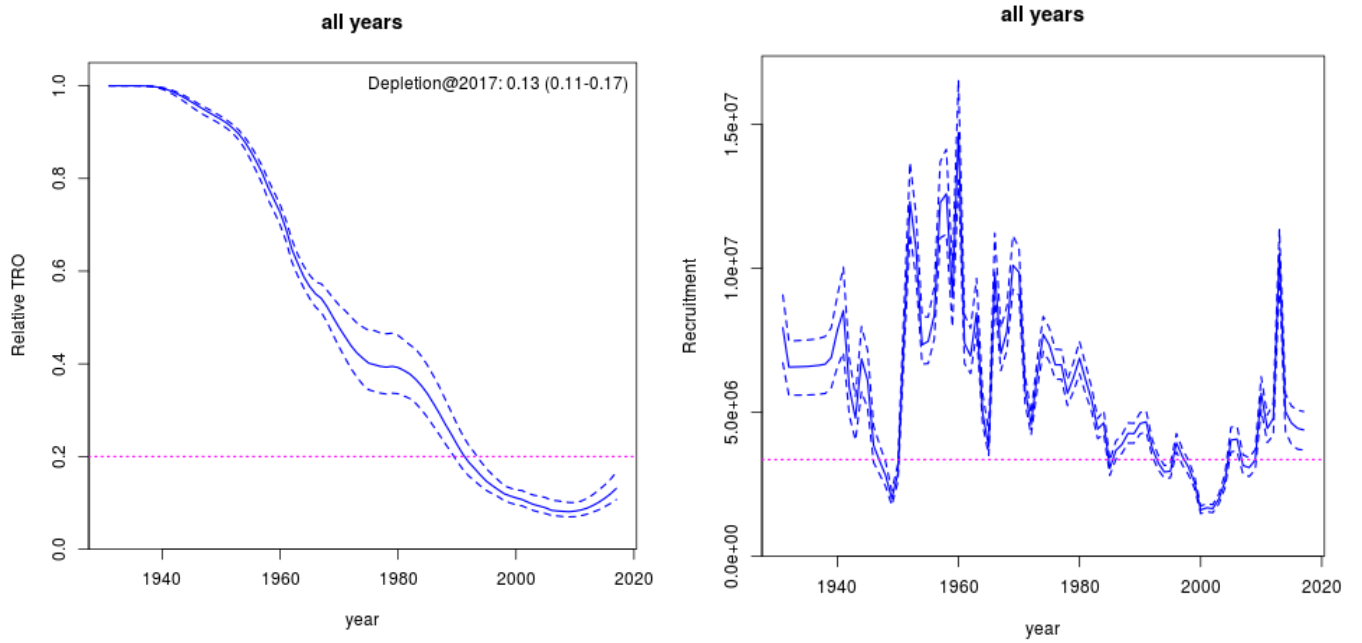


Figure 2: Summary of MSY (top), the ratio of F to F_{MSY} (middle), and surplus production (bottom) for the reference set of OMs. The surplus production is estimated by adding catch in year t and total biomass difference in year t from year $t-1$ together.

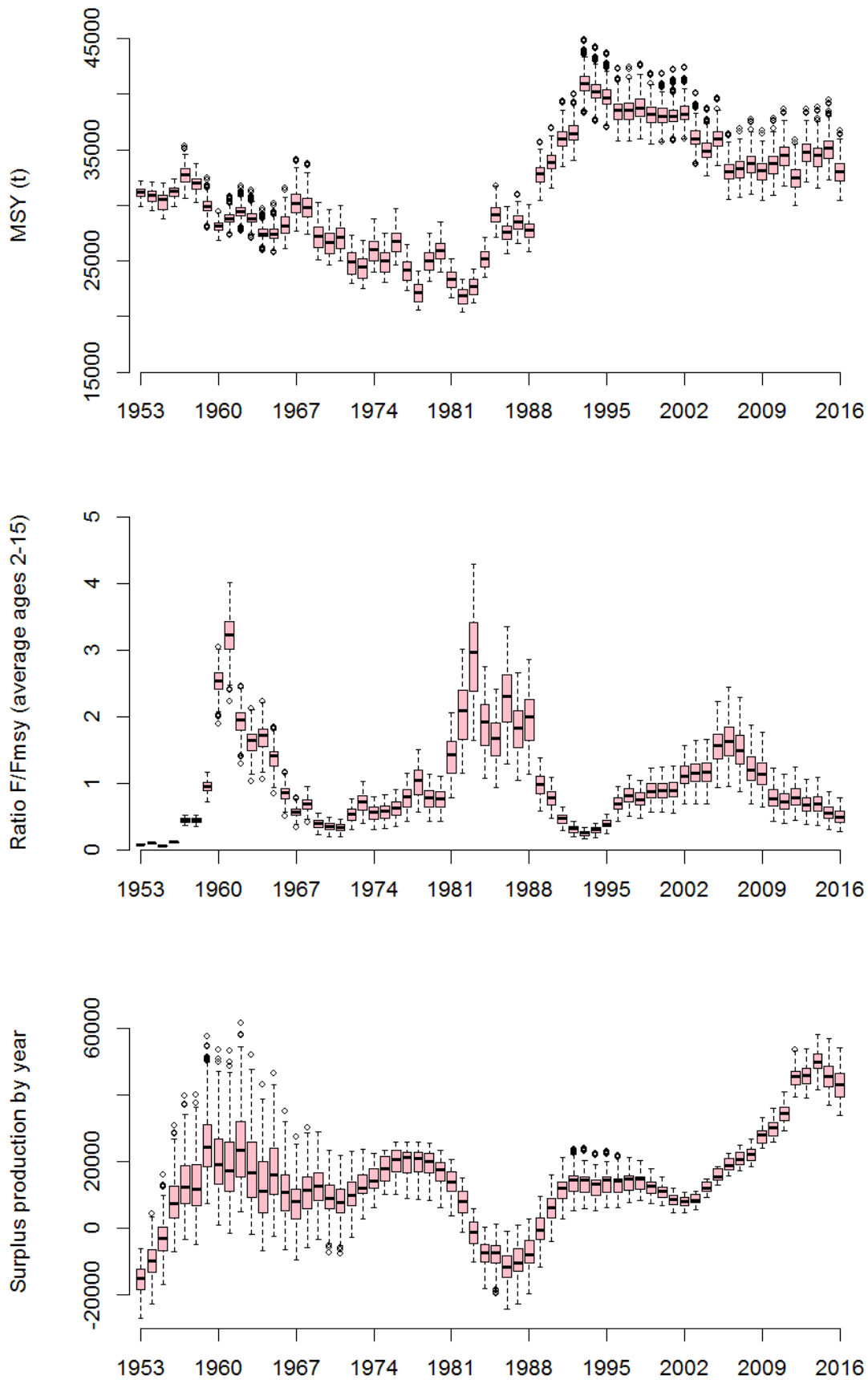


Figure 3: Likelihood profiles for steepness (top left), M_0 (top right) and M_{10} (bottom).

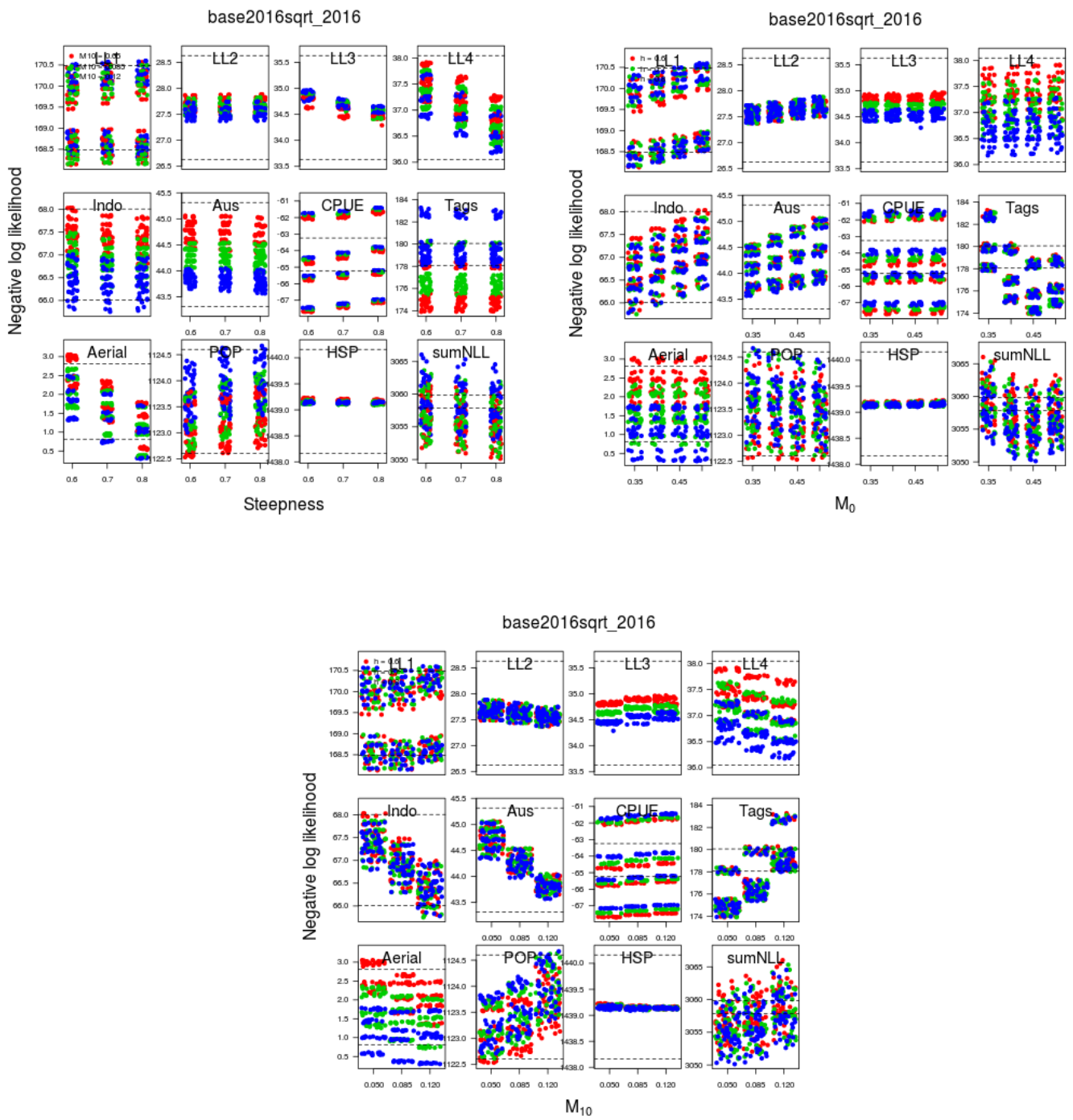


Figure 4: level plot for the grid parameters in the reference set of OMs.

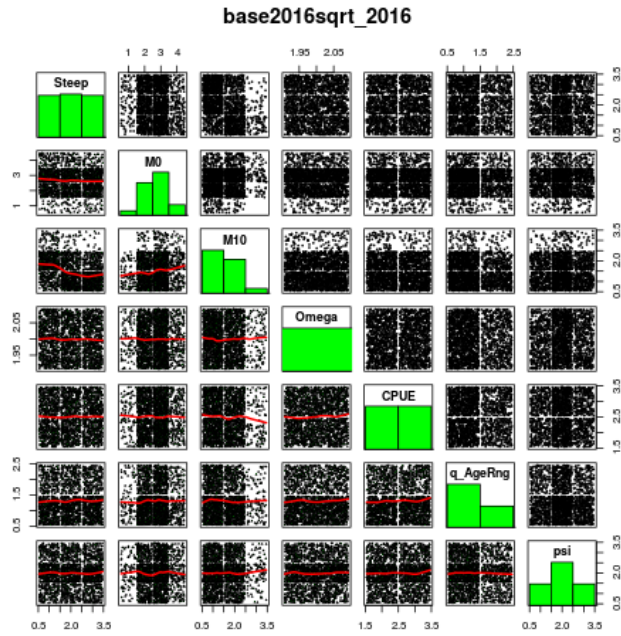


Figure 5: Observed (magenta circles) and predicted mean and approximate 95%iles (blue solid and dotted lines) for the Japanese long-line CPUE (left) and the aerial survey (right).

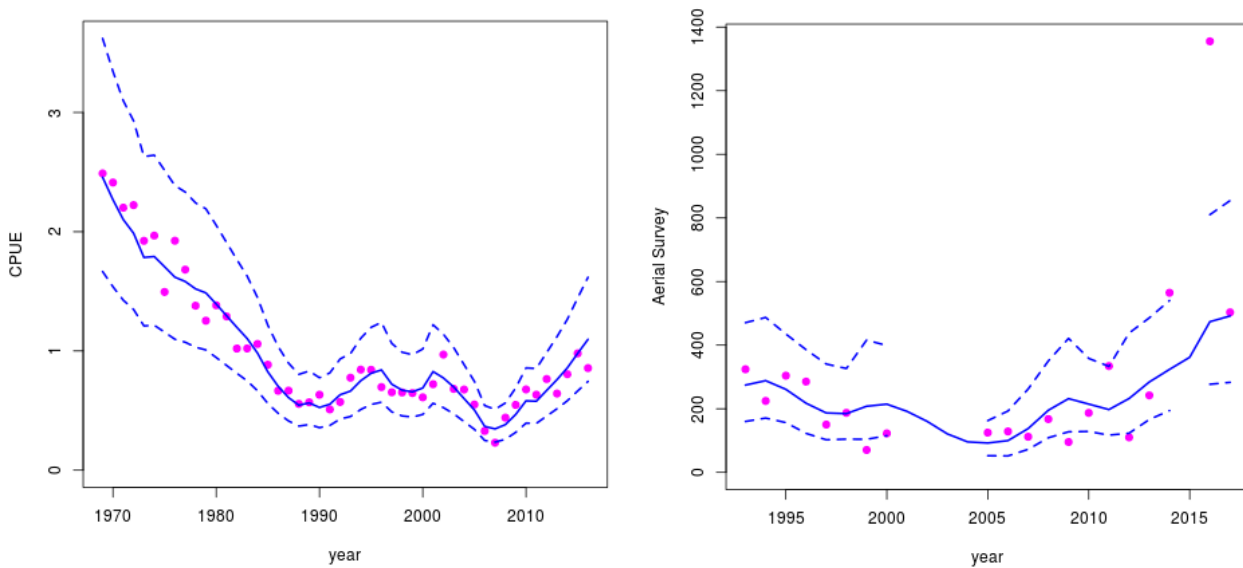


Figure 6: Fits to the tagging data, aggregated across taggers and at the release year and recapture age level.

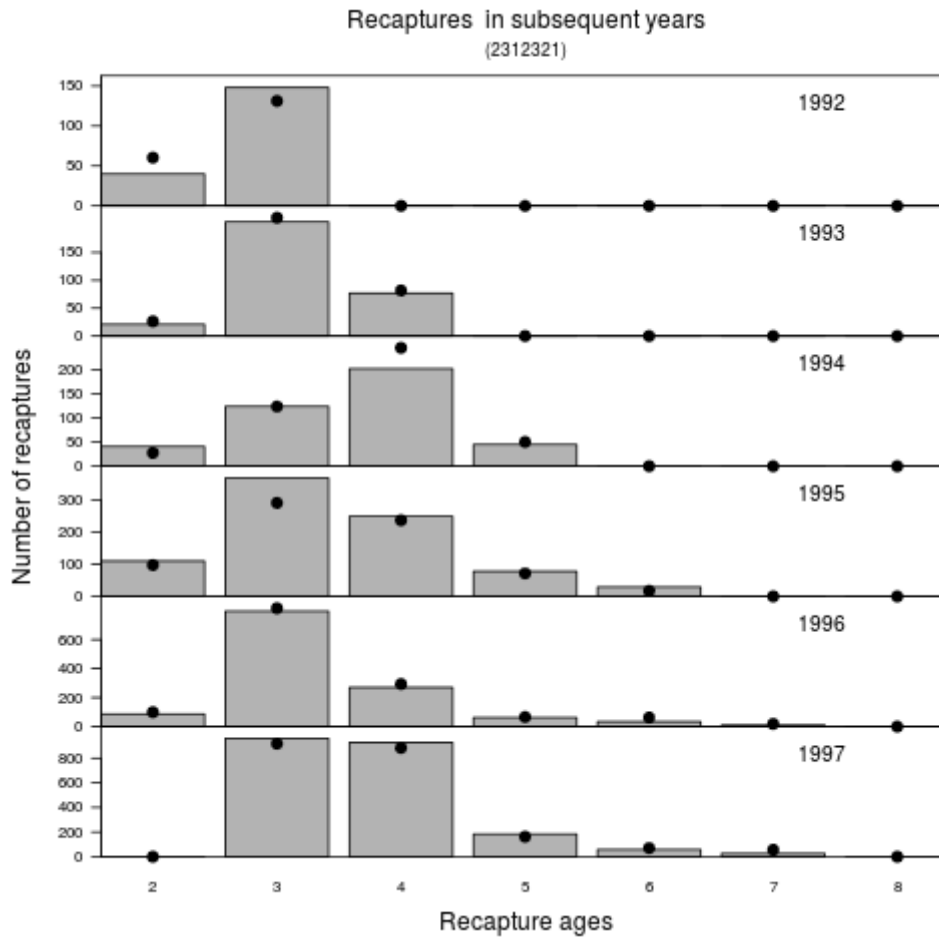


Figure 7: Fits to the CKMR POP data at the cohort (left) and adult capture age (right) aggregation level.

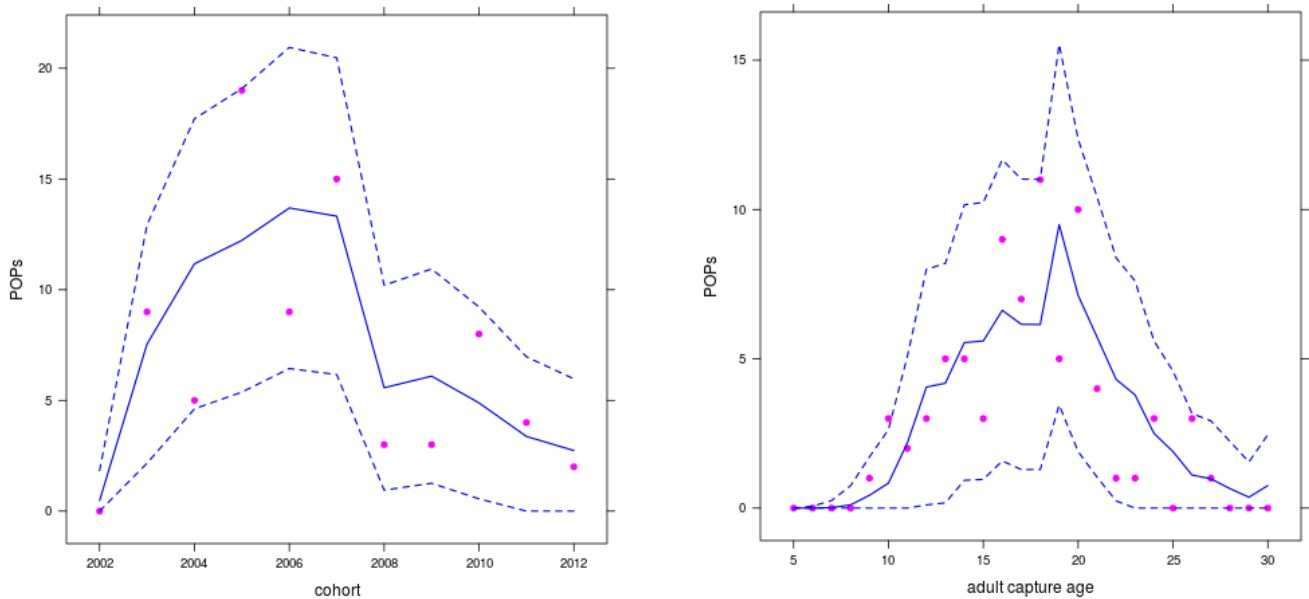


Figure 8: Fits to the CKMR HSP data at the full disaggregation (left) and initial cohort (right) aggregation level (the initial cohort is the oldest animal in the juvenile comparison group).

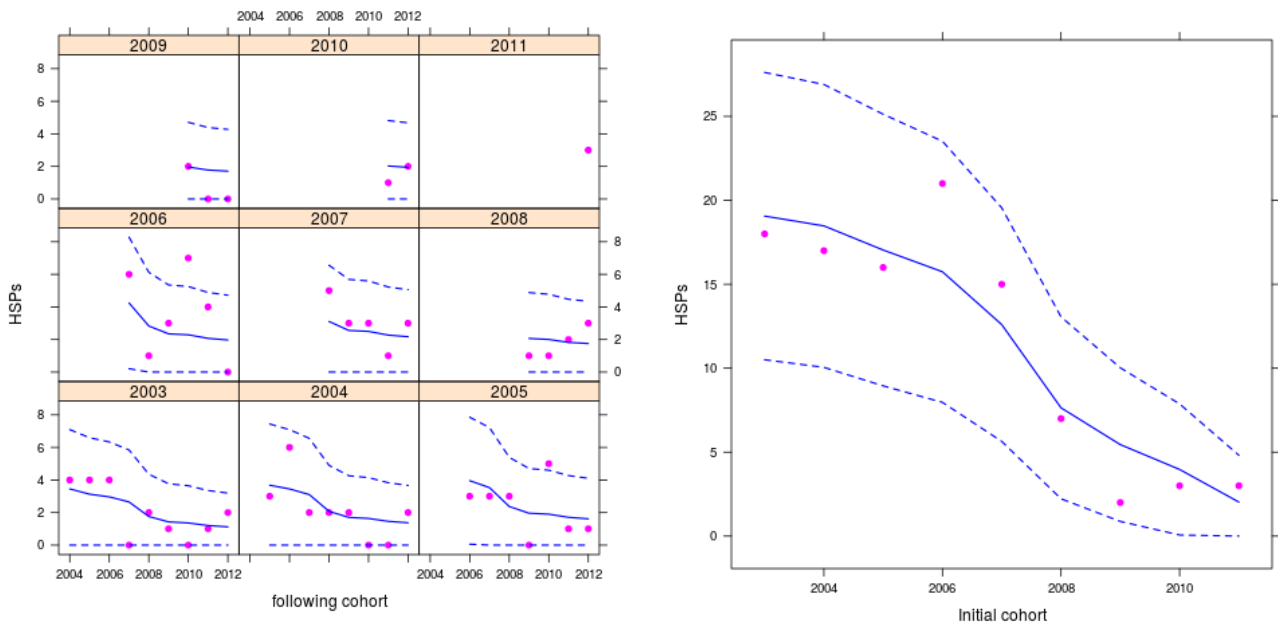


Figure 9: Fits to the age frequency data for the surface (left) and Indonesian (right) fisheries.

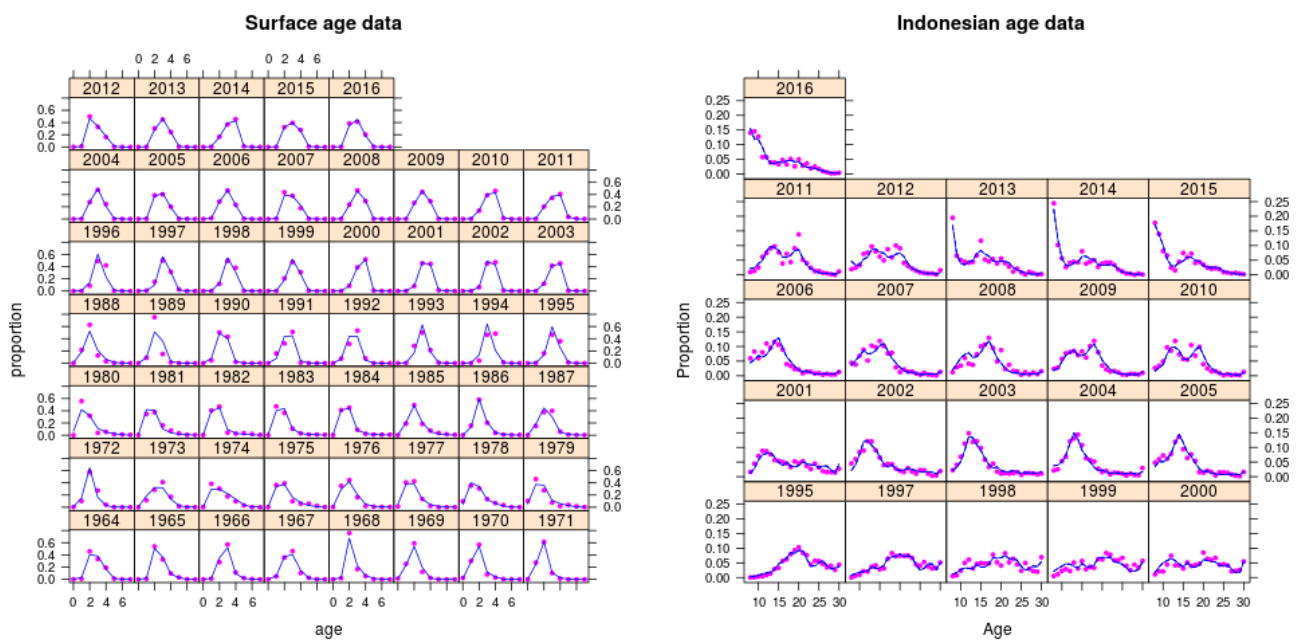


Figure 10: Fits to the length frequency data for four other long-line fisheries (LL1, LL2, LL3 and LL4).

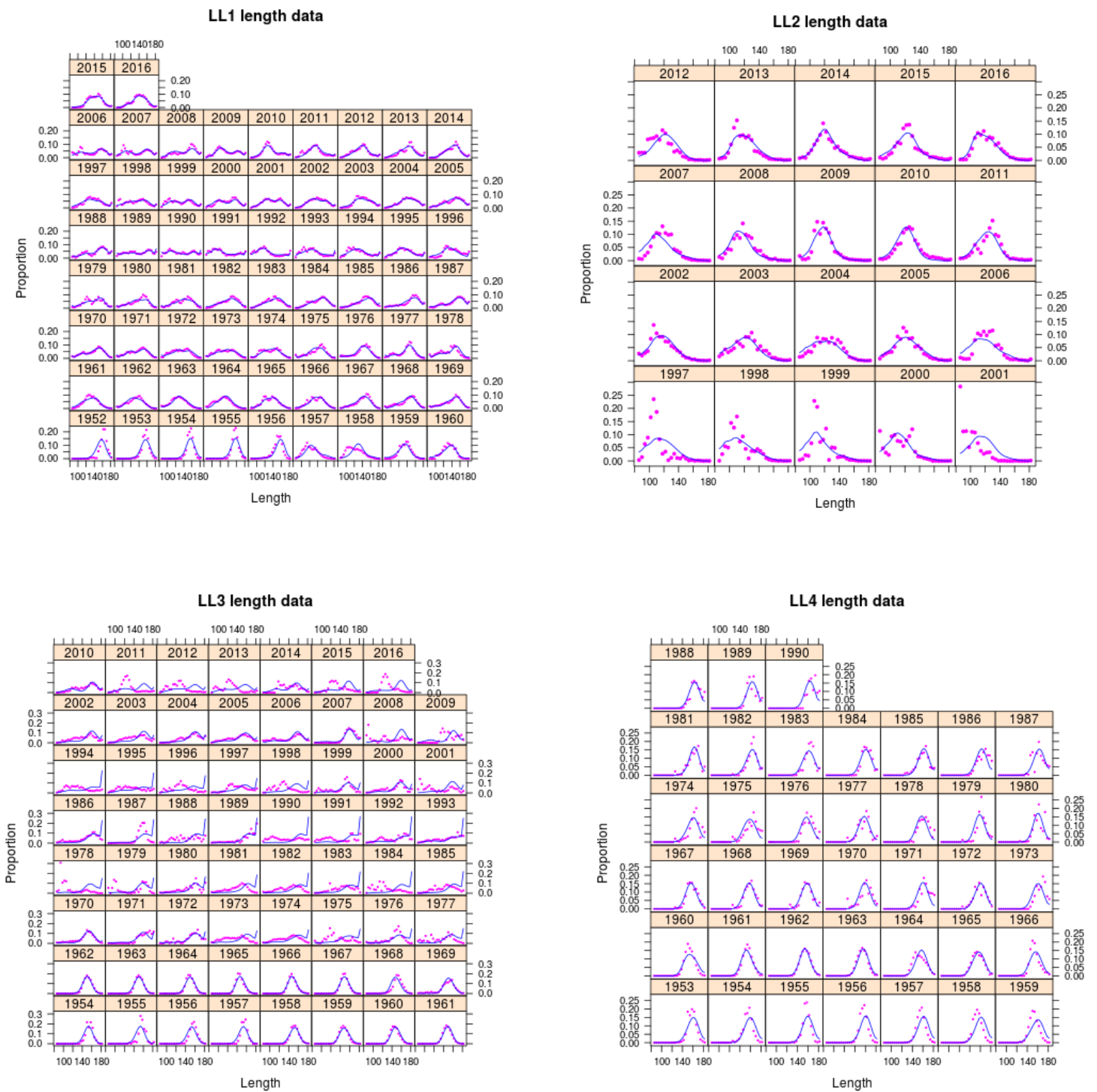


Figure 11: Predictive distribution (top) and the associated observed and predicted discrepancy statistics (bottom) and p-values for the long-line CPUE (left) and the aerial survey (right)

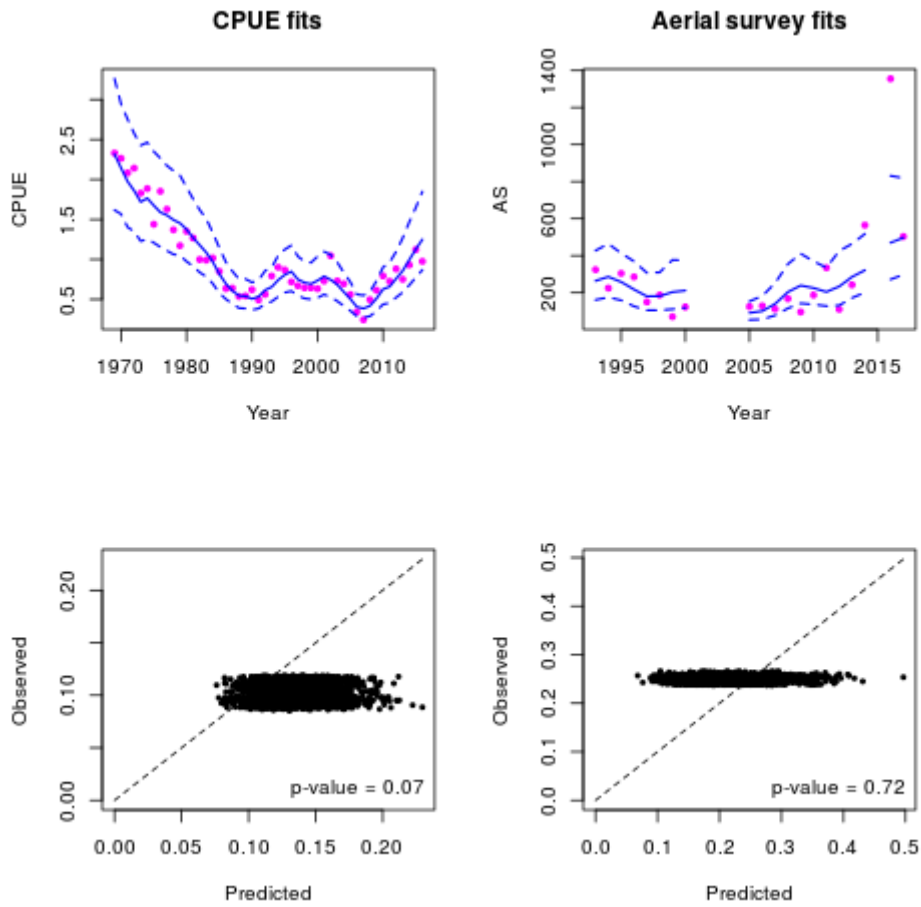


Figure 12: Predictive discrepancy statistics (and p-values) for the CKMR POP data at the cohort aggregation level (POPc, top left), the adult capture age aggregation level (POPa, top right), and the CKMR HSP data at the initial cohort reference level (HSPc1, bottom left). The x-axis is the predicted discrepancy and the y-axis the observed.

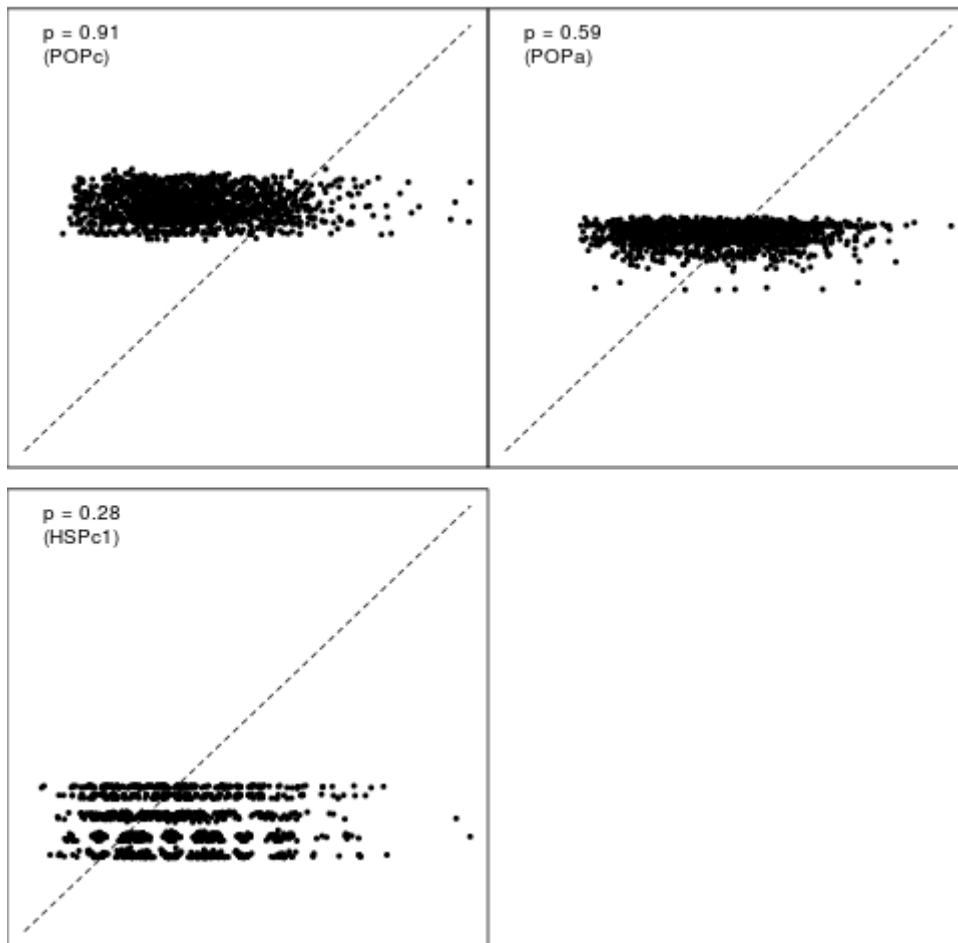


Figure 13: Historical and projected trajectories of the reference set for a) recruitment, b) biomass of age 10+ fish, and c) total reproductive output (TRO). The red line with the pink region represents the median and 90% probability intervals of the 2017 reference set (current assessment). The blue line with the light blue region represents those for the 2014 reference set (previous assessment). The dotted lines indicate the boundaries of the conditioning and projections.

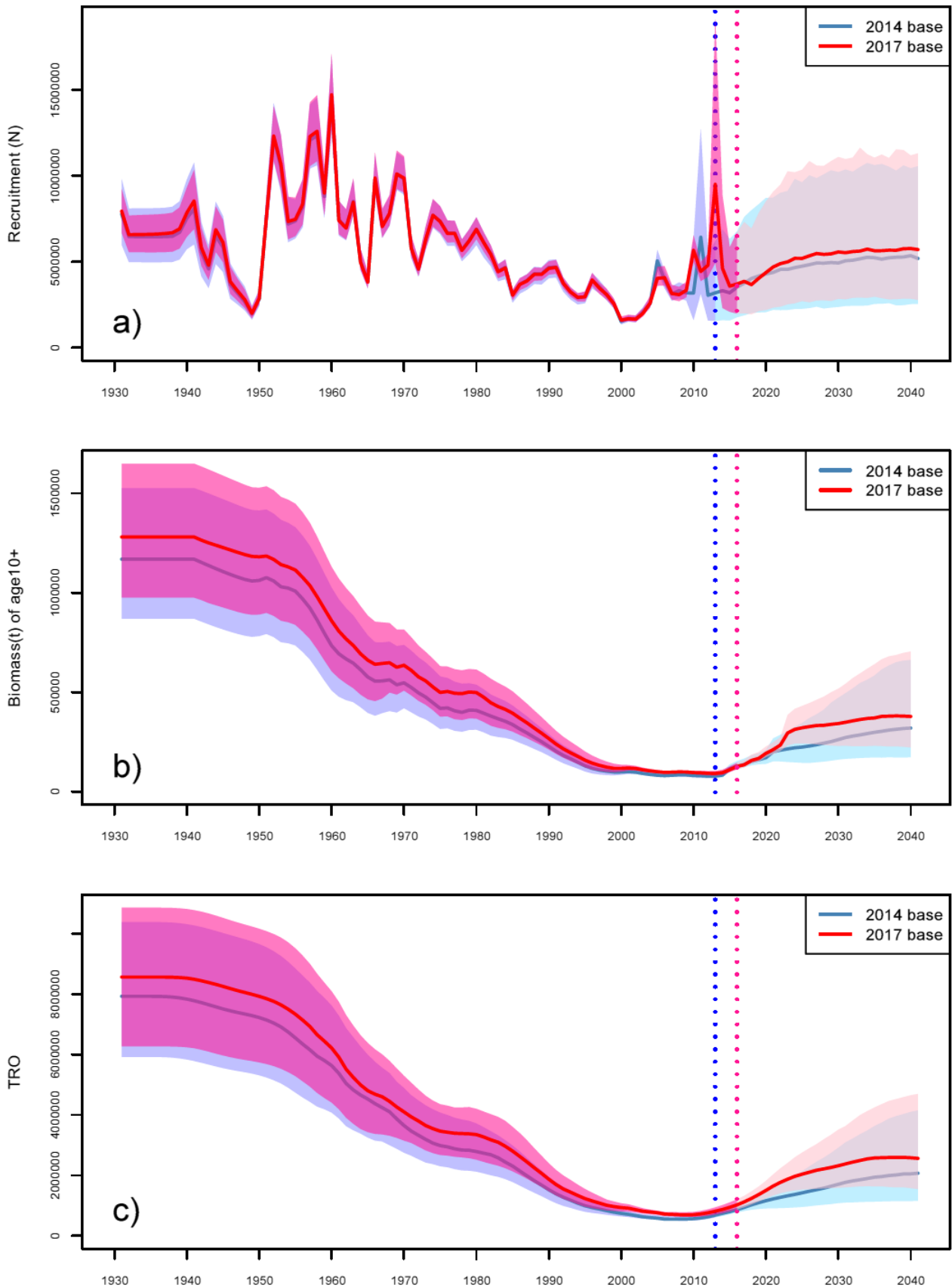
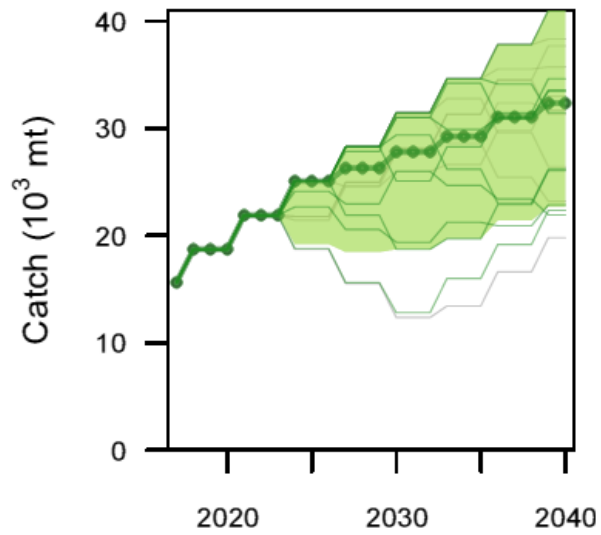


Figure 14: Projected future TAC trajectories for the reference set projections. The bold green line with the greenish yellow region represents the median and 90% probability intervals. The thin greenish lines represent worm plots for each simulation trial.



Appendix A.3

Preece AL, Davies CR, Hillary RM. 2017. Meta-rules and exceptional circumstances considerations. CCSBT-ESC/1709/15, Twenty Second Meeting of the Scientific Committee, 28 August - 2 September, Yogyakarta, Indonesia.



Meta-rules and exceptional circumstances considerations

Preece AL, Davies CR and Hillary RM.

CCSBT-ESC/1709/15

Prepared for the Extended Scientific Committee for the Twenty Second Meeting of the Scientific Committee, Yogyakarta, Indonesia, 28 August - 2 September, 2017

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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. The purpose of the review is 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 2017, the ESC will review MP implementation in the context of the TAC for 2018, recommended at the 2016 meeting of the ESC and adopted by the Commission.

Issues of potential concern in 2017 include: 1) changes in estimates of the population dynamics and productivity of the stock; 2) the unresolved shift in selectivity in the Indonesian fishery since 2013; and 3) potential for total catches (members and non-members) to be greater than the TAC (either annually or over the quota block).

The projections for rebuilding the stock, using the Bali Procedure MP and reference set of reconditioned operating models for the 2017 assessment of stock status, indicate that the interim rebuilding target may be reached earlier than expected. The population dynamics are different to the operating model conditions when the MP was tested. The change is positive, in that rebuilding may potentially occur earlier, and operating model changes do not impact directly on the MP or TAC advice and therefore no action on the 2018 TAC is required. The potential changes in population dynamics will impact on testing candidate MPs to replace the existing MP in 2019.

The second issue of change in selectivity in the Indonesian fishery is of continuing concern, but not for the operation of the MP and 2018 TAC advice; rather for the monitoring of the spawning stock, close-kin sample collection and the impact on OM conditioning and advice on stock status.

In terms of the third issue, progress has been made by the Extended Commission to account for all sources of mortality; however, uncertainties remain and limited information is available on quantities of additional mortality that will be accounted for by members in 2018, or the historical estimates for these sources. These data are required for reconditioning operating models and management strategy evaluation of candidate MPs in 2018.

1 Introduction

The meta-rules for the CCSBT Management Procedure (MP) include: 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). The aim of the meta-rules process is 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)). In 2017, the ESC will review MP implementation in the context of the TAC set for 2018 recommended at the 2016 meeting of the ESC.

Issues of potential concern in 2017 include: 1) changes in estimates of the population dynamics and productivity of the stock; 2) the unresolved shift in selectivity in the Indonesian fishery since 2013; 3) potential for total catches (members and non-members) to be 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.

These issues 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. Additional exceptional circumstances may be identified at the ESC following review of stock and fisheries indicators.

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 Exceptional circumstances in 2017 and potential severity for MP implementation

The following items may represent exceptional circumstances and will be reviewed by the ESC in 2017:

- 1) changes in estimates of the population dynamics and productivity of the stock,
- 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.

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 2011 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. Further exceptional circumstances may also be identified at the ESC as part of the 2017 assessment of stock status, and annual review of stock and fishery indicators.

3.1 Changes in population dynamics and productivity of the stock

The 2017 assessment of stock status is based on a revised reference set of reconditioned operating models, which include new and updated data and structural changes. Results are presented in Hillary et al. (2017a). Historical estimates of absolute biomass aged 10+ are substantially different from the 2011 operating model results used to test and tune the current MP, mainly as a result of inclusion of close-kin data in the 2014 stock assessment (Anon 2011; Anon 2014). The historical estimates of relative depletion are more consistent, and the estimates for the most recent years indicate an improvement in stock status. The projections of the 2017 reconditioned reference set of operating models indicate that the interim rebuilding target (70% probability of rebuilding to 20%B₀ by 2035) may be reached much earlier than previously anticipated. The population dynamics are potentially significantly different from those used for MP testing in 2011.

Changes in the population dynamics are not unexpected because there have been a number of changes in the operating models since 2011. The substantial differences in the projections results are positive: rebuilding to the interim target under the Bali MP are predicted to occur earlier, or with higher probability. Sensitivity tests are used to explore the impacts of alternative scenarios

and interpretations of data on population dynamics and rebuilding of the stock. The stock status results are similar across the sensitivity tests, and the rebuilding for the sensitivity tests is slower or faster than the 2017 reference set depending on the scenario. All of the sensitivity test results indicate that the probability of reaching the interim rebuilding target are greater than that specified for the MP, i.e. a probability of 0.7. We note that changes to the operating models have no impact on operation of the MP or TAC calculations, as the MP parameters and inputs are fixed and remain unchanged, apart from each additional year of data added to the two input data series (i.e. CPUE and aerial survey indices).

To identify the factors influencing the optimistic projection results, we explore the operating model changes since 2011 and sensitivity test results (Table 1). The close-kin data were first included in the operating models in 2013 (Hillary et al., 2013), and have been substantially updated in 2017 with additional Parent-offspring Pair (POP) data and new Half-sibling Pair (HSP) data (Hillary et al., 2017b). In addition to inclusion of these data, the operating models have a new maturity ogive based on fecundity information with parameters for change in growth (Hillary et al., 2017b). These changes contributed to modification of the range of natural mortality values in 2014 (Anon 2014) and steepness values in 2017 (Anon 2017) that are included in the reference set, as the range of uncertainties that is considered changes with updated information on the population dynamics. Sensitivity tests that exclude the new POP and HSP data (“No POPs/HSPs” and “No HSPs”) indicate only small changes in rebuilding trajectories relative to the reference set (probability of reaching rebuilding target is 0.79 for the “No POP/HSP” sensitivity test, and 0.88 for “No HSP” test, compared to 0.88 for the reference set). The stability in these rebuilding results is due to the structural changes (i.e. to maturity, natural mortality and steepness values used in the reference set) that were adopted when integrating these data.

The impact of the structural change to the range of steepness values (reference set: 0.6, 0.7, 0.8) in the reference set is evaluated by the sensitivity test which evenly weights runs with steepness equal to 0.6 and 0.7 and gives zero weight to the 0.8 steepness runs (“No h=0.8”). There is a relatively small reduction in the probability of rebuilding to 0.83 (from 0.88 in the reference set).

The possibility of future low recruitment is examined with the “Low Recr” test (similar to test used in 2011), which sets the first 5 years of recruitment in the projections to 50% of the predicted value. The impact of this test is to reduce the probability of recovery to 0.75, which is lower than the reference set but higher than the target. The MP responds appropriately and the population rebuilds above the current interim target level.

Updated CPUE and aerial survey data have shown positive trends in recent years which appear to contribute most to the faster rebuilding dynamics. CPUE has had an increasing trend since 2007. The upq2008 sensitivity test explores an increase in catchability from 2008 which affects the interpretation of the CPUE data, changing the probability of rebuilding by 2035 to 0.73 (which is still above the interim target) from the reference case of 0.88. The influence of recent high catch rates in area 7 on the CPUE is explored in the CPUE without area 7 (“CPUE w/o A7”) sensitivity test results, which indicates change in the probability of rebuilding by 2035 to 0.83 (from reference set estimate of 0.88).

We note that the 2017 aerial survey estimate of juvenile relative abundance is within the range of values for which the MP was tested (Takahashi et al, 2017), however, recent very high values (2016 and 2014) have been outside the bounds or very close to it. These very high values and the

series of high estimates since 2012 appear to have a large effect on the rebuilding trajectories. Sensitivity tests that exclude the highest 2016 aerial survey data point (“No AS 2016”) indicate that the rebuilding target will still be met but will be much slower (the probability of rebuilding by 2035 is 0.74 compared with reference set 0.88). The sensitivity test with high aerial survey coefficient of variation (“High Aerial CV”) gives a similar lower probability of rebuilding by 2035 (0.72).

Table 1. A subset of the sensitivity tests and results from Hillary et al., 2017a (table 3), plus an additional test of potential rebuilding for the Low Recr robustness test (defined in 2011), where recruitment is 50% lower than predicted for the first n years (5 years in this case). Columns 1-6 are:

1. “Run”, the name of the sensitivity test, defined in Table 2 of Hillary et al 2017,
2. “Rel. TRO (2017)”, summary statistics (median and 90th %-iles) for the Total Reproductive Output (TRO) in 2017 relative to TRO(0),
3. “Rel. B10+ (2017)”, biomass of animals age 10+ in 2017 relative to 10(0),
4. “F-to-FMSY 2017”, the ratio of current F (2017) to F at MSY,
5. “Rel. TRO (2035)”, TRO in 2035 relative to TRO(0),
6. “P(B10+ > 0.2B10+(0)) @ 2035”, the probability that biomass of animals age 10+ is greater than 20% of the unfished state in 2035 (the original tuning objective).

Run	Rel. TRO (2017)	Rel. B10+ (2017)	F-to-FMSY (2017)	Rel. TRO (2035)	P(B10+ > 0.2B10+(0)) @ 2035
Reference	0.13 (0.11-0.17)	0.11 (0.09-0.13)	0.5 (0.38-0.66)	0.3 (0.21-0.46)	0.88
UAM1	0.13 (0.1-0.17)	0.11 (0.09-0.13)	0.57 (0.43-0.74)	0.28 (0.18-0.43)	0.80
High Aerial CV	0.12 (0.1-0.16)	0.11 (0.09-0.14)	0.58 (0.43-0.78)	0.26 (0.16-0.41)	0.72
No AS 2016	0.13 (0.1-0.16)	0.11 (0.09-0.14)	0.59 (0.44-0.78)	0.26 (0.17-0.40)	0.74
Upq2008	0.11 (0.1-0.15)	0.09 (0.08-0.12)	0.56 (0.42-0.75)	0.26 (0.17-0.42)	0.73
CPUE w/o A7	0.12 (0.1-0.15)	0.1 (0.08-0.12)	0.54 (0.4-0.71)	0.29 (0.19-0.44)	0.83
No HSPs	0.13 (0.11-0.17)	0.11 (0.09-0.13)	0.5 (0.38-0.66)	0.30 (0.21-0.47)	0.88
No POPs/HSPs	0.12 (0.1-0.15)	0.1 (0.08-0.11)	0.52 (0.4-0.67)	0.29 (0.19-0.45)	0.79
No h = 0.8	0.13 (0.1-0.16)	0.11 (0.09-0.13)	0.57 (0.44-0.67)	0.28 (0.20-0.43)	0.83
Low Recr	Same as reference	Same as reference	Same as reference	0.26 (0.17-0.38)	0.75

Source: Hillary et al. (2017a), Table 3.

The two data inputs to the current MP are the CPUE and Aerial Survey indices. The most recent updates for these two time series do not trigger exceptional circumstances review of MP data inputs as they are within the ranges tested (Takahashi et al, 2017). Both declined from the most recent high data estimates in 2016. These recent high aerial survey estimates (2014 and 2016) were examined in detail in 2016 (Anon 2016). The MP TAC advice was shown to be primarily driven by the CPUE data and recent positive trends in the CPUE time-series.

The changes to the rebuilding timeframe are substantial and may be considered exceptional circumstances. As the direction of the change is positive (i.e. more rapid rebuilding) and these changes do not impact the calculation of recommended TAC in the MP, we do not recommend any action to review the 2018 TAC (set in 2016). These potential changes in population dynamics will, however, impact the development of operating models for testing candidate MPs that will replace

the existing MP in 2019. Given this, and the relatively few observations of the cohorts that make up the high 2016 aerial survey observation, this issue (change in population dynamics) should be reviewed again as part of finalizing conditioning of operating models for MP testing in 2018.

3.2 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., 2017). It has not been possible to determine 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, and the issue remains 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 OMs used at the time of testing the MP. The advice from the 2015 ESC regarding this issue remains the same for the 2018 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 a basis for recommending modification to the MP TAC. The previously recommended action should be urgently pursued by the CCSBT and Indonesia so that the shift may be addressed in the next reconditioning of the operating models in 2018 for management strategy evaluation of candidate MPs.

3.3 Total fishing mortalities exceeding the TAC

The design and simulation testing of the current MP assumed that all removals from the stock were accounted for, i.e. the implementation of the TAC was exact. Additional unaccounted mortality by members and non-members has the potential to undermine the MP based rebuilding strategy of the Commission. 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 could only use simple scenarios (i.e. the level and trajectory of potential unaccounted 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, 2015 and 2016 the ESC has 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 in any of these years, but has requested that the Commission provide more informative data on unaccounted mortalities.

Accounting for sources of additional mortalities by members has progressed, with the Extended Commission defining a common definition for member's "attributable catch". Members will account for all sources of mortality as defined by the Commission, within their TAC from 2018

onwards, and report on their attributable catches to the ESC and CC. If the catch quantities to be attributed to total catch by members do not account for their total fishing mortality, then the potential for impact on the rebuilding plan for SBT will remain. Limited information is available on quantities of additional mortality that will be accounted for by members in 2018, or the historical estimates for these sources.

Reported catches by members have been greater than the global TAC in recent years. In 2013 and 2014 member's reported catches were greater than the TAC (477t and 324t). In 2015 and 2016 (preliminary figures) the member reported catches did not exceed the TAC (CCSBT, 2017) (451t and 434t under TAC respectively). Papers have been presented over many years on uncertainties in members' catches (e.g. Anon, 2016), but the issues remain unresolved.

Attempts to quantify potential levels of non-cooperating non-member unaccounted mortality in the Pacific, Indian and Atlantic Oceans by indirect methods has also progressed (Edwards et al., 2016). There are substantial uncertainties and assumptions made in these analyses. As part of boarding and inspection activities in the Tasman Sea in 2016, catches of undeclared SBT were seized (103t) from a single vessel operating in the same area at the same time as three other vessels from the same company (NZ MPI, 2016)). The Commission has set aside 306t to account for non-cooperating non-member catches through a "direct approach" in each year in the 2018-2020 TAC block. For TAC recommendations for 2021 and beyond, an "MP approach" will be used (Anon 2016) to encapsulate the uncertainty in total fishing mortality in tuning of candidate MPs to replace the current Bali procedure.

The ESC 2016 noted that the added catch scenario was potentially still plausible given the available data, analysis and reports. The additional catch scenario has been updated as the "UAM1" sensitivity test in 2017. The current stock status estimates are unaffected for this sensitivity test. The rate of rebuilding is slower than the reference set of projections, with the probability of rebuilding to the interim target estimated as 0.8 (down from 0.88 for the reference set). The target rebuilding objective would still be met under the current population dynamics model. This differs from 2014, where it was noted that although the MP was able to respond to the additional catches being taken (Anon 2014), the MP could not respond quickly enough to rebuild to the target within the specified timeframe.

The combination of the UAM1 sensitivity test with another sensitivity test with less optimistic rebuilding results could result in probability of rebuilding below the target objective, so this potential exceptional circumstances still poses a threat to rebuilding of the stock. Since there is a positive trajectory for rebuilding the stock, there is no requirement for action on the recommended TAC for 2018 in relation to this potential exceptional circumstance.

4 Conclusions

Through the meta-rules process we have examined changes in the (most likely) population dynamics since the MP was adopted in 2011, 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 in the context of the 2018 TAC (recommended in 2016).

The change in the estimates of the population dynamics in the reconditioned operating models does not affect running of the MP or the 2018 TAC recommendation, and the MP input data do not trigger exceptional circumstances.

The Indonesian selectivity change remains unresolved. Similarly, this does not directly impact on the running of the MP or TAC advice, but this issue will need to be addressed for reconditioning operating models in 2018 for management strategy evaluation of candidate MPs. As such it should remain a priority for CCSBT and Indonesia to resolve, particularly as this issue potentially impacts on the close-kin data collection into the future.

The potential for total catches to be greater than the TAC remains a concern. Action has been taken by the Commission and members will account for their attributable catches from 2018 onwards, and an allowance for non-cooperating non-member catches has been made in the 2018-2020 TAC block.

These potential exceptional circumstances have been considered in isolation from one another, and the ESC may wish to consider the risk that cumulative impacts could impose on performance of the MP and the ability of the ESC to provide robust advice on stock status.

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Appendix A.4

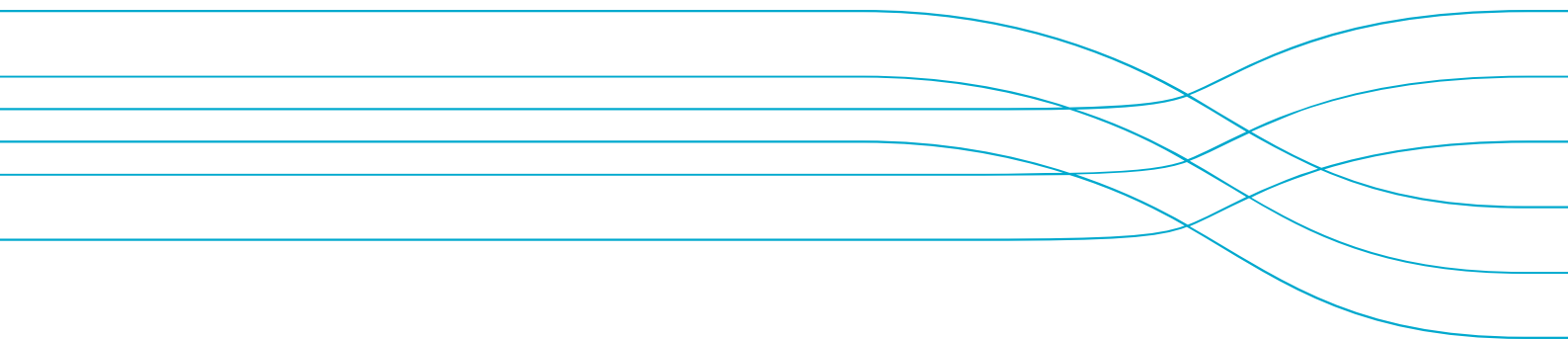
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An update on Australian otolith and ovary collection activities, direct ageing and length at age keys for the Australian surface fishery.

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CCSBT-ESC/1708/11

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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 and (ii) estimates of proportion-at-age of the Australian surface (purse seine) fishery to include the 2015/16 fishing season.

Otoliths from 174 SBT caught in the Great Australian Bight in 2017 were received and archived into the CSIRO hard-parts collection. It is anticipated that ovaries will be collected opportunistically from SBT caught by commercial longline operations off southeast Australia over the next month (July/Aug). In addition, samples of ovaries from 17 SBT caught off southeast Australia were collected and archived.

Age was estimated for 100 SBT from the 2015/16 fishing season 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 2015/16 season, the proportion at age estimates from the M&B method with unknown growth are 49% age 2 and 48% age 3. These estimates suggest a smaller proportion of age 2 and larger proportion of age 3 fish in the catches in 2015/16 than in the previous two seasons, but are similar to several other past seasons (e.g. 2010/11 and 2011/12).

2 Introduction

2.1 Age estimation & proportion-at-age

Many stock assessments, including those for southern bluefin tuna (SBT), use age-based parameters within the models to estimate stock abundance, with annual catch in numbers at age (catch-at-age) from some fisheries as input data. 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 or infer age from length within the model. 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 year olds made no contribution to the spawning biomass or reproductive output of the population and 10+ year 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 and ovary sampling 2017

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 2017 (see CCSBT-ESC/1708/08). 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.

A small number of ovaries were collected opportunistically from SBT caught by a commercial longline operation off southeast Australia in late July 2017. The fish were measured to the nearest cm (FL) and the ovaries (or part of one lobe) removed and brought to the laboratory fresh. A core subsample will be taken from each ovary and fixed in 10% formalin for future histological analysis.

3.2 Direct ageing for 2015/16

Of the 137 otoliths collected from the Australian surface fishery in the 2015/16 fishing season (see Farley and Eveson, 2016), 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 78-122 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.

3.3 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:

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

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 2014/15 (see Farley and Eveson, 2015). Here we update the analysis to include data from the 2015/16 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 $\hat{\pi}_l$, the frequency of fish of length l over all tow cages, to be

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

where

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

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.

and

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

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

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

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

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

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 and ovary sampling 2017

A total of 149 sets of otolith were collected from the Australia surface fishery in the 2016/17 fishing season (Table 2). The sampled fish were 81 to 122 cm in length (Fig. 1).

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

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.

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 2016/17 fishing season. Reliable estimates of catch-at-age are also dependent on measuring a representative sample of the catch.

An additional 25 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).

Ovaries were collected from 17 SBT in 2017 ranging in size from 123-161 cm FL. A total of 195 ovaries ranging in size from 89-195 cm FL have been collected from Area 4 (Fig. 2) and should provide an adequate number of samples of the size range over which the transition to maturity occurs.

Table 2. Number of SBT with otoliths collected from the Australian surface fishery and during gene-tagging operations in the 2016/17 fishing season.

SOURCE	NO. OTOLITHS	LENGTH RANGE (CM)	MEAN FL (CM)
Australia surface fishery	149	81-122	103.0
Gene-tagging operations	25	60-98	81.2

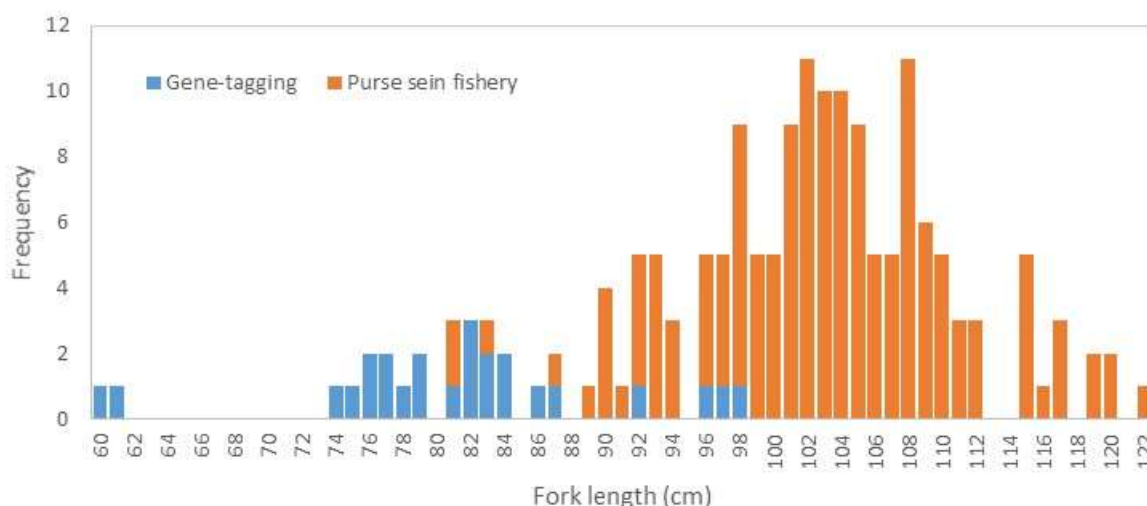


Figure 1. Length frequency of SBT with otoliths sampled from the Australian surface fishery and during gene-tagging operations in the 2016/17 fishing season.

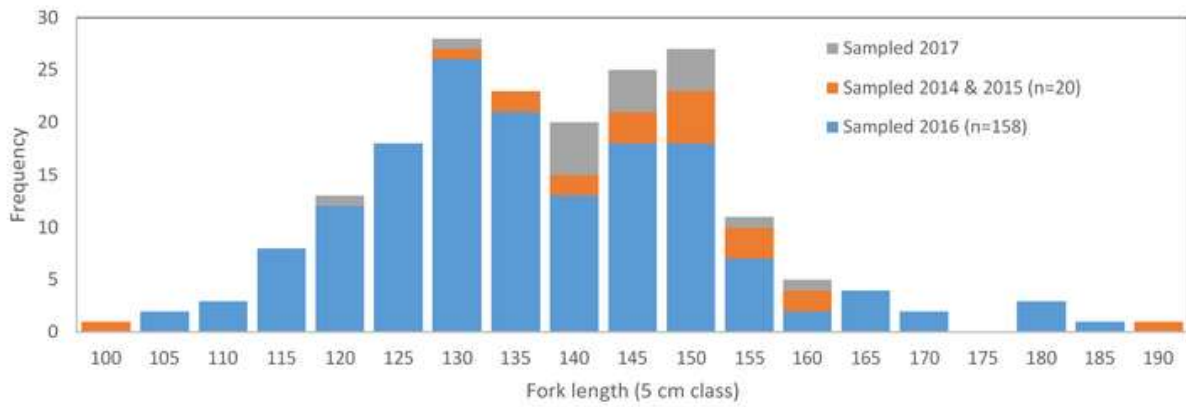


Figure 2. Length frequency of SBT with ovaries sampled in Australia.

4.2 Direct ageing for 2015/16

A final age estimate was given all 100 SBT selected for ageing from the Australian surface fishery. Ages ranged from 2-5 years and the length to age relationship is given in Fig. 3. The average percent error between readings was 3.78% and the percent agreement was 78.0%. 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.

Table 3. Age-length-key for the 2015/16 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.

LENGTH (CM)	2	3	4	5	TOTAL
75	1				1
80	1				1
85	6	2			8
90	20	3			23
95	8	5			13
100		19			19
105		17	4		21
110		2	4		6
115		1	4	1	6
120			1	1	2
Total	36	49	13	2	100

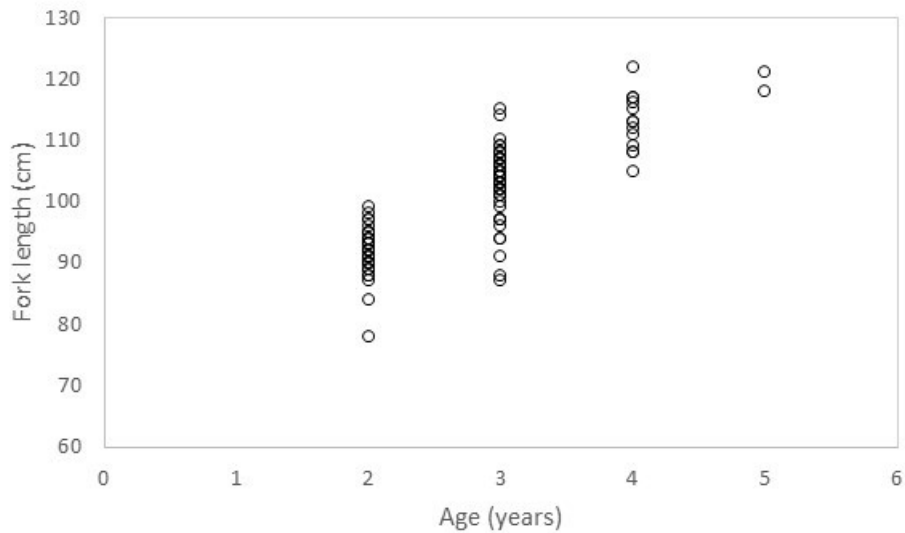


Figure 3. Length at age for SBT caught in the Australian surface fishery in the 2015/16 fishing season (n=100).

4.3 Age distribution of the surface fishery 2001/02 to 2015/16

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 most recent season (2015/16), the two M&B methods (with known and unknown growth) match closely, but the standard ALK method estimates a considerably greater proportion of age 2 and lower proportion of age 3 fish. However, in the previous two seasons (2013/14 and 2014/15), the standard ALK and M&B method with unknown growth match much more closely than the M&B method with known growth; in particular, the M&B method with known growth estimates a much smaller proportion of age 2 and greater proportion of age 3 fish than the other two methods.

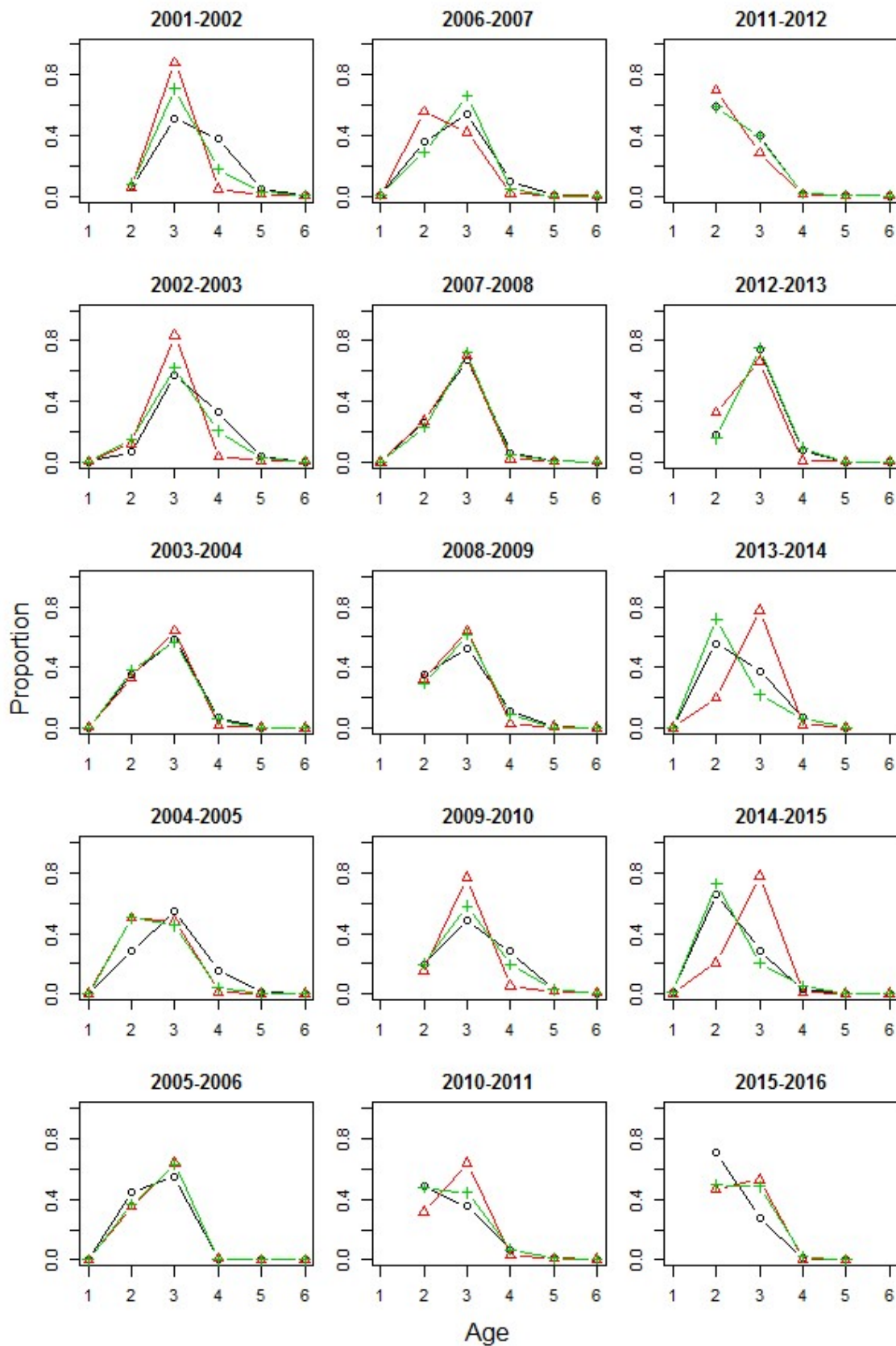


Figure 4. Estimated proportions of fish at age in each fishing season using i) the ALK method (black, open circles); ii) the M&B method with known growth (red, open triangles); iii) the M&B method with unknown growth (green, plus symbols).

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 2015/16 season are 49% age 2 and 48% age 3 (Table A3 in Appendix A). These estimates suggest a smaller proportion of age 2 and larger proportion of age 3 fish in the catches in 2015/16 than in the previous two seasons, but are similar to several other past seasons (e.g. 2010/11 and 2011/12). The mean length at age estimates for the 2015/16 season for ages 2, 3 and 4 are 91.7, 93.0 and 105.6 cm respectively (Table A4 in Appendix A).

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 priori* 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 2015/16 season, the CV of the estimates for ages 2-4 are 6%, 6% and 42% 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 42%) 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 other seasons due to a contrast between the direct age data and length-frequency data for fish of ages 2 and 3 in this season.

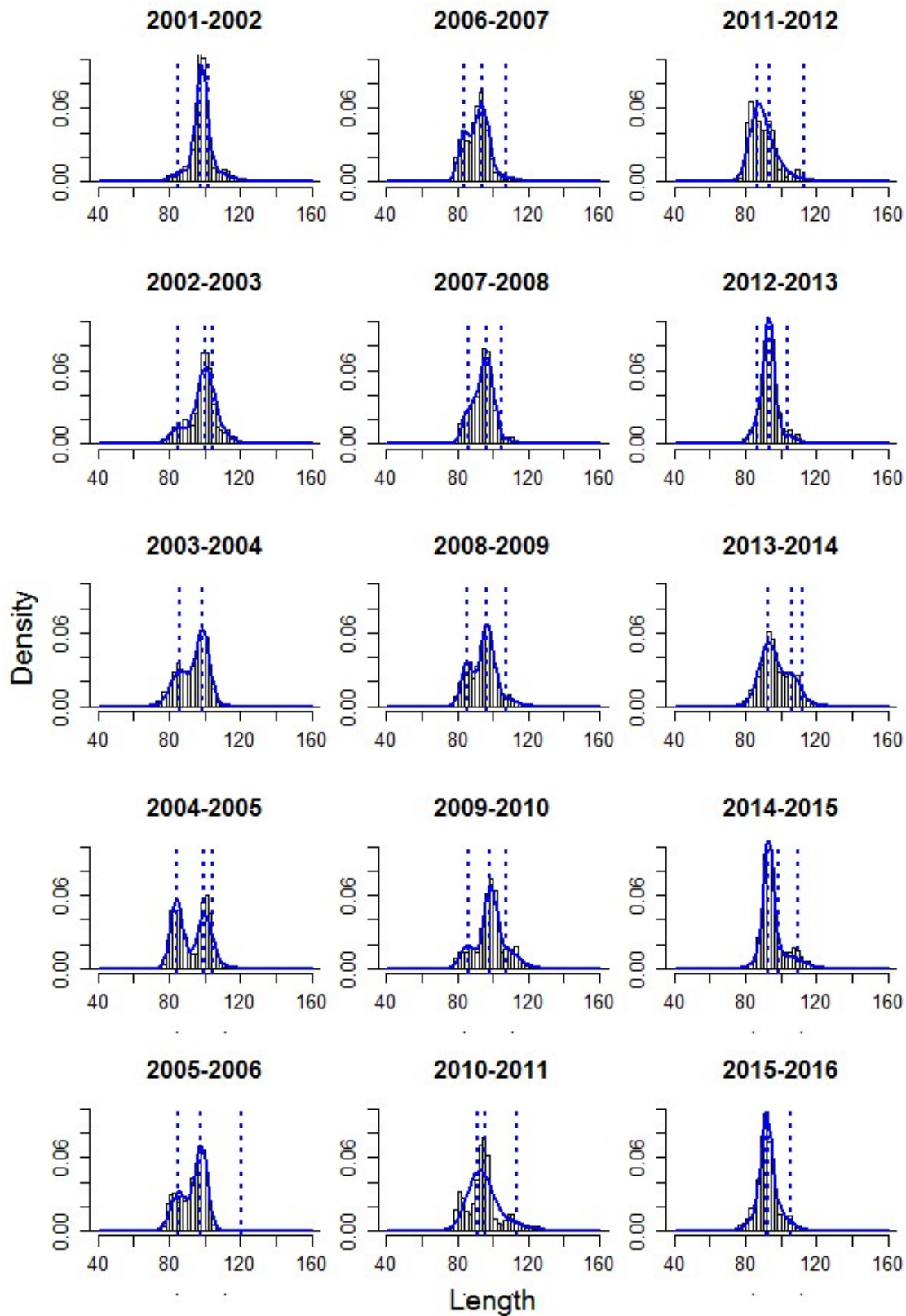


Figure 5. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and estimated mean lengths at age for ages 2-4 from the M&B method with unknown growth (solid blue curve and dashed blue vertical lines).

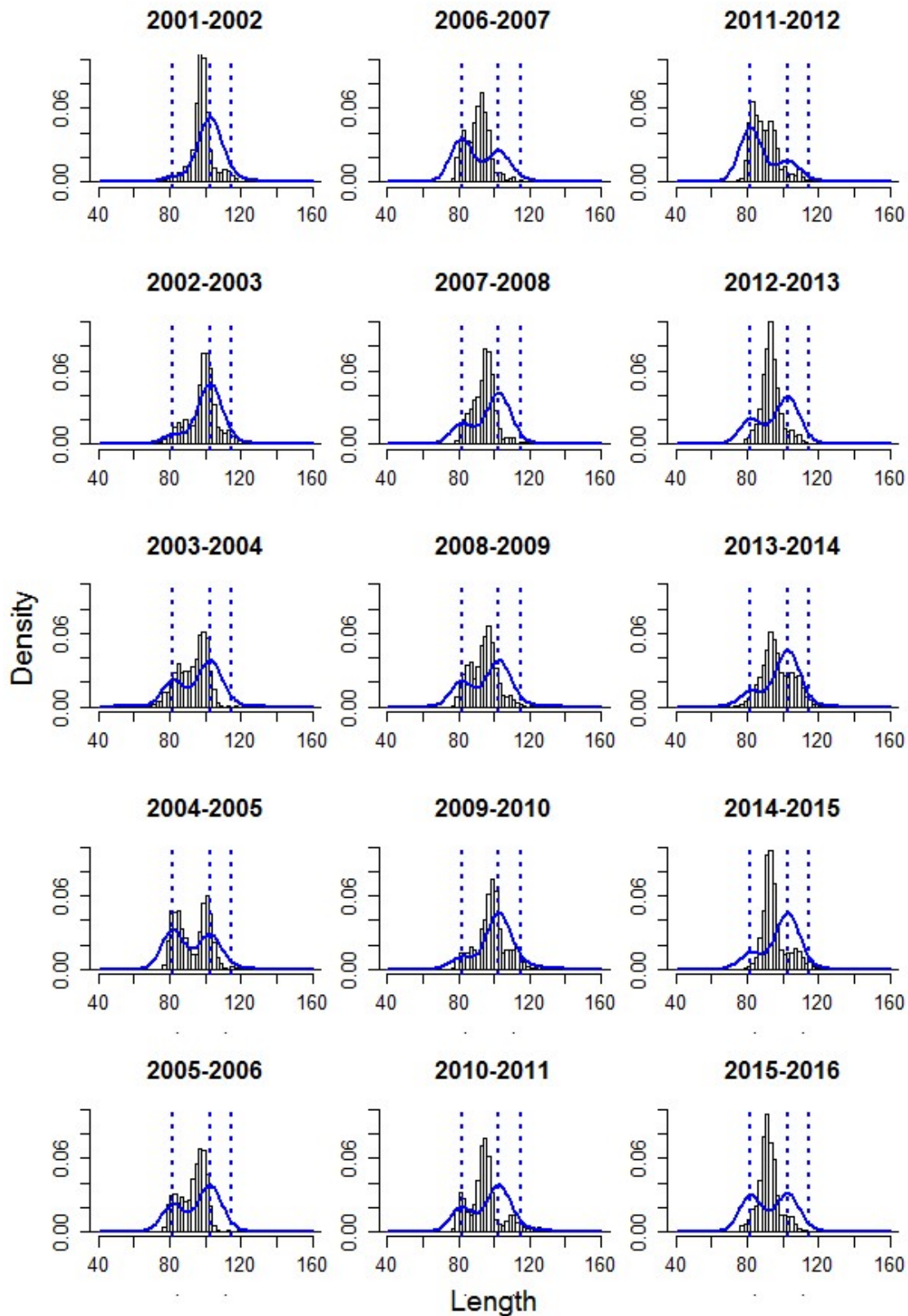


Figure 6. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and “known” mean lengths at age for ages 2-4 from the M&B method with known growth (solid blue curve and dashed blue vertical lines).

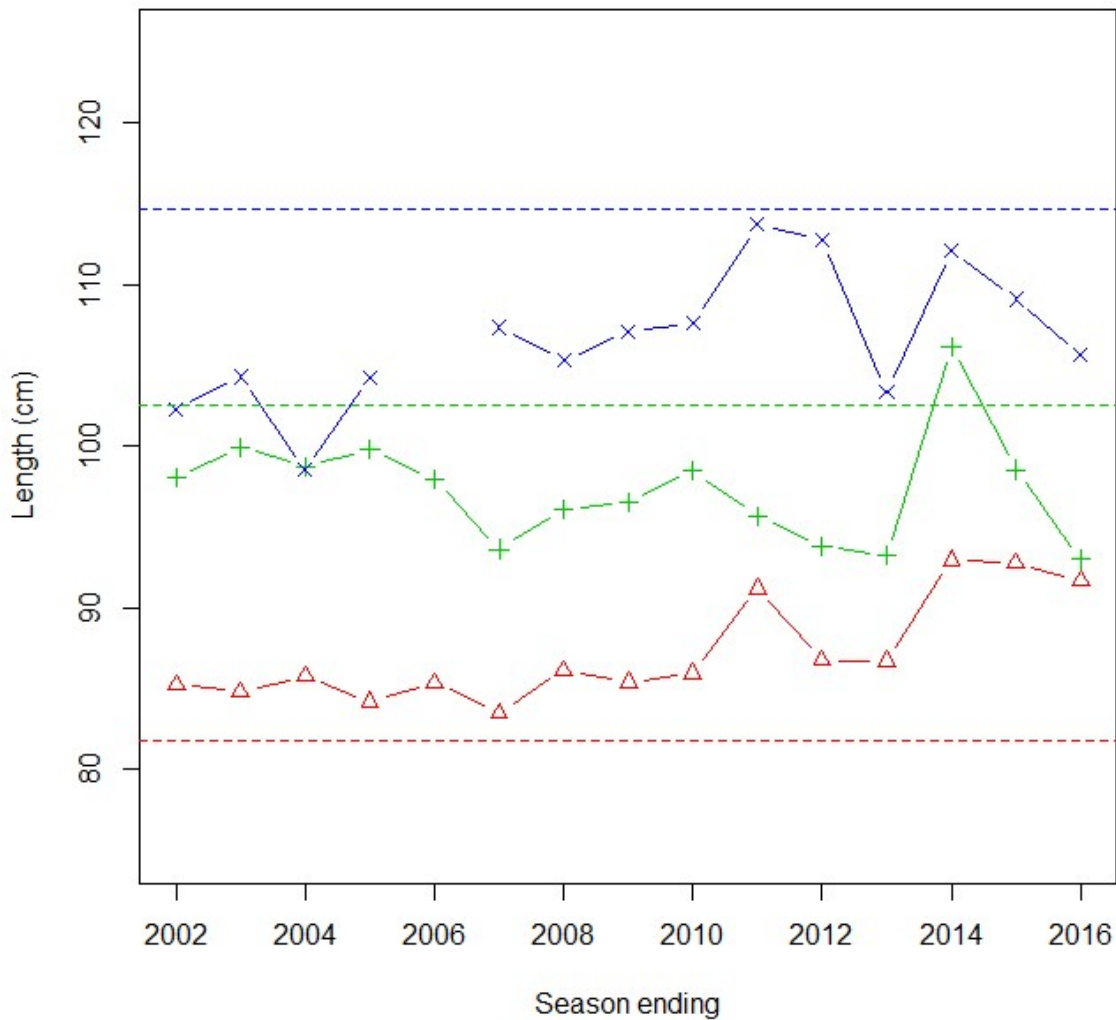


Figure 7. Mean length at age estimates using the M&B method with unknown growth (red triangle = age 2; green plus = age 3; blue cross = age 4). Note the age 4 estimate for 2006 is omitted because there were insufficient data to get a reliable estimate. For comparison, the horizontal dashed lines show 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 174 otoliths and 17 ovaries were collected and archived in 2017. Direct age estimates were obtained for 100 SBT caught in the 2015/16 fishing season in the GAB.

For the 2015/16 season, the proportion at age estimates are 49% age 2 and 48% age 3. These estimates suggest a smaller proportion of age 2 and larger proportion of age 3 fish in the catches in 2015/16 than in the previous two seasons, but are similar to several other past seasons (e.g. 2010/11 and 2011/12). The mean length at age estimates for ages 2, 3 and 4 are 91.7, 93.0 and 105.6 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.

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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.

SEASON	AGE							
	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	0.0297	0.0043	0.0001	NA	NA
2015-2016	NA	0.7070	0.2796	0.0127	0.0002	NA	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.

SEASON	AGE							
	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
2015-2016	NA	0.4671	0.5266	0.0055	0.0008	NA	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.

SEASON	AGE							
	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
2015-2016	NA	0.4941	0.4846	0.0203	0.0010	NA	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.

SEASON	AGE							
	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
2015-2016	NA	91.7	93.0	105.6	118.9	NA	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.

SEASON	AGE							
	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
2015-2016	NA	2.8	7.4	5.8	0.9	NA	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.

SEASON	AGE							
	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
2015-2016	NA	0.06	0.06	0.42	--	NA	NA	NA

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